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TEACHING SCIENCE FOR UNDERSTANDING AND APPLICATIONS: THE ROLE OF TECHNOLOGY

By

Mario Fernando Cajas

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ABSTRACT

TEACHING SCIENCE FOR UNDERSTANDING AND APPLICATIONS: THE ROLE OF TECHNOLOGY

By

Mario Fernando Cajas

In the international arena as well as in the American context, current science educational reform proposals are asking for the introduction of technology. However, technology has not had a real impact on the science curriculum. Rather, the long history of the lack of connection between technology and science in general education continues.

This dissertation studies the role of technology, as curricular content, in school science. Given the current concerns of educational reforms regarding the connection between science and students' everyday lives, two generic goals are analyzed: teaching science for understanding and teaching science for applications. It is suggested that in order to connect science to students' everyday lives, it is important to expand traditional science curriculum across alternative territories, with technological territories being one option.

The dissertation provides a scenario to discuss applications of school science to students' everyday life experiences and the potential role technology may play. Using data available from the Salish I Research Project, the dissertation shows how science teachers are connecting school science with students' everyday lives. The starting point is a set of general outcomes of the Salish I Research Project which guided this research toward the study of the knowledge science teachers need in order to help their students perceive the relevance of their science studies to their everyday lives. The dissertation shows that the introduction of applications of science in students' everyday lives requires a different kind of subject matter knowledge than traditional scientific knowledge. In doing so, a framework on science teacher knowledge which asks for the introduction of technological knowledge is constructed.

The dissertation also develops a framework in which technology is seen as artifact, knowledge, and social practice. This framework is used to clarify the potential role of technological knowledge in science teacher knowledge. The conception of technology and its relation to science education, as presented in Project 2061 and the National Science Education Standards, are studied. A theoretical explanation on the translation of technological knowledge into the curriculum and its implications for science education is provided. Using the construct *translation of knowledge*, it is explained how school science knowledge has been the product of views of science which have overemphasized abstract over practical knowledge erasing most traces of technology from the curriculum.

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To Nadia.
I see in her face the smiles of millions of Guatemalans
who one day may have access to a democratic education.

ACKNOWLEDGMENTS

To say thanks to the people who have affected our lives is a basic human act which reflects that we are not alone in this universe. For me, this is an opportunity to link my emotions with their lives. It is an attempt to keep memories in a special place. Although some of them may not read this dissertation, I still want to thank those who have transformed my life.

This dissertation has been possible because of the support of several people and institutions. They have allowed me to pursue my interest in science and technology education. I would like to thank all of them, particularly my colleagues, professors and friends.

I want to thank my advisor and dissertation director James Gallagher. He has given me a lot of support during my years at MSU. He has made time to listen to my fears and plans. He has guided my studies and encouraged my research. Jim has shown me a world of respect, work and peace. I am grateful for having him as my advisor. At the same time, I want to express my gratitude to the committee members, Deborah Ball, Edward Smith, David Labaree and David Wong. In different forms they have been very important during these years of doctoral studies. During my first year at MSU Deborah helped me to understand the norms and practices of a new community. She provided me guidance in the complex world of education. Ed has shown me a conception of science education in which children are able to understand powerful scientific concepts. He gave me opportunities to work in his projects and learn several useful and beautiful things from these experiences. The sociologist David Labaree showed me a critical position toward education. He allowed me to develop my dissertation ideas through two courses I took with him. David Wong kindly and critically discussed my ideas from the perspective of learning. He always had a powerful contra argument to my ideas. Thanks to all of them.

There are two institutions that have helped me to study in America. I owe the privilege of studying at MSU to a Fulbright scholarship provided by the Latin American Scholarship Program of American Universities (LASPAU). Also, I have had the support of my home university, Universidad de San Carlos de Guatemala.

Now that I am preparing the final report of this dissertation, the image of several friends comes to mind. All of them have a special place in my heart. Angela Shojgreen-Downer and her family gave me a new home...gracias familia. My friends have been patient enough to hear my complaints and to show me a world that I could not see by myself. Don Duggan-Haas, Helene Alpert Furani, Gaston Dembélé, Maria Eulina Carvalho, Qasim AlShannag, Washington Carvalho, Francisca Garcia Kidder, Doug Gordin and Matt Bliton are among these beautiful folks.

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Tracy Wardle, my love, has shared with me good and difficult times. We have grown together during these years at Michigan State. During our long conversations she saw the evolution of my ideas on the relevance of school science and the role of technology in society. She always asks me why I am suggesting the introduction of practical knowledge into the science curriculum when I, myself, am so abstract. I still do not have a concrete answer. We are able to move our conversations from science education to delicate topics of school psychology, from teacher education to poetry, from neuropsychology to everyday life. I am grateful for having her in my life.

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OVERVIEW

In the international arena, as well as in the American context, current science educational reform proposals are asking for the introduction of technology in general education. The two leading science education reforms in the United States: Project 2061 and the National Science Education Standards are important examples (AAAS, 1990; National Research Council, 1995). At the same time teachers and researchers are making important contributions to the field of technology education (e.g., Olson, 1997; Lewis & Gagel, 1992, Raizen, Sellwood, Todd & Vickers, 1995, etc.). Despite the calls of national reform proposals and the interest that researchers have shown for introducing technology into the science curriculum, there has not been a real impact on teaching science. Rather, the long history of the lack of connection between technology and science in general education continues.

The role of technology in science education emerges in my thinking as an alternative to an old epistemological tension between two kinds of knowledge, abstract and practical (Becher, 1993). This tension has taken several forms throughout the history of ideas. One of them is the tension between abstract and concrete knowledge (Turckle & Papert, 1992). Another is the tension between causal (mechanists) and finalistic (teleological) explanation (Wright, 1971). One more is the tension between sacred and popular knowledge (Muller & Taylor, 1995). Another is the tension understanding and application which I suggest has important implications on teaching science. In order to tackle this problem, I framed my dissertation research using a set of questions which were suggested in my original research proposal. They are:

1) What is the relationship between teaching science for understanding and teaching science for applications?
2) What are the possibilities of technological knowledge for being used in teaching science for understanding and teaching science for applications?
3) What are the demands that the introduction of technology would place on science teacher knowledge?

These preliminary questions have guided my research. As one expects they have changed while I have been writing. The very meanings of the terms understanding and applications have changed. However, the basic three research questions remain my general guides. They have helped me to: a) present an epistemological scenario in which I show a tension between understanding and application, b) clarify what I mean by technology, and c) develop more language to understand what I mean by science teacher knowledge.

These three areas are represented in my work in the form of theoretical frameworks. To develop such frameworks I open my dissertation with a discussion on the current concern on connecting science to students' experiential world. In this first chapter, I illustrate the notion of relevance of science using data from the Salish Research Project.[1] I have studied some outcomes of this research project to show how difficult it is for science teachers to connect science with students' everyday lives. My analysis of the relevance of science, that is, meaningful applications of science to everyday life, uses of students' experiential world in teaching science, attempts to show the reader the need for including technology into the science curriculum. I explain why technology can provide an epistemological basis to use science in meaningful ways in students' experiential world.

In the context of my argument, it is important to show the reader what the problems that technology -as content knowledge- would solve are. My thesis is that in teaching science, there is an intrinsic epistemological tension between understanding and application. This tension is not a simple dichotomy between understanding and applications; rather this is a complex interaction which has important pedagogical implications. Only if the reader is willing to give a chance to this option, she or he can

[1] The Salish Research Project is a collaborative effort on the part of 10 Universities throughout the US which aims to research the effectiveness of science and mathematics teacher preparation programs. From 1993 to 1996, Salish I has been gathering data from three groups of individuals: a) science, mathematics and education faculty involved with the teacher preparation programs, b) new teachers who are recent graduates of the programs, and finally, c) the students of these new teachers (see Salish, 1997 for an extensive report).

make a space for other kind of knowledge in science education (e.g., technological knowledge). Therefore, pointing out the tension understanding/applications is an important step. This is the topic of the second chapter.

As I said, I think the tension understanding-application is a reflection of a wider and old tension between abstract and practical knowledge. The pedagogical implications of such tension are enormous and little understood. Although researchers have reported that the tension between abstract and practical knowledge has some responsibility on the lack of impact of technology on science education (e.g., Lewis, 1991), there has been little attempt to explain why that is. Moreover, the same researchers who tend to prescribe technology as part of general education are not explicit with the knowledge that students can learn with such introduction. I argue that this dissertation fills this gap. In doing so, I examine the demands that some general meanings of understanding and applications, such as the use of science in everyday life and the knowledge needed to design artifacts, place on science teacher knowledge.

Despite that there are several meanings of understanding, in the second chapter, I use a generic meaning of understanding in the sense of describing, explaining and predicting natural phenomena. This conception seems to be widely shared within school and scientific communities (Reif, & Larkin 1991; Wolpert, 1993). I decided to contrast a conception of understanding and applications within scientific communities and others from school settings. In doing so, I constructed:

1) a brief case from some examples of the Richard Feynman's Lectures to illustrate one meaning of understanding/applications, and

2) a case from a new science teacher with the pseudonym of Dave who was part of the Salish Research Project.

The case of Feynman illustrates a generic conception of understanding while the case of Dave is a study of the difficulties that Dave is having in connecting understanding with applications in the context of a Mid West High School. From these cases emerged several

observations in the form of problems. Here I raise more questions than answers. However, the reader should not be confused by the observation that I do not present any solution, strategy or alternative in this chapter. For her/his tranquillity she/he should know that later I face some alternatives.

The importance of the first two chapters is that they provide a preliminary scenario to talk about everyday life applications of science in relation to students' experiential lives. This goal of current science education reforms is usually seen in line with the goal of understanding. In these first two chapters I seek to show that understanding and applications are quite different epistemological positions toward the world.

The epistemological difference between understanding and application is the basic argument of my work. I show that by pointing out differences between micro (e.g., atomic) and macro models of teaching and learning science such as the use of atomic models to teach electricity or more phenomenological approaches. I show that by clarifying what kind of discussion Dave's students were having about the topic of electricity. I show that by studying some epistemological demands of the knowledge behind understanding and behind applications. I also show that by pointing out that traditional topics such as electricity (e.g., experiment with bulb light, batteries and wires) seem irrelevant for dealing with everyday life situations (despite the fact that electricity is a theme that is accepted as very relevant to students' everyday lives).

I move to the next chapter by developing a theoretical framework to talk about what teachers need to know in order to teach for understanding and applications. The first thing I learned was that in order to talk about what teachers need to know, I needed to develop a language to clarify the kind of knowledge teachers use. Here I found that, in general, scholars do not make a distinction between knowledge within disciplinary departments (e.g., scientific communities) and knowledge within school settings. I mean, people seem to acknowledge that there is a difference between science and school science, but when one needs to know more about such differences and similarities (e.g., what, why, how, when),

the literature does not offer much help (Deng, 1997 is an exception with his contribution on key ideas in teaching school physics and key ideas in the discipline of physics. Chevallard, 1991, with his "Transposition Didactique" in the context of mathematics education is also an exception and a fundamental reference of my work).

The inclusion of a framework of science teacher knowledge could be seen, in the best of the cases, as a simple aggregated chapter of my dissertation, or as an unconnected chapter of my argument in the worst case. However, its existence has an explanation. While I was writing, I was assuming that my readers knew what I meant by science teacher knowledge. A review of the literature convinced me that I had to be more specific with my own terms. I did that in Chapter 3 by developing a framework on science teacher knowledge. At the same time, I was assuming that my readers could make a general distinction between the knowledge science teachers need to know to teach for understanding in relation to the knowledge teachers need to know to teach for applications (e.g., facing every day life applications as opposed to solving academic problems). I could not support this assumption at least for two reasons. First, as I show in the first chapter, there is an incredible lack of research, that is, papers, books, web sites, etc., on how students use science in everyday life (e.g., out of school). As a logical consequence we know few things on what teachers need to know if they are going to face everyday life problems. A second reason is that the meanings of understanding and applications that I use are quite different from the common connotations of these terms. The very meaning of the term technology in my work has a different meaning than the use of the term in the popular discourse and even academic circles. Therefore, I needed to tell the reader what I meant by understanding and applications and how it can be connected to technology. I did that by creating a minimal model of science teacher knowledge. This model includes three types of knowledge: Scientific knowledge (SK, the subject-matter knowledge of teachers), pedagogical content knowledge (PCK) and knowledge of knowledge (KK), that is, <SK, PCK, KK>.

I used this minimal model of science teacher knowledge to clarify what teachers need to know in order to teach for understanding. I developed the argument that the knowledge needed to teach for applications is not necessarily the same knowledge that teachers use to teach for understanding. Using the case study of another Salish science teacher with the pseudonym of Judy, who consistently was rated high in the personal relevance scale of the Constructivist Learning Environment Survey (CLES), I developed an analysis of the knowledge she used during her three years of teaching that we have access to. Judy taught biology. However, the case study I developed shows that the relevance of biology was not limited to biology itself. Biology was one part of her knowledge. There is evidence that she consistently included important applications of biology regarding students' lives (health, food production and consumption, etc.). In addition, biotechnology played an important role of her teaching (e.g., genetic engineering). The case of Judy was my first attempt to connect my minimal model of science teacher knowledge with other kinds of knowledge. In her case, subject-matter knowledge was a mix of scientific knowledge (SK) with technological knowledge (TK), in addition to other mundane knowledge MK (knowledge of how to use biology in a florist shop). Therefore, I extended my original model of science teacher knowledge. Particularly the "new" subject-matter knowledge, SK, was represented by <SK, TK, MK>. I also developed an extension for pedagogical content knowledge and the knowledge-of-knowledge component.

Pedagogical content knowledge for applications seems to include a new, or at least different, set of demands. The case of Judy also helped me to illuminate potential scenarios. One important scenario was the creation of contexts in which students could use science in meaningful ways. In the second chapter I point out that research in science education has developed knowledge on how students learn. This knowledge would be used to develop PCK in both substantive and procedural aspects. The case of research on students' naive conceptions of science was an important part of that. I called for a re-evaluation of this research in light of other meanings of understanding and application, such

as the relevance of this knowledge to develop pedagogical content knowledge for applications to: a) real world problems, b) everyday life, and c) design of artifacts.

From the case of Judy, and also from my general discussion on science teacher knowledge, one can expect that PCK for applications differs from PCK for understanding. Therefore, the demands of pedagogical knowledge that applications introduce in science teacher knowledge should be reconsidered, I think, in light of the several meanings of the terms understanding/ applications which I already have pointed out. In fact, at this moment I think that the most important argument of this section is the argument that knowledge for understanding is quite different from knowledge for applications. This set the basis for my discussion on the introduction of technology into the science curriculum.

My argument in the fourth chapter is that traditional science teacher knowledge has had for referent scientific knowledge in contrast to other kinds of knowledge (e.g., practical knowledge). In relation to the model presented in the third chapter, the big difference that I presented in this fourth chapter is the introduction of other kinds of knowledge. For "other kinds of knowledge" I refer to

a) knowledge needed to solve real-world problems (as opposed to "academic" problems),
b) knowledge of how to use science in everyday life, and
c) knowledge needed to deal with technological tasks (e.g., to design artifacts).

These three generic "applications" of science also carry different epistemologies, methodologies, and ontologies. In other words, applications of science beyond scientific knowledge require a re-examination of new epistemological territories, methodological rules and ontological worlds. With such discussion, I also connected with the knowledge needed for applications regarding technology. At this moment, I felt it was a good time to provide my readers a more detailed clarification of what I meant by technology and mainly by technological knowledge.

In the fifth chapter, I developed a framework on technology. The starting point of this framework is based on works of contemporary philosophers of technology such as Mario Bunge (McGill), Rodolfo Herrera (University of Costa Rica), Carl Mitchman (Penn

State), Paul Durbin (Delaware), and Steve Goldman (Lehigh University). Here the term technology has three different, yet complementary, meanings:

1) technology as artifact (a concrete system)
2) technology as knowledge (a conceptual system), and
3) technology as social practice (an activity).

I argue that these three meanings are important elements for a framework for technology. The framework on technology has helped me to clarify the potential role of technological knowledge in science teacher knowledge. Using such a framework I clarified, in this chapter, what I meant by the introduction of technology into the science curriculum. In addition, the framework provided tools to study current national reforms that include technology as part of their proposal. I studied the conception of technology and technology education of Project 2061 and the National Science Education Standards and their relation with science education.

My discussion on understanding and applications; the cases of Feynman, Dave, and Judy; the framework on science teacher knowledge, together with the framework on technology and its use on the analysis of current reforms, provided the basis to study the translation of technological knowledge into the science curriculum. In different chapters, I developed the argument that technology can and should be part of general education. From the very beginning I showed that technological knowledge would close the gap between understanding and application in school science. Based on an eminent epistemological tension between understanding and applications, I called for a re-evaluation of school science knowledge. Using the example of engineering, that is, based on an epistemology of engineering, I clarified the specificity of the epistemology of technology. I illustrated the epistemological richness that technology has and its potential in science education. I reinforced the idea that technology (e.g., engineering) generates its own knowledge somewhat related to scientific knowledge in contextual and complex ways. The point that remains to be explained is why it has been so difficult, throughout the history of science

education, to introduce technology in the science curriculum. The last chapter of my dissertation deals with this problem and its implications on science teacher knowledge.

The last conceptual link of my argument faces the critical problem of introducing technology into the science curriculum. The attempts of introducing technology as part of the science curriculum are nothing new. What is the norm in these attempts is that they have not had real impact on the science curriculum. One of the reasons is that usually these propositions are not explicit with the kind of knowledge that students can learn with the introduction of technology. Therefore, it is important to know what the connections between scientific and technological knowledge are in order to be aware of the potential that technology has for teaching science. This is a missing element of the intents made to introduce technology as part of the science curriculum. I argue that my dissertation presents a contribution to this point. However, even if one clarifies this knowledge, the introduction of technology into school knowledge, that is its translation, still presents serious dilemmas.

I finish my argument developing a theoretical explanation on the translation of technological knowledge into the curriculum and its implications on science education. I recapitulate several parts of my arguments. Using the construct of "translation of knowledge" I explain how school knowledge has been the product of the translation of a clean history and philosophy of science which has denied (and perhaps erased) nearly all traces of technology. An epilogue explains the implications of this argument for the preparation of science teachers.

CHAPTER 1

CONNECTING SCHOOL SCIENCE WITH EVERYDAY LIFE: THE ROLE OF TECHNOLOGY

In the past decade, there have been renewed calls for reforming education in the United States. Such calls have markedly focused on science and mathematics with a particular concern for teaching and learning for understanding. Within the context of science education the reform proposals are also calling for meaningful applications of science to students' experiential worlds. Science teachers are expected to have an in-depth knowledge of subject-matter and a high level of capacity for connecting that to real-world situations (e.g., use of students' out-of-school experiences). Consequently, understanding and application are two key terms that partially define current science education reforms (e.g., the National Science Education Standards and Project 2061).

Although there are several potential interpretations of what it means to understand and use science in meaningful ways, the current concern for relating subject-matter to students' everyday lives experiences, that is, the personal relevance of school science, is the focus for this chapter. Later in the dissertation I offer a detailed analysis of several meanings of the uses of the terms *understanding* and *applications*. What is important at this moment is to note that contemporary reforms are asking for a stronger connection between school science and students' everyday lives. In this chapter, I set an introductory scenario from which the reader can see some of the problems that science teachers are having in connecting science with students' out-of-school experiences. I seek to show the potential role technology has in connecting school science with students' everyday lives.

The relevance of school science: The Salish Research

The Salish Research Project was an exploratory study conducted by a national collaborative team with members from 10 universities. It was monitored by the National Center for Improving Science Education (NCISE) and the Council of Scientific Society

Presidents (CSSP) and was supported with a three-year grant from the Office of Educational Research and Improvement (OERI) of the U.S. Department of Education. Many relationships were explored which included a consideration of the personal relevance of school science and teachers' knowledge and beliefs. The Project also studied potential connections among personal relevance with teachers' actions, students' outcomes and program features (teacher preparation), that is, characteristics of the program experienced by these new science teachers that would affect the relevance of science perceived by students and teachers. Preliminary findings from this project show that science teachers are not perceived by their students as making science highly relevant to their lives outside the school (Salish, 1997).[1]

The concept of personal relevance in the Salish Research is related to uses of science out-of-school as perceived by students and teachers. Although one can access records of in-depth interviews and videotapes of actual teaching to discern how teachers were connecting science to students' everyday lives, a preliminary study was developed using the Constructivist Learning Environment Survey (CLES) (Taylor, Fraser, & White, 1995). On the CLES Personal Relevance Scale (PR), students and teachers rated the relevance of their science lessons. For each item the minimum score is 7, which means "almost" no relevance, and the highest is 35, which means that they "almost always" perceived relevance. Between "almost no relevance" and "almost always" there are different degrees such as "seldom" (14), "sometimes" (21) and "often" (28). The Personal Relevance score is calculated as an average of all scores.

The first general outcome of the Salish I Research regarding the relevance of science and mathematics studies showed that "Students in science classes perceived their

---

[1] This dissertation uses data from the Salish I Research Project. Salish was sponsored by the U.S. Department of Education, Office of Education, Research, and Improvement, Grant No. R168U3004. Any opinions, findings, conclusions or recommendations expressed in this dissertation are those of the author and do not necessarily reflect the views of the U.S. Department of Education or of the Salish I Research Project as a whole.

study to be personally more relevant to their lives than did students in mathematics classes" (Salish, 1997, p.18). This finding was based on data from 241 classes taught by 116 new teachers (207 of these classes were science and 34 were mathematics classes). The survey included more than 5,000 students. Therefore, one may suggest that science studies were being perceived highly relevant. However, when one sees the average scores of science and mathematics (23.3 and 21.2 respectively), the situation is less promising. The following figure displays data of personal relevance as it was perceived by science teachers and their students.

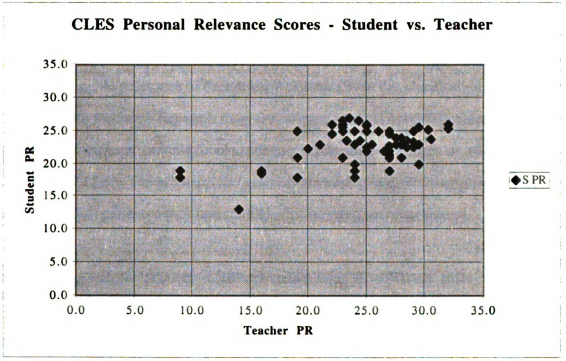


Figure 1.1 Students personal relevance scores as a function of teacher personal relevance scores.

A first interpretation of the data displayed in Figure 1.1 is that few science teachers were seen as making science highly relevant according to their students. Only about 10% of the sample obtained personal relevance scores greater than 25. In fact, one can sort the sample of Salish science teachers in two subsets: those teachers whose classes were seen as highly relevant and those who were perceived with medium and low relevance. The vast

majority of science teachers were rated by their students with scores between 20 and 25 (medium scores). These teachers saw their teaching as being more relevant than students did. This is especially valid if one notes in Figure 1.1 that the majority of students are between the 20 and 25 interval while their teachers are between the 20 and 30, and mainly between 25 and 30. At any rate, few science teachers were seen by their students as making science study highly relevant.

There are, of course, several more interpretations or perhaps concerns about the data displayed in Figure 1.1. One would argue, for example, about the validity and reliability of the survey or the conditions in which the test was applied (see Taylor, et al. 1995 for specific discussions on the instrument). Nonetheless, this data can be used as a starting point, that is, as exploratory research on the perceptions that teachers and students have regarding the relevance of their science classes. Given this clarification, one can see that data from the Salish Research show that science teachers have difficulties in connecting science with students' out-of-school experiences (relevance of science as measured by the instrument CLES). The problems that teachers are having in connecting science to students everyday life experiences may become clearer if we examine other studies.

Connecting school science with everyday life: A difficult task

The connection of school science with students' everyday lives is another of these educational goals which looks simple, plausible and desirable. However, it seems to be complex, difficult, and rarely studied. Of course, there have been researchers and even movements concerned with the topic (e.g., the science technology and society movement, usually called STS). Take a look of the following titles*: **"Cognition in scientific and everyday domains: Comparison and learning implications"*** (Reif, & Larkin 1991) or ***" Bridging the gap between school and real life..."*** (Roth, 1992), etc. Unfortunately they are just titles. None of these papers attempts to study what the title suggests (Reif, & Larkin, 1991 studied everyday life thinking as opposed to scientific

thinking rather than the uses of science in students' everyday lives). In fact, one easily finds an incredible lack of research on how students use science in their lives. There is even less research on how teachers can help students to connect students out-of-school experiences with science.

There have been some works about the relevance of science education, for example the reports of Lewis (1972), and also Newton (1988). The problem with these studies is that they tend to be general recommendations (opinions), rather than research based on actual observations of classroom situations or everyday life activities. Nagel (1996) is an exception, but her work is still general. Linn has studied the use of thermodynamics in everyday life and her work is studied later in this chapter. Lave (1988) is another exception in mathematics education; unfortunately, her work does not have a parallel in science education.

One of the few systematic works on school science and students' out-of-school experiences is the recently published paper of K. Mayoh and S. Knutton (1997). They reported the way in which twelve science teachers were using students' out-of-school experiences in their science lessons. The authors set an experimental design which included data collection from one hundred lessons during the period of fourteen months (Mayoh, & Knutton, 1997, pp. 850-851). In their report, Mayoh and Knutton stress their decision of preserving -as much as possible- the naturalistic setting of classrooms investigated. Both the level of teachers investigated (secondary education) and the exploratory nature of the research make Mayoh and Knutton's study similar, in part, to the Salish research. However, Mayoh and Knutto research was much more specific in the sense that it was planned to study the way in which secondary science teachers use students' out-of-school experiences in their science lessons.

There are several important points of the Mayoh and Knutton report that are important for my discussion (Cajas, 1998a). In principle they ordered the data using a "taxonomy of episodes involving out-of-school experiences" which seems to be useful to think about the

uses of science in real life (e.g., episodes referring to: the mass media, use in everyday life, industry, etc.). In addition, they reported different roles that out-of-school experiences play in teaching science. Some of them are: linking everyday experiences with scientific ideas, raising students' awareness of science related to everyday life situations, increasing students' interest in science, etc. (pp. 862, 863). What is really striking from this study is that almost no teacher from their sample seems to be able to connect science to students' out-of-school experiences (i.e., everyday life of students). Although we all know that it is difficult to connect science to students' out-of school experiences, one would expect that some teachers can make this connection. However, for the set of teachers studied by Mayoh and Knutton, it was an impossible task. If this is indeed the case, one should ask why.

One immediate answer regarding the lack of teachers that connected science with students' out-of-school experiences would be that perhaps these teachers simply do not know how to do so because they only have a few years of experience. From this perspective, connecting students' out-of-school experiences with school science may be a matter of teachers' experience.

Years of teaching experience may be an important factor enabling teachers to connect school science and students' out-of-school experience. However, the Salish Research Project revealed that some new science teachers were able to make this connection. Although in general terms students tended to perceive that their classes were not very relevant to their every-day life, the Salish research found a set of teachers -about 10% of the sample- which included students who perceived their science lessons as being highly relevant to their personal lives (Salish, 1997, p. 47). The problem with this sample of Salish teachers was that classroom observations showed that they were "telling" students what was relevant (ibid. p.47). Therefore, one cannot say that the problem of relevance of school science was solved.

Another potential answer to the lack of connection between science and students' out-of-school experiences may be the teachers' lack of pedagogical knowledge to do that. This deserves a better understanding of the sample of teachers studied by Mayoh and Knutton. For the case of the few episodes in which there were potential attempts to connect out-of-school experiences with science lessons, Mayoh and Knutton report that:

> ...teachers appeared to possess some knowledge-in-action concerning the importance of linking everyday experiences to scientific knowledge. However, their awareness of the role of out-of-school experience within their teaching seemed largely to be tacit. Rarely, were teachers explicit about the potential relationships of out-of-school experiences to their science learning (p. 865).

The question is: What is this "tacit" knowledge teachers need to know to help students connect everyday experiences with science lessons? Why is it so difficult for these teachers, and teachers in general, to be explicit with the connection between out-of-school experiences and science learning? One specific example would help to see this point.

Consider the case of the 'Episodes developing skills of use in everyday life' section of Mayoh and Knutton's paper. This is related to the topic of electricity (p.859). Electricity seems to present a meaningful context for using science in everyday life. Moreover, there is abundant research on electricity, particularly on circuits (Arons, 1997; McDermott & Shaffer 1992a, 1992b). In fact, the topic is considered as one with several real-world applications. However, such applications tend to be difficult because normally science teachers work with very simple circuits (e.g., closed circuits constructed with flashlight bulbs, wires, and batteries) while real-world circuits tend to be different (Black & Harlen, 1993). More important, working with bulbs, wires and batteries is to develop models to understand how electricity works rather than developing skills to be used in everyday life. This becomes clearer when one reads the specific episode reported by Mayoh and Knutton on the electricity unit:

> This was rarely observed but one episode which could be interpreted as deliberate skills training involved wiring an electrical plug. However, for safety reasons pupils were not allowed to test their wired plug in a socket...Pupils also carried out a range of classroom-based skills such as plotting graphs and recording numerical

> data in tables as well as open-ended problem-solving investigations. However, the extent to which these skills might be transferable to other problems and issues in their lives is not clear (p.869).

There are at least two different episodes in this quotation. The first is an attempt to do practical things (e.g., wiring an electrical plug). As the authors say, problems of safety did not allow students to fully develop the task. My interpretation includes more alternatives. First, I think that usually science teachers do not have the kind of practical knowledge needed to help students with these tasks. And second, it is possible that science teachers are not interested in this kind of knowledge.[2] Certainly, one can see that in order to wire an electrical plug, teachers need to draw from practical knowledge (technical knowledge on circuits) that usually is not integrated in science education. This contrasts with the second part of the quotation from Mayoh and Knutton's paper which reflects the classical goal of science education: to develop analytical investigations. In this case, what matters is the collection of data, development of graphic interpretations, which are strategies to develop understanding rather than practical applications of electricity in the real world. The connection between these two approaches seems to be very difficult if not impossible for these science teachers. Again, one should ask why is it so?

A second example taken from the same report clarifies this question. This time the example comes from the topic of energy. The episode identified is on the use of 'analogies based on students' everyday experiences. Here the teacher says:

> Imagine if you had some hot water from the tap at the back and you had to tip it into a bucket at the front. You've got a saucepan to carry it in...but as you walk along it slops all over...So what do you do?

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[2] Science teachers do not have this "practical knowledge" nor they are interested in it. For example, a recent project developed in Thailand that attempted to connect school with community by including in the curriculum the topic of "social forestry" showed that: "Resistance remained particularly great among the four science teachers who continued to argue that such field-base program was inconsistent with the curriculum they were mandated to teach and represented an inappropriate learning style [practical] for students in lower secondary school" (Wheeler, Gallagher, McDoDonough & Sookpokakit-Namfa, 1997 p. 213)

> You put a lid on it to stop the water escaping while you're carrying it. Well, that's like the water pipes, except in that case, you don't want the heat to escape so you put lagging on the pipes. The lagging is like the saucepan lid. It stops the heat escaping (p.858).

According to Mayoh and Knutton, with this analogy there "...is a clear attempt by the teacher to bridge pupil's understanding from a familiar experience towards an unfamiliar science concept" (p.858). I do not analyze the quality of the analogy. What is important is the assumption that it is possible to use familiar experiences (everyday) to understand unfamiliar explanations (scientific). Here the notion of insulation and transfer of heat have been identified as simpler phenomena. One can argue that for this topic, there are better analogies that allow teachers to connect science with students' everyday experiences. Yes there are, and one can help students to develop a scientific understanding of processes of heat transfer, temperature changes and thermal equilibrium (see examples in Arnold & Millar, 1996). The problem begins when one tries to develop scientific understanding and practical applications at the same time.

As I have illustrated, the demands of teachers' knowledge in the sense of practical applications of science to students' everyday experiences and scientific knowledge is problematic. Mayoh and Knutton recognize that by pointing out that the few teachers who attempted to connect science with students' out-of-school experiences were using a kind of "tacit" knowledge, that is, "knowledge-in-action". However, Mayoh and Knutton did not clarify the nature of this knowledge. In fact, they do not explain why it is difficult for teachers to connect students' everyday lives with science lessons.

Connecting science with everyday life: Some alternatives

The problems that Mayoh and Knutton are reporting is not the difficulty of developing students' scientific understanding. The problem is the lack of connection of this scientific understanding with practical applications, particularly the lack of connection between science and students' out-of-school experiences. Think of the suggestion made in Project 2061

regarding the models of heat that should be taught in K-12 education. *Science for All Americans* suggests an approach in which energy is understood using mainly atomic and molecular models. For example, the process of transformation of heat from "warmer" places to "cooler" is explained in the following terms:

> Heat energy in a material consists of the disordered motions of its perpetually colliding atoms or molecules. As very large numbers of atoms or molecules in one region of a material repeatedly and randomly collide with those of a neighboring region, there are far more ways in which their energy of random motion can end up shared about equally throughout both regions than there are ways in which it can end up more concentrated in one region (AAAS, 1990, p. 51).

Some, actually few, science education researchers have studied the relevance of the kind of models of heat advanced by Project 2061, that is, atomic and molecular models, regarding students' everyday lives. For example, Linn and her colleagues at the University of California, Berkeley, have developed a curriculum that attempts to connect science with everyday life applications on the topic of thermodynamics. Since their earlier works, Linn and her team have criticized the uses of atomic and molecular-based models of thermodynamics in K-12 education (Linn & Songer, 1991). In doing so, they have argued the lack of relevance of these models in students' everyday lives

> These elegant models may not be very effective for many students...As a result of this abstraction, many elegant theories do not appear directly linked to the world around us" (Linn, & Muilenburg, 1996, p. 19).

In contrast, they suggest alternative models that can be used in more relevant ways: "We find alternative to the abstract, elegant models in the relatively concrete, pragmatic models used by experts in heat transfer" (ibid., p.21).

From the perspective of Linn and her colleagues, the problem of connecting school science with students' everyday lives experiences is an epistemological problem. What she suggests is to reduce the abstractness of school knowledge by introducing more concrete and pragmatic models. The problem here is not necessarily years of experience of teachers or their pedagogical knowledge, not even social limitation of schooling. These factors may or may

not affect the teaching of science (Linn, & Butler, 1991; Linn, & Burbules, 1993). What is urgent, from their perspective, is to reduce the epistemological distance between students' everyday knowledge and scientific knowledge. Note that the Linn team is asking for the introduction of more concrete and pragmatic models as opposed to deeper and abstract theories. The solution is epistemological.

The epistemological solution that Linn has suggested is nothing new. The problems is so important that it has been the very topic of specific conferences, such as the European Science Education Conference: ***"Relating Macroscopic Phenomena to Microscopic Particles: A Central Problem in Secondary Science Education,"*** held in Holland a few years ago (Lijse, & Licht 1990). In reading the proceedings of this conference, one realizes the existence of research that has attempted to discuss the problems and advantages that the inclusion of micro models (e.g., atomic or molecular models) has had in science education. However, Linn's suggestion is more specific in the sense that she has advanced specific "pragmatic" models (macro models) which have important philosophical assumptions and crucial pedagogical implications.

In principle, according to Linn's research, it is possible to reduce the epistemological distance between scientific knowledge and everyday life knowledge (Linn, & Songer, 1991; Linn, 1992; 1993; Linn, & Muilbenburg, 1996; Linn, 1997). The price is to sacrifice abstract models. Therefore, one would increase the relevance of science by reducing the level of abstractness of school knowledge. This has some favorable empirical evidence beyond Linn's research. One is the historical case of the *Movement of Common Things* in England which last century attempted to include more practical knowledge into the science curriculum (Layton, 1973, see also Goodson, 1996 for a critical analysis of this historical case). Another is closer to home: the Salish research itself which found a set of teachers (about 10% of the sample) that included students who perceived their science lessons as being highly relevant to their personal lives (Salish, 1997, p. 47). What is interesting is that "several teachers with high personal relevance ratings from students had prior careers in applied fields such as the

military, geology, engineering, scientific research, and business" (Salish, 1997, p. 48). It is clear that the knowledge from which these teachers based their practice tended to be more applied.

The knowledge behind the use of science in everyday life

In attempting to connect school science, particularly topics like thermodynamics, to students' everyday lives Linn has suggested the use of more pragmatic models (Linn, 1993; Linn & Muilenburg, 1995). Pragmatic models means specific macroscopic models of transfer of heat in which "..heat energy flows from objects at higher temperature to objects at lower temperature" (Linn & Muilenburg, 1996, p. 21). There are mathematical interpretations of such models based on the works of the French scientist J. Fourier (1890). The rate of heat transfer can be determined by the expression $q=UA\,\Delta T$ in which A is the area of transference of heat, U the coefficient of transfer (determined by the mechanics of transfer which can be either radiation, convection or conduction), and ΔT the change of temperature. Linn and her team have developed computer simulations for this expression (Linn, 1991).

The important point of Linn's research is that she thinks that such kinds of models, (pragmatic) are more useful for connecting science with students' everyday lives (Linn, 1993; Linn & Songer, 1991). Particularly her team has reported that:

> ...students taught the heat-flow model learned more about heat and temperature and solved more relevant problems than those taught the molecular-kinetic model...the heat-flow model can help with many personally relevant phenomena, including keeping Cokes cold and hands warm..." (Linn, & Muilenburg, 1996, p. 21).

Here, these particular "pragmatic" models seem to help students to have more "real" experiences with science.

When one examines the knowledge in which the curriculum suggested by Linn and her colleagues is based and the knowledge in which the relevant Salish teachers based their practice, one finds that they have drawn from epistemological territories different from, yet

perhaps complementary to, science. In the case of Linn's curriculum, these models come from technology. In fact, Linn and her colleagues have often used engineering models of transfer of heat (see examples in Kreith, 1973). Therefore, one would defend the idea that technological knowledge can increase the connection between school science and students' out-of-school experiences. In other words, it is possible that this kind of knowledge can be more relevant to students' everyday lives. However, the problem of relevance of science, use of science in everyday life, connecting science to students' everyday lives experiences, etc. is much more complex. For example, how can one support, that understanding how to keep Cokes cold and hands warm is something that students will find interesting and useful? What are the intellectual challenges of such kinds of tasks? What are the learning outcomes of these activities? Moreover, the same topic of heat and temperature can be approached from another more pragmatic perspective such as the case of knowledge about refrigeration, insulation, etc. This has been a topic of vocational education which has not been translated into science education. Therefore, there are several pedagogical alternatives from which one would draw in order to make the topic of heat and temperature more relevant to students' out-of-school experiences. This requires a clarification of what are we looking for in science education and what the role of the uses of science in students' everyday lives is.

The problem of the relevance of science can be seen from several perspectives. From a pedagogical point of view, it requires a better understanding of the kind of knowledge teachers need to know to connect students' everyday lives experiences with school science. Given the concern of science education reforms -teaching science for understanding and also for meaningful applications in students' everyday lives- this is an imperative task. However, pedagogical actions may be conditioned to epistemological decisions. For example, it is possible that overvaluing abstract and universal knowledge over practical knowledge does not allow teachers to connect school science with students' out-of-school experiences. This should be investigated further. Therefore, a first step for

analyzing the relevance of school science in relation to students' experiences is to study the epistemological demands that applications of science -regarding students' everyday lives- place on science teacher knowledge.

A second step is the study of other epistemological alternatives to traditional science curriculum. For example, we have seen that Linn and her team have advanced a curriculum which is basically formed for "...more concrete and pragmatic models used by expert in heat transfer" (Linn, & Muilenburg, 1996, p. 21). This argument also needs to be investigated. What is the epistemological nature of such models? Where do they come from? How can we connect them to science education?

The specific case of transfer of heat studied at Berkeley only illustrates the replacement of one kind of knowledge (classic thermodynamics) for another (heat transfer). In principle, one can deduce that this knowledge comes from engineering models of heat transfer; however, thermodynamics is only a small piece of the K-12 science education curriculum. Therefore, we need to know more about the general potential of this kind of knowledge in other topics of science curriculum, that is, technological knowledge. Moreover, the argument that the inclusion of more concrete and pragmatic models can increase the relevance of school science is conditioned to other factors. There are at least two dimensions that seem to be important: a) our knowledge about these pragmatic epistemological territories (e.g., engineering knowledge), and b) the goals of science education.

The introduction of technology in forms of more concrete and pragmatic models with the explicit goal of increasing the relevance of school science has not been systematically studied. The work of Linn and her team suggests the introduction of this knowledge without discussing its epistemological status. In other words, although Linn has developed an argument to show the case of thermodynamics, she has not unpacked the epistemological nature of the models she is advancing. In fact, she is assuming that more concrete and pragmatic models can be more relevant to students. However, what does it

mean more concrete or more pragmatic? What does it mean to be relevant? The former question is related to the nature of the knowledge suggested (e.g., epistemology of engineering) and the latter to the goals of science education (e.g., teaching for understanding).

Technology: Reducing the gap between school science and everyday life

Technology would reduce the gap between school science and students' out-of-school experiences. The examples taken from Linn's research and the general discussion on the potentiality of using more concrete and pragmatic models support that. This is because I am assuming that technology, as epistemological field, tends to be based on pragmatic models which have a closer relation to students' everyday lives. However, there are many questions that need to be analyzed. First, one may ask: What is the nature of the technological knowledge that can help us to connect science to students' everyday lives? Second, how do the goals of science education transform such knowledge and vice versa? Moreover, the very conception of technology is by itself a problem. In fact, the term technology is mainly used for referring to educational technologies (computers). I argue that this extensionalist connotation limits the richness that technology, as epistemological territory, would provide to teaching science.

One should be aware that the introduction of technology into the science curriculum is not a new idea as one can conclude by reading the abundant reports on the Science Technology and Society (STS) movement (see Solomon, & Aikenhead, 1994; Yager, 1996 for reviews). Many of them have justified the approach as a means for increasing the relevance of the science curriculum (Yager, 1996). Unfortunately, the conception of technology that these movements have presented tends to be obscure and its connection to science education unclear.

On the other hand, current science education reforms are asking for the introduction of technology into the K-12 curriculum. The two leading science education reforms in the United States, Project 2061 and the National Science Education Standards, include

technology as a significant part of the content of science curriculum. In other words, reformers are asking for the introduction of technology, as content knowledge, in K-12 education. In contrast to previous reforms, these documents include conceptions of technology that go beyond the notion of artifacts. Project 2061, for example, includes a solid and rich epistemological conception of technology that needs to be connected to science education.

This dissertation analyzes the role of technology as curricular content in science education and its implication on science teacher knowledge. In doing so, I propose to examine carefully recent works of philosophy of technology, mainly epistemology of engineering -a field of research that has just emerged in the last twenty years (Bunge, 1976; Goldman, 1984). Moreover, what is needed is to connect these emergent works - philosophy of technology- with the conceptions of technology advanced for science education reforms such as the case of Project 2061 and the National Science Education Standards. This dissertation attempts to do that.

The basic point of this dissertation is the idea that technology provides an important epistemological referent for teaching of science. Particularly, technology becomes almost indispensable when one wants to connect science with students' everyday lives. Therefore, I do not study technology for its own sake. Rather, technology appears in scene given the problems of connecting science to students' everyday lives experiences. This is why one needs to study in detail the nature of technology and its multiple faces. This of course is a means. The end is to explore alternative epistemological territories that can help us to reduce the gap between school science and students' experiential world.

In order to frame my argument, it is important to show the reader that in fact there is a tension between teaching science for understanding and teaching science for applications. This tension is not a simple dichotomy between two opposite approaches. Throughout this dissertation, the reader will see that this relationship, understanding and application in its pedagogical context, is a complex relation which takes several forms that at the end have

important implications for science education. It is in this context where I develop the idea that technology can play an important role in teaching science given its unique epistemological characteristics. Particularly, I show that technology lies somewhere between knowing and doing, that is, between creation and understanding. This condition places technology in an optimal position to teach science if one is interested in connecting science to students' everyday lives. However, before studying in detail the conception of technology, it is fundamental to clarify what the problem that technology will solve is. In others words, what is this so-called tension between teaching science for understanding and teaching science for applications, and how it is related to technology? These are questions I study in the followings chapters.

CHAPTER 2

THE TENSION BETWEEN UNDERSTANDING AND APPLICATIONS

> "Interviewer: What science concepts do you believe are the most important for your students to understand by the end of the school year?
>
> *Dave*: I think first of all, they should have a good understanding of the fact that every thing is made up of small particles...atoms. I think that's very important. Other than that, they should understand some hazards of chemicals, some benefits of chemicals, and how we use chemicals in our everyday life" (3/23/1995) [1]

Dave is a new secondary science teacher who seems to reflect in the quoted statement one of the most accepted current goals of scientific literacy: teaching science for understanding and teaching science for everyday life. *Dave* does not present this goal as the tension between understanding and application. From his perspective understanding and applications do not seem to compete. By the same token, the two leading science education reform proposals in the United States, Project 2061 and the National Science Education Standards (AAAS, 1990, 1993; National Research Council, 1995) are also asking for deep conceptual understanding and applications to everyday life.

In this chapter, I study the emergence of a potential epistemological tension between understanding and application in the context of teaching science. I partially illustrate my points using preliminary data from the Salish Research Project. I also examine the recently published audio information of the lectures of Richard Feynman as representative of a kind of understanding.

The Case of *Dave* and Feynman

In trying to make sense to *Dave*'s response to a query about the most important concepts that his students should learn, one has to deal with several possible explanations. I would like to begin with a position adopted by Richard Feynman when he suggested

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[1] Question # 34 of the Salish's protocol called Teachers' Pedagogical Philosophy Interview (TPPI). The quotations of the interviews that appear in this dissertation have not been edited.

what was the most valuable knowledge for his students: "I believe it is the atomic hypothesis...that all things are made of atoms, -little particles that move around in perpetual motion..." (Feynman, 1995, p.4). Both, Feynman and *Dave*, are concerned with teaching science for understanding. However, in contrast to *Dave*, Feynman was teaching with the assumption that his students would be physicists: "This two-year course in physics is presented from the point of view that you...are going to be...physicist[s]" (ibid., p.1). This assumption introduces a special meaning of the term "understanding", that is, the meaning of the term is tied to the meaning of understanding within scientific communities, particularly a community of physicists.

Understanding within scientific communities has traditionally been characterized by explanations based on scientific theories. Although there are several philosophical schools that have "defined" criteria for accepting what constitutes a scientific explanation, the dominant school has been positivism.[2] Explicit and implicit followers of this position argue that, "The criteria for scientific understanding are well specified" (Reif, & Larkin, 1991, p.739). From this perspective, "...understanding in science is a working goal pursued deliberately in the service of the central goal of explaining and predicting..." (ibid.). Moreover, this position assumes that a given theory is formed by well specified postulates and understanding will be derived from the use of these theories.

Although it is difficult to translate the above conception of understanding into school settings, I suggest one possibility. Understanding in school settings using the above criteria of explanation and prediction will require that teachers and students master scientific theories. One common translation of this "understanding" to school settings is exemplified by traditional textbooks in which scientific knowledge is presented with the addition of exercises that have to be solved. Such exercises usually appear at the end of

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[2] I refer to the philosophical school that defends the idea that : a) science consists in the subsumption of individual cases under general laws, b) scientific explanations are causal, c) mathematics is the language of science. See Wright (1971) for a discussion on positivism. See also Philips (1983) for a differentiation among different kinds of

each chapter. For example: "Calculate the work done when a 20-N force pushes a car 3.5 m" (Hewitt, 1997, p.120).

Rather than explaining and predicting natural phenomena traditional science classes tend to be based on canonical school knowledge that is taught for solving exercises invented by textbook writers. These problems force students to learn the "right" formula which will produce the right answer (W=Fd=20Nx3.5m=70J in the above example). Refined versions of this conception of understanding is the use of established algorithms for solving text-book exercises. For instance: "If a car traveling at 60 km/h will skid 20m when its brakes lock, how far will it skid if it is traveling 120km/h when its brakes lock?" (Hewitt, 1977, p.121). From this perspective, the original notion of understanding is transformed into the manipulation of formulas for solving textbook problems or the "understanding" of specific rules. I see this shift, from understanding as explanation and prediction using theories to applications of formulas, as an outcome of a complex social and epistemological process in which expert scientific knowledge (ESK) is translated into school canonical knowledge. A specific analysis of this process *(translation)* is offered in chapter 7 of this dissertation.

As I said, it is difficult to make the case that a given conception of science, for example understanding as prediction and explanation, can be purely translated to school settings given the multiple factors that affect schools. However, one can accept that the conception of science might affect science teaching. *Dave* for example, believes that "...a theory is just someone's idea [which has] not been proven at all. A law is proven and a fact is proven and believed..." (Interview, 3/23/95). *Dave*'s general conception of science is based on truth facts which are the basis of scientific laws. Moreover, in a specific question about the relationship between science and truth *Dave* expressed that: "Science is based on truth. What we believe to be true we teach" (Interview, 3/23/1995).

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positivism, such as Comtenian positivism, logical positivism.

From this conception of science, one can expect that *Dave* will develop pedagogical structures which will help him to teach "what we believe to be true".[3] In some respects this is not difficult for *Dave* given the existence of an official curriculum which is represented in textbooks. In fact, in answering the question of how he decides what to teach and what not to teach, *Dave* expressed that " ...it goes pretty much right from the book, and I'm kind of following that pattern, going chapter to chapter." (Interview, 3/23/95). One year later, *Dave* also pointed out the existence of external factors that affected his decision on what to teach: " I do not know if this is a bad thing or anything, but, we get [the] goals and objectives book, and we look at the proficiency test, what's going to be tested, that puts a lot of pressure on the school..." (Interview, 1/29/96). Consequently, the conception of science (e.g. "science is based on truth") and the external pressure of an official curriculum (e.g. proficiency test), just to mention two factors, play important roles in *Dave*'s teaching. In this case, both factors tend to reinforce science as a body of knowledge already made, that is, canonical knowledge in which students have to master formulas and algorithms already developed by others. This is only one kind of translation of canonical knowledge into school science.

When Feynman agreed to teach basic physics for freshman at California Institute of Technology in the early 60's, the notion of understanding that he stressed in the lectures seems to be explanation and prediction based on theories. The recent reproduction of his lectures (audio tapes) provides a basis for concluding that Feynman kept this notion of understanding throughout his lectures (Feynman, 1995). Feynman developed pedagogical

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[3] The literature on the relationship between nature of science and science teaching is enormous (e.g. ,Duschl, 1994 ; Matthews, 1994). With the exception of some important contributions of philosophy of science to *learning* science (Carey, 1992; Chi, 1992; Duschl & Hamilton, 1992), the contributions of the research on the nature of science to *teaching* science is quite limited (see Lederman, 1992 for an extensive analysis). Although we think that nature of science is important for teaching science, we have not shown useful relationships between conception of science and *teaching* science (Cajas, 1995a). We know that science teachers are not exposed to programs that include nature of science (Gallagher, 1991). However, we have not produced knowledge relating teachers' knowledge, teachers' actions and nature of science beyond general descriptions.

structures which presented science as a body of knowledge. Although his pedagogical actions were centered in key ideas and frequent uses of interesting examples, his teaching had the goal of introducing students to the discipline of physics for its own sake. This approach would be problematic if one needs to teach in the context of general education and from the perspective of everyday life. The scientific account would be valuable, but its applications to everyday life should be examined further.

Feynman's pedagogical actions: The glasses of STAM

During our research in Salish, particularly in the classroom observations through analysis of video tapes, we used the *Secondary Teaching Analysis Matrix (STAM)* developed by J. Gallagher and J. Parker. The instrument includes several categories of teaching styles; however, one can summarize them in three general categories of teaching: teacher-centered, conceptual and student-centered (personal communication, J. Gallagher, February 1997). The teacher-centered category is related to didactic approaches in which teachers tend toward factual knowledge, that is, isolated pieces of information. Conceptual teachers in this category place the subject-matter of science as the central focus. The pedagogical structure of a conceptual teacher is organized around "key ideas" of the discipline and the pedagogical strategies includes real world applications of such content. The meaning of real-world applications here is related to explaining or predicting using everyday phenomena. These connections are usually made or leaded by the teacher. Student-centered category is related to teaching styles which focus on students. In this category, teachers and students negotiate the understanding of the content. The connections with real-world applications are elaborated by students and teacher related to investigations, data analysis and concept building.

When one sees Feynman's pedagogical actions through the glasses of STAM, that is, the above typology, one observes a mix between teacher-centered and conceptual teaching styles. There is evidence (e.g., audio tapes) that several of Feynman's lectures

included interesting connections of science to every-day phenomena. However, these connections were important for the sake of the discipline. As I said, from the perspective of the typology used in Salish (Gallagher & Parker, 1995), Feynman tends to be a mix of conceptual teacher (content) and didactic (actions).[4] What is important for my account is that his conception of understanding, which is tied to explanations and predictions using theories, is at the end the "real" application of science. In other words, understanding and application are somewhat inseparable given that understanding means the application of theories for explaining and predicting.

External and internal relevance: *Dave* and Feynman

Dave, in contrast to Feynman, has a different reality. In principle, *Dave* is being asked by current educational reform for explicit connections between science and their students' everyday lives (scientific literacy). For example, the National Science Education Standards as well as Project 2061 assume that understanding science and being able to use it in everyday affairs are hallmarks of scientific literacy. From this perspective, the interests and experiences of students play an essential role in current calls for reforming science education.

As I mentioned in the first chapter, the Salish Research Project explored this connection using the concept of *personal relevance*. In doing so, the Project used the Constructivist Learning Environment Survey -CLES- (Taylor, et al. 1995). In analyzing the questions in CLES, one can deduce that personal relevance was not defined in relation to the notion of understanding as explanation and prediction using scientific theories. Here, the application of science is embedded in the notion of personal relevance which goes beyond the use for explaining and predicting. Personal relevance in the context of CLES is

[4] Feynman acknowledged the limitations of his pedagogical work: "I think, however, that there isn't a solution to this problem of education other than to realize that the best teaching can be done only when there is a direct individual relationship between a student and a

related to the direct connection between science and uses of science in everyday life, such as how students perceive science in their out-of-school lives.

Relevance is a tricky term. Douglas Newton, for example, defines two kinds of relevance: external and internal. The former, external, is related to the connections between science and people's lives while the latter are those meaningful uses students make of science within the subject-matter. In his own words, "In science teaching, some courses are described as having *internal relevance* and by that is meant the connections between and the interdependence of different parts of the subject" (1988, p.8). For example, a) the importance of Euclidean Geometry as a formal support of Newton's Laws, b) the connection of key scientific ideas in different context of the discipline such as energy in biology, mechanics, electricity, chemistry, etc. External relevance, in contrast, is more related to meaningful uses of science in real life, here "...science might be used as a model for thinking about and solving problems of a more mundane nature. Now the relevance of science to such needs is real" (ibid.).

It seems to me that Feynman was more concerned with internal relevance (less mundane nature) while *Dave* is being asked to satisfy both: external and internal relevance. The following table illustrates a preliminary contrast between Feynman's pedagogical positions and *Dave*'s in light to the notions of internal and external relevance.

---

good teacher- a situation in which the student discusses the idea, thinks about the things, and talks about the things" (Op. cit., p. xxix).

Table 2.1. Contrasting external and internal relevance.

	Feynman	***Dave***
Internal Relevance	YES High concern on the uses of scientific theories for describing, explaining and predicting. Commitment with the subject-matter.	YES Concern for students learning scientific concepts.
External Relevance	NO Disregard on how students use science in their everyday life (out-of-school). Stress on the uses of theories within the scientific community.	YES Concern on how students use science in everyday life (out-of-school)

The notions of internal and external relevance are preliminary terms in order to tackle a possible distinction and connection between two goals of science education. These terms are problematic, like all of our concepts, in principle, because what is considered internal or external depends on the position of the observer (personal communication with David Wong, June 1997). What is relevant for a scientist, for example, should include internal and external relevance given that her/his everyday life turns around scientific activities. Everyday life for students also includes several hours within schools. Therefore, defining external relevance in the sense of the use of science out-of-school is problematic. The very distinction between understanding and applications is problematic because for some people understanding implies applications. However, despite these potential limitations, I think that the terms, external and internal relevance, are useful tools for a preliminary analysis.

Understanding and applications: The case of *Dave*

Throughout the course of our research in Salish we followed *Dave* for three years. *Dave* consistently showed a concern for teaching science for understanding and application. In 1995, when he answered what learning in his classroom he thinks his students will

value, he said: "Just the basics of scientific literacy like the first half of our physical science class is all Chemistry...I tried...[to teach] concepts they may use at home, and figuring out the bounds between chemistry and home (Interview, 2/23/1995).

The second year of our research, *Dave* also showed interest for these two kind of goals in his teaching. This time, 1996, the class that he reported as the best experience that he had had was electricity.

> Interviewer: Describe the best teaching/learning situation you have ever experienced?
>
> *Dave*: I would say my electricity unity. We have little kits where...two kids work on a kit together. It does a great job of getting them to test different types of circuits, see what happens...during the period they are going to do certain light bulbs. These kids can really get into...they are always working with something (Interview, 1/29/96)

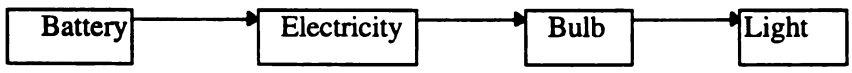
During this interview *Dave* constantly refered in a positive sense to his electricity class. Classroom observations of this unit showed interesting features. Let us transport ourselves to the day of *Dave*'s electricity class (source: video 2-08-1).

For this morning *Dave* planned to teach concepts related to electricity. In dealing with this topic, *Dave* divided his students in groups of three. There were approximately 6 groups. He asked them to discuss within their groups what people can or cannot do with electricity and what life would be like without electricity. The groups discussed for almost 15 minutes while *Dave* walked around checking some discussions. He engaged in some specific discussions with his students. He asked all the groups for a summary on their discussion. As far I can see, *Dave* was setting a real world context for the uses of electricity. He also attempted to take into consideration what his students already knew about electricity and how this was connected to the real world. It seems to me that he had a specific pedagogical plan: 1) forming groups, 2) asking for important aspects of electricity in everyday life, 3) asking the groups for reports. *Dave*'s students talked about electricity during 25 minutes without moving their discussion toward scientific explanations of electricity.

The report of each group took place with the help of *Dave*. The class became engaged in what appears to be an interesting discussion on the importance of electricity in everyday life; that is, what life would be look like without electricity and how electricity has changed our current life. All the examples that students presented tended to be technological artifacts (TV, CD player, VCR, etc.). *Dave* directed the discussion toward the uses of these artifacts and how they have changed our lifestyle. One group perceived the message and reported examples more congruent with *Dave*'s suggestion, such as " the importance of electricity for the illumination of cities". Other groups followed this suggestion presenting examples such as air conditioning, keeping food in the refrigerator, etc.

After 35 minutes of discussion, *Dave* gave each group batteries, flashlight bulbs and wires for constructing circuits and moves the discussion to another level (source: Video tape with the code MSU 2-08-1 Time 40:00). The transition from the general discussion on the uses of electricity in everyday life to the potential laboratory on electricity would reflect the concern that *Dave* has for both: applications and understanding. Each group had to create a circuit in order to light the bulb and then each individual had to draw a picture which described and explained the arrangement that made the circuit works.

From the video tapes, I cannot infer the quality of the discussions of each group; however, the goal that *Dave* had for his students is quite clear: To light the bulb, study the various arrangements of a battery and bulbs and study the potential effects that these arrangements have on the bulb. In addition, he expected his students to construct diagrams and develop mental representations of the circuits that they constructed. In the best of the cases, students would development explanations on how the circuits work. One potential outcome is the develop of causal models about electric energy which can be represented by the following structure (e.g., Devi et al., 1996):



These preliminary models, circuits and energy models, would be the basis for more developed models for explaining and predicting natural phenomena. In fact, *Dave* was looking for deeper models. After 45 minutes of class he asked students to include in their drawings a description of the circuit and mainly an explanation on how it works. At this moment *Dave* moved the discussion to another level by suggesting that: "Electricity is just the movement, of electrons which are negative...What do you think, is there a lot or very few electrons in your circuits? " (source video 2-08-1 Time: 51:00). Therefore, explanations on how the circuits work, what flows in the circuits (electrons), and the source of electricity (battery) were expected.

From my observations of this class, I can see a clear concern for introducing a real life context for the uses of electricity, particularly in the first part of the class. I also see a moderated ability for introducing explanations using scientific knowledge, mainly in the second part of the class. What is interesting for my discussion is the contrast between these two features of the class. The following table is a summary of that.

Table 2.2 Summary of the pedagogical actions and goals in *Dave*'s class on electricity.

	Application	**Understanding**
Pedagogical actions	Exploring what students already know about electricity in everyday life. Discussing the role of electricity in daily life	Doing experiments with batteries, bulbs, etc. Drawing circuits. Making descriptions, and explanations
Goals of the class	Being aware of the importance of electricity	Understanding electricity in terms of electrons. Developing causal models on the role of battery in the "production" of electricity.

Despite *Dave*'s concern in both teaching science for understanding and applications, our research team in Salish found that " He *[Dave]* leads the students to make connections to real world (about electricity), but he has problems in connecting the real world examples

to key ideas of the subject-matter" (Video analysis, STAM report, 5/27/96). In other words, there are some important limitations in *Dave*'s pedagogical actions, mainly regarding the connection of key idea and students' examples. I argue that this lack of connection between key ideas of the subject-matter (internal relevance) and real world examples (external relevance) is in part because of an intrinsic epistemological tension between understanding and application. That is, this may not be only a problem of *Dave*; rather, it would be a limitation of some type of scientific knowledge to be used in real-world problems. However, one would argue that this is not related to the tension between understanding and applications; instead it is the lack of pedagogical knowledge of *Dave* for helping students to do both. This is one potential answer that should be considered.

Educational research on electricity

From the perspective of his pedagogical actions, *Dave* is trying to take into consideration what students already know about electricity and mainly how electricity is connected to their everyday life. In relation to Feynman, *Dave* is more concerned about the uses of science regarding students' everyday lives. Certainly, *Dave* set an interesting real world context for introducing the topic of electricity (external relevance). However, the connection between this context and the goal of teaching for understanding is difficult for him. My argument is that this connection is by its own right complex. One of the options that *Dave* had for dealing with students' naive conceptions is using conceptual change model or another version of science teaching which takes into consideration what students already know. In fact, one would speculate that if *Dave* had drawn from research on naive conceptions, conceptual change, or other framework, he would have gotten better outcomes.

Among several science topics, research on naive conceptions has analyzed the ideas that students have about electric circuits (see Driver et al., 1994 for an extensive summary of research on naive conceptions on electric circuits. See also Osborne & Freemanm 1989

for specific guides on how to teach electricity as well as McDermott, 1997, MacDermott & Shaffer, 1992a, 1992b). One can expect that *Dave*'s students will have similar conceptions. For example, in the first part of the experiment *Dave* gave each group one battery, one flashlight bulb and two wires. The task was to light the bulb and then draw a circuit and explain how it works. A common conception is the idea that in order to light the bulb, one only needs one wire rather than two. This naive conception which states that "...electricity can leave a battery go to an electrical device throughout a single wire, and not return to the battery" (Chambers & Andre, 1997, p.114, see also Fredette & Lochhead 1980; McDermott and Shaffer, 1992a, 1992b for similar reports). Some of *Dave*'s students could have this idea.

One goal of teaching science from the perspective of conceptual change is to replace these conceptions with accepted canonical ideas:

> If a person has properly assimilated the circuit model for direct current electrical circuits, there must be recognition of what we now call the 'passing-through' requirement. That is, whenever an element is either part of, or added to this kind of circuit, the device must include an 'in' and 'out.' Furthermore, if a device is connected so that it allows a conducting path for passing through, then it must be considered a part of the circuit (Fredette & Lochhead, 1980, p.198)

Teaching for understanding also asks for explanations. The tendency of these explanations is the use of deep models. One of the vignettes of the Fredette and Lochhead study is an example of the kind of answer which one can expect from this perspective. Here, the student ("Ellen") was asked to light the bulb and draw a diagram of the circuit explaining the process (which was exactly what *Dave* asked of his students). In the process of constructing the circuit, this student says:

> I'm making a circuit; making it because I know that electrons travel through a wire and this is positive [points to end of battery so labeled] and that's negative [points to other end of battery]. One of them (inaudible) one or the other--and then I have to-it's broken now so if I connect it there...the current is running (p.198).

According to Fredette and Lochead, Ellen was able to light the bulb and provide some "reasonable" explanation of her action. As far I can see, her explanation is not clear; however, what called my attention is the concern of the researchers in asking for deep

explanation based on flow of electrons. A question that comes to mind in reading this research is my lack of clarity on what is the problem to be explained. This takes me back to the context of *Dave*'s electricity class again. When *Dave* or any science teacher asks students "to explain" the circuit, what do they mean? What are they actually asking for?

For a physicist there are different phenomena in a "simple" circuit. One can think of three generic elements: the battery, the wires and the bulb. The battery is the source of energy. Free energy is transformed in electric energy within the dry cell. The very explanation of this transformation is incredibly complex given the fact that the system (dry cell) is not in equilibrium. Within the battery, electricity is due to the movement of positive and negatives ions rather than free electrons, an outcome of chemical reactions. What the battery does is to provide a difference of potential, that is a form of electrical energy that can be used to do work. Let us see what is going on within the wires. When the wires are connected with the battery and the bulb (as Ellen did), a difference of potential is established between the extremes of the wires (and the bulb). The role of such difference of potential is to accelerate all the free charges (in metal they are free electrons). A physicist will think in terms of electric and magnetic fields. These fields are the means for accelerating the electrons. However, the movement of electrons in metals is incredibly slow (0.01 cm/s). So in order to explain the instantaneous effect of conduction of "electricity," one should note that there is not material movement of electrons rather than a perturbation, that is, an electromagnetic field which is propagated with the speed of light. When we go to the flashlight bulb, the electron flow model can be used with the addition of the Joule effect in the filament, an effect that also is taking place in the wires but is not evident with low electrical power (Reference: any contemporary college physics book).

In the context of science education, there are specific models that have translated these explanations to school settings. For example, Licht says: "We would like to make a case for seeking a model of model-building which provides students [with] explanatory tools...Therefore we have generated a subatomic model of electron flows and electron

density...Our expectation that such a model can be useful and productive in educational terms..." (1990, pp. 219-320). The model is based on the ideas of charge densities and is coherent with the canonical explanation that I suggested earlier.

This model nicely matches with the concern of science education reforms on the need of introducing explanations based on constructs such as electrons (or electron densities in the specific model of Licht) and how they behave in the circuit. However, from the perspective of real life applications, these explanations sound very abstract because they are far away from students' everyday lives (see Licht's paper for a different argument). In fact, the first part of *Dave*'s class, for example, was about real life applications of electricity in relation to students' everyday lives. The examples suggested by *Dave*'s students were very mundane, such as technological artifacts or practical uses of electricity.

Teaching for this real world context is also one goal of current science education reforms. For example, the Michigan Essential Goals and Objectives for Science Education (MEGOSE) suggests the following objectives, concepts and real-world applications regarding this topic represented in Table 2.3.

Table 2.3 Objectives and concepts for a part of the topic of electricity according to MEGOSE (Taken from Michigan Department of Education, 1991, p.85).

Objectives	**Related concepts, terms and tools**	**Real-world contexts**
15) Describe electron flow in simple electrical circuits	Complete circuits, open circuit, closed circuit	Household wiring, electrical conductivity testing, flashlight, electric appliances

Looking at Table 2.3 one can see that *Dave* is trying to satisfy these goals. However, the connection between the objectives (electron flow) and the real-world context (e.g., electric appliances) is complex and problematic. The illumination of cities, the illumination of a given house, the testing of electrical conductivity or the way in which electric appliances work would be explained using atomic models or models based on the idea of flow of electrons. However, stressing the uses of atomic models does not

necessarily mean uses of theses models in the context of students' everyday lives . The connections of these models based on micro variables is problematic when teachers need to connect them with macro variables and mainly with students' everyday lives (see reports on problems on teaching science via atomic models in Millar, 1990; Lijnse, 1990; Lichtfeldt, 1996; Mashadi, 1996).

The knowledge behind teaching science for understanding and applications

In school settings, the potential tension between understanding and applications can be explored by analyzing what we can gain by introducing atomic models and how these models can be related to the everyday life of students. I am using the example of electricity given the fact that Dave pointed it out. In addition, this is a common topic in K-12 science education. Moreover, there is a lot of educational research on electricity and the topic is considered, without discussion- as one with several real world applications.

For me, the real world examples that *Dave*'s students suggested and the goal of developing mental models based on constructs such as electrons, are in tension. The suggestions of *Dave*'s students on the uses of electricity and even *Dave*'s conception of applications are more related to a different type of knowledge (more practical). This is reinforced by another interview now in the context of *Dave*'s third year of teaching. *Dave* reported again the importance of real world applications of his electricity class:

> With electricity we use kits to set up certain types of circuits, series and parallel circuits, for one type of circuit if you unplug one light all electricity goes out because it cannot get from the battery to the back... on the other hand there is a parallel circuit where if you unplug one the other will stay up... one good application is to ask them how about in your houses?....how would in your home things work if they weren't in parallel? (Interview, 4/22/1997)

In this interview, *Dave* framed the applications of his electricity class in a middle position, that is, he neither takes the students' position (which presented more mundane examples) nor the existence of atomic model's position (e.g., flow of electrons model). The quotation reflects a well-accepted role of the "applications" of electricity. However, even in this middle position, there is no consensus on the relevance of these circuits in the everyday life

of students. For example, Paul Black and his colleague Wynne Harlen have pointed out this situation: "Work on closed circuits [like the circuits used in *Dave*'s unit] seems irrelevant for dealing with torches, bicycle dynamos, motor car electric and some devices at home..." (1993, pp. 220-221). The introduction of atomic models is even more problematic.

One way of reducing the tension between what I am calling understanding and applications is by using macroscopic models, such as models that include: voltage, current, electrical energy, resistance. These models, together with a phenomenology of simple circuits, could provide bases for understanding difference between different kinds of circuits (see a specific model in Arons, 1997). In this line of thinking, one can expand these applications to other examples such as discussing the role of conductors and insulators. It is possible to discuss the kind of electricity that we consume, the way of calculating the consumption of electricity in our houses, etc. These examples can be connected to explanations in the context of everyday life.

What I call here an epistemological tension between understanding and application is a tension between internal and external relevance when teaching science keeps traditional scientific knowledge by stressing abstract theories. I suggest that the tension does not appear, or at least it is not so critical, when the constructs used are more macroscopic. As I showed in the first chapter, in explaining everyday problems, such as how to keep a soda cold, students successfully used models of heat transference based on macroscopic variables (temperature, mass, volume) rather than microscopic (either atomic or molecular) explanations (Linn & Muilenburg, 1996). The same holds, I argue, for topics like weather when teachers use macroscopic variables (temperature, mass of air, pressure) for explaining changes in weather. Therefore the argument is not that it is impossible to teach for internal and external relevance at the same time. Instead, the argument is the potential conflict between two different kinds of knowledge, abstract and applied. In the case of *Dave*, the knowledge needed to engage students with everyday life applications of

electricity, for example, does not require, in principle, the uses of atomic models. Therefore, the connection that *Dave* tries to make between his students' conceptions of electricity in everyday life and atomic models, as the electron model of electricity, is an incredible epistemological jump.

Understanding and applications: One example from Mechanics

My argument on the potential tension between understanding and applications goes beyond the case of electricity. Think of examples related to teaching the Newtonian concept of force (see Minstrell, 1984 or Smith, 1990). Although science teachers seem to assume that this theory has several real-world applications, when one sees it from the perspective of students' everyday lives the knowledge itself would have intrinsic limitations because it requires specific contextualizations which can be interesting for academic purposes but unnecessary for everyday life . *Dave* is an example of how science teachers do not see problems in the relevance of applications of Mechanics:

> ...the next unit is motion, forces and energy ...and that is an excellent one for real world applications. How fast can you run? How much power can you generate? (Interview, 4/22/97).

In everyday life the quantification of how much power can one generate is unnecessary. The problems teachers face is the creations of contexts in which these scientific problems can make sense to students.

In the same interview, *Dave* also reported another activity in the context of mechanics which is important for my account. Given the importance of this activity for my argument I transcribe here the specific sections of this interview (D= *Dave*, I= Interviewer, 4/22/97):

I: In some of the laboratories, have your students made some stuff [asking about the role of students in laboratory work]?

D: This is not related to the class, but this is fine. Thursday we have a half day, I only have two of my classes and I do not want to use my fourth hour by getting too far ahead...so what we are doing is we are building bridges and then we are going to test them next week, actually test them in a couple of weeks, to see how much mass they can hold

before they break and then if they do not break you look at the ratio of the mass they hold to the mass of the bridge...

I: How do you do you that [designing the activity of building a bridge]?

D: I use science Olympiad...I have a lot of their materials and I just make few changes...

I: Do you give them some specifications about the kind of bridge?

D: I will give them a print-out of the specifications...I will bring toothpicks and glue...

I: At this moment, do you know what kind of knowledge they are going to need for dealing with this project?

D: No, It does not matter to me...it does not have anything to do with where we are going...we are doing that because we have time and also we are moving into a new book...

I: Do you know what kind of knowledge they need in order to do this project?

D: I think they are going to get out more by doing it, this is a new challenge... We might talk when we get into certain parts of physics chapter....but this is something that we are doing because we have a strange schedule...

I: Is part of the curriculum to design a bridge?

D: No, this is for a competition....

I: Can you guess the kind of knowledge that they are going to need?

D: I think what would happen is that they will have to think of how to put the toothpicks together to get the strongest [inaudible] structure...if they are good they are going to start to think in some geometry things and make triangle shapes to get the more strength...some people might put square shapes and we can talk about that at the end...because we are not giving it much time we are going to test them only once...If they break perhaps they can make another one on their own...

From the perspective of teaching science for applications one can make the case that the design of a bridge provides a meaningful and practical context for the uses of Newton's laws (Roth, 1995). From the perspective of teaching for understanding, the picture is quite different because the design of the bridge has a different epistemological assumption than the uses of Newtonian laws for predicting and explaining natural phenomena. In fact, from the perspective of teaching science for understanding (internal relevance) what matters is the use of scientific ideas for explaining.

Traditionally, teaching about mechanical forces takes place in the context of Newton's laws and their applications. Teaching activities include the study of horizontal

motions or the analysis of gravity such as the classic case of "free fall". More progressive teaching approaches are based on the wide research on naive conceptions.

For example, E. Smith (1990) reports his experiences in teaching forces. The problem of the book-on-the-table is the case in point (see also Minstrell, 1982; Arons, 1997; McDermott, 1996). What matters here is to learn, understand, what are the forces that act on the book (normal, **N**, and gravity, **W**). The goal is to help students to "see" these forces by explaining why the books is at rest.

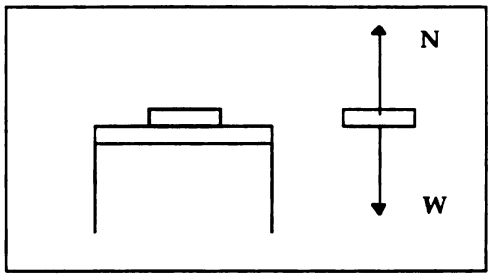


Figure 2.1 The book-on-the-table problem stresses the use of knowledge for explaining and predicting (Smith, 1990).

The point that I want to make is that teaching science from this perspective tends to stress questions of *"why"* which are answered by the use of canonical scientific knowledge. For example, why is the book at rest, why is gravity different on the moon than on the Earth, or more specific problems such as the following example taken from a text-book: "If you were on the moon and dropped a hammer and a feather from the same elevation at the same time, would they strike the surface of the moon at the same time?" (Hewitt, 1997, p.68). Even more mundane problems such as motions on the Earth (e.g., cars on ice) have the purposes of explaining and predicting using canonical knowledge. In this context, understanding means describing, explaining and sometimes predicting. In contrast, the design of a bridge has a different ontological and epistemological frame. The purpose is to invent a structure which supports as much weight as possible; that is, the practical problem of creating a useful object. This problem, the design of a bridge, requires different epistemological demands than the analysis of forces.

The purpose of scientific knowledge, from the perspective of understanding, is explaining natural or even artificial phenomena. Therefore, teaching science for understanding tends to have a clear and clean epistemological position toward the world. Given a structure, for example, students are usually asked to determine what the forces that act on the structure are (whether it is an apple, a book, a car or a bridge) . All Newtonian mechanics, for example, tends to isolate the components of the structure and consider the forces that act on it. The assumption is that knowing the forces that act on the structure means understanding what is going on; that is, it is assumed that these conceptual tools (forces) help to describe, explain and predict the behavior of objects.

A bridge, from the perspective of understanding, is an interesting object because it provides opportunities to apply the concept of force (torque, stress, etc. for more advanced approaches). Teaching activities from this perspective tend to focus on what the forces that act on the bridge are. From a static point of view, they are the weight **W** (considered in the center of mass of the bridge) and the reactions of the supports which are represented by $\mathbf{R}_1$ and $\mathbf{R}_2$ in Figure 2.3). The design of the bridge, however, is a different kind of problem. ***The problem is not to analyze a given structure. The problem is to invent a structure for a given problem.***

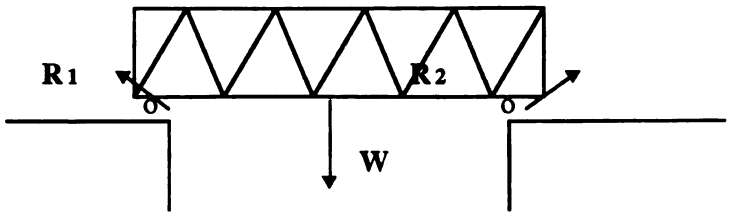


Figure 2.2 The forces that act on a given bridge.

Note that the notion of applications here is not only the meaningful uses of scientific knowledge. The notion of applications here is related to the possibility of designing and constructing artifacts. This possibility is not only in the topic of forces. In fact, one can develop practical applications of science via technological knowledge using several science topics. For example a reconceptualization of the unit of electricity taught by *Dave* can also be presented in light of this notion of in which electricity is more related to practical applications. Table 2.6 summarizes a preliminary analysis of the knowledge behind both topics, forces and electricity, in light of my interpretation of teaching science for understanding and applications.

Table 2.4 Goals, knowledge and pedagogical actions in teaching forces and electricity from the perspective of understanding and applications.

	Teaching for Understanding	Teaching for Applications
Forces	Questions: Why is the book at rest? Why is gravity different on the Earth than on the Moon?	Questions: How to design a bridge? How to produce structural stability?
Goals	Describing, explaining, predicting	Designing, solving, using
Knowledge	Newton's laws (forces) (related to natural world)	Proprieties of materials, stability of different structures, geometrical knowledge, (related to artificial world)
Potential pedagogical knowledge and actions	Naive conceptions on mechanics, analogies, laboratories	Constructing different geometrical structures, testing stability, designing and constructing a bridge, testing the bridge
Electricity	Questions: Why does the bulb light?	How can we generate electricity? How can we construct a circuit?
Goals	Developing atomic models for explaining electricity (e.g. based on the free electron model)	Designing circuits (e.g. similar to those that are used in a house). Designing an electric generator.
Knowledge	Electric charge, electron, conservation of charge, polarization.	Current, voltage, resistance, power. Knowledge about circuits. Knowledge about specific electric generators.
Potential pedagogical knowledge and actions	Naive conceptions, analogies, laboratories.	Constructing circuits. Constructing models of electric generators

Concluding Comments

Throughout this chapter I have presented examples and evidence that there is a potential tension between teaching science for understanding and teaching science for applications. This, of course, is related to how one defines understanding and applications. In fact, one meaning of understanding is the very application of knowledge (applications for describing, explaining, predicting). Another meaning of understanding and applications was related to the uses of science in students' everyday lives which was explored by the construct "external relevance". Another sense of application is the design and creation of artifacts (technology). These multiple meanings of understanding and applications will be clarified during this dissertation.

The case of *Dave* and the references on Feynman's lectures have been an important source of concrete reference for analyzing the relationship between teaching science for understanding and applications. I also illustrated some of my arguments using preliminary findings of the Salish Research Project. In general I based my discussion on the idea that understanding and applications are quite different epistemological positions toward the world. My assumption is that these positions, understanding and applications, have implications in how we teach science. Think of the topic of forces. The question "Why is the book at rest?" reflects one epistemological position, whereas the question "How to design a bridge?" represents another. How are they connected? How are they in tension? How does this relationship between understanding and applications affect teaching science and mainly the knowledge that teachers need to know? These are questions that will be analyzed in the following chapters.

Dave's case raises the complex problem of *what* science teachers need to know in order to teach for understanding and applications. Differently from Feynman, *Dave* is asked to satisfy internal and external relevance in his teaching of science. If we accept an identification of understanding as explanation and prediction (internal relevance), more

subject-matter knowledge will be needed. One would conclude that more deep scientific knowledge is one condition as well as connecting pedagogy with content, that is, knowing how students learn, developing powerful pedagogical strategies such as analogies, experiments, etc. (e.g., Clements, 1993; Smith, Blakeslee and Anderson, 1993; Freedman, 1997, Tamir, 1991; Wong, 1993). In fact, teaching science for understanding is a complex task. Teaching science for understanding and applications, in the sense of satisfying external and internal relevance at the same time, could be an impossible task if we do not rethink what the knowledge that science teachers need is.

The problem of *what* science teachers need to know if they are going to teach science for understanding and applications should take into consideration a potential epistemological tension between understanding and application. For example: a) the idea that explanations do not lead necessarily to practical applications, and b) the assumption that there are different kinds of knowledge (e.g., abstract versus applied, scientific versus technological).

Because school is an important place for learning science, teaching for conceptual understanding is an important goal. However, if we also want to teach for applications, we need to analyze the demands of knowledge that this goal places on science teachers. My thesis is that the knowledge that teachers need to know in order to teach science for understanding and applications requires a re-examination. For example, I think that to stress the development of atomic models of electricity (e.g., flow of electrons) does not necessarily help teachers to develop practical experiences with electricity (e.g., experience with electric circuits). The question still is: What is the knowledge that teachers need to know in order to help students to learn science in meaningful ways? In other words, what is the knowledge that science teachers need to know in order to teach for understanding and applications in relation to students' everyday lives? These are questions that are examined in the following chapters.

CHAPTER 3

SCIENCE TEACHER KNOWLEDGE: A FRAMEWORK

In this chapter, I study the construct *science teacher knowledge*. My starting point is a minimal theoretical model in which I have been working during the last years (Cajas, 1991; 1995a; 1995b). This model includes three general domains: knowledge of the subject matter (SK), pedagogical content knowledge (PCK) and knowledge about knowledge (KK). Given this minimal model, **<SK, PCK, KK>**, I review part of the literature on teacher knowledge in order to interpret my own constructs. I study how the demands of understanding shapes our conception of science teacher knowledge. I illustrate what I mean by "science teacher knowledge" using data and instrumentation from the Salish Research Project and research on science education. The main point of the chapter is to clarify my own framework of science teacher knowledge, its relation with the literature and its contact with reality.

Science teacher knowledge

Science teaching (ST) assumes the existence of a knowledge that can be taught. I call this knowledge: Expert scientific knowledge (ESK) which I consider a conceptual system, that is, a set of scientific concepts that are interconnected (theories) and used within scientific communities in a specific era. Only a part of expert scientific knowledge is taught in schools. The part of scientific knowledge that is translated to schools will be called scientific knowledge (SK). This knowledge, SK, is transformed in a specific kind of knowledge: School science knowledge (SSK)- by a process which usually takes place within classrooms.

The *translation* from expert scientific knowledge (ESK) to school science knowledge (SSK) is a complex social and epistemological process (Chevallard, 1985).[1] In

[1]Note that the translation from ESK to SK is a different process than the translation from SK to SSK. The former tends to be a political process while the latter is the process that

this chapter, I focus on the knowledge that teachers need to know for doing such translation which requires, in principle, the use of a specific kind of knowledge: Pedagogical Content Knowledge (PCK). In the context of teaching science, the concept of pedagogical content knowledge represents the emergence of a new kind of knowledge property of teachers (either individual or communities of teachers) who intend to construct and reconstruct scientific ideas with their students. Although, researchers have reported other kinds of knowledge and teachers actually use several "knowledges" (e.g., knowledge of cultural diversity, knowledge of classroom management, etc.), the starting point of my model only includes: SK, PCK and SSK in which PCK is the conceptual bridge between SK and SSK.

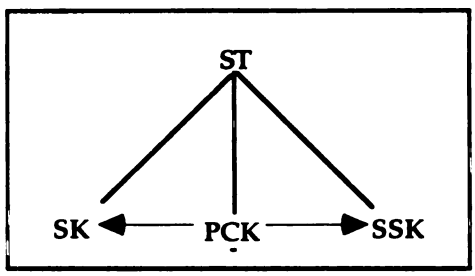


Figure 3.1 A minimal model for the knowledge base of science teaching.

Given this minimal model one can see that there are at least two kinds of knowledge that science teachers need to know: Knowledge of the subject matter of science (SK) and knowledge of how to teach this specific subject matter (PCK). Note that my model does not assume that teachers need to know expert scientific knowledge. I argue that teachers learn transformations of expert scientific knowledge (ESK) that I call scientific knowledge (SK). In this sense, I see science teachers -in general education- as cultural workers who help students to reconstruct versions of science designed for general education (scientific literacy)

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usually takes places within classrooms. French researchers have called the all process: *The transposition didactique* (Verret, 1975. See Chevallard, 1985 for the case of mathematics education).

rather than formal representatives of scientific communities. In addition, the model assumes that teachers need to know other kinds of knowledge such as knowledge *about* their subject matter, that is, knowledge about knowledge (KK) (e.g., philosophical knowledge about science, history of science, sociology of science), or knowledge *about* science teaching (e.g., the goals of teaching science).

To say that there is a knowledge base of teaching does not mean that teaching is only about knowledge. Teaching is also about feelings, values, histories, power, actions, love, creation, production, reproduction, etc. In other words, teaching is about human relationships. All these characteristics of teaching cannot be captured only by one framework. I choose to work with the science teacher knowledge framework given my interest in clarifying what is the role of technological knowledge in teaching science. The route that I suggest includes a general clarification of the term "science teacher knowledge" in the context of teaching science for understanding. Then, in the next chapter, I study the demands that applications introduce in our conception of science teacher knowledge. Therefore, from the beginning until the end of my work, I assume that teaching has knowledge base. The existence of this knowledge is a different problem than the evolution or even the acquisition or creation of such kind of knowledge (e.g., learning to teach). My assumption is that we cannot find out how knowledge is learned or how it evolves unless we know of what knowledge we are talking about.

The model of science teacher knowledge that I present tends to be a model of competence rather than a model of performance. In other words, I explore theoretical possibilities of a minimal model of science teacher knowledge rather than deducing this model (knowledge) from teachers actions (performance). In this way, I respect the following distinction:

> It is important to distinguish studies directed to building up a theory of competence, in ways recognizably appropriate to, and constitutive of, the collectives to which they belong, from studies directed to a theory of performance, that is, a theory of how on particular occasions an individual actor draws on corpus of knowledge

> relevant to the occasions in question to control his or her contribution to the social fabric (Harré, 1981, p.152).

Although I illustrate my model with particular teachers' actions (e.g., the case of *Dave*), I do not pretend to develop a theory of performance. [2]

The model I endorse assumes a general conception of teaching. I have constructed this conception throughout my life, in part, during my long period of apprenticeship of observation (Lortie, 1975) and also by reflecting on my own teaching (Cajas, 1992a). I have spent time thinking, that is, writing about the teaching of my teachers, and the teaching of other teachers that I have studied (e.g., Salish teachers). In addition, I draw my conception of teaching from works of educational researchers, philosophers, psychologists, sociologists, etc. For example, Gary Fenstermacher has advanced an important philosophical framework for understanding teaching which has influenced my thinking.[3]

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[2]Regarding the distinction competence/performance some scholars use the expression normative/descriptive, i.e., what teachers should know (normative) in contrast to what teachers actually do (descriptive) (Fenstermacher, 1994; Shulman & Quinlan, 1996). My model is not totally encapsulated by the dichotomy normative/descriptive. I present a very preliminary model of competence with illustrations of performance.

[3]Thus far, the following features of the activity called "teaching" have been isolated: 1) "There is a person, P, who possesses some 2) content, C, and who 3) intends to convey or impart C to 4) a person, R, who initially lacks C, such that, P and R engage in a relationship for the purpose of R's acquiring C. " (Fenstermacher 1986, p.38). This model of teaching can be expanded to more complex relations (ibid. p..58). In addition, this is not a definition of good teaching: "The question, What is teaching? is different from the questions, Is this good teaching?, and, Is this teaching successful?..."(ibid. p. 38). It is important to note that I have been working in some aspects of philosophy of education during the last years. In 1992 I presented at the University of Morelia, Mexico, a paper called "The Role of Philosophy of Science In Teaching Science." In 1994 I published at the University of Costa Rica a paper in which I introduced, independently, a definition very similar to Fenstermacher's definition. Two years ago (1995) I published at the University of Havana, Cuba, a paper on the limitation of this framework. In this paper (Educational Ontology), I pointed out that this relationship (teaching defined in Fenstermacher's way) is somewhat poor from the logic and semantic point of view. It seems to me that the formal logical (classic propositional logic) does not explain teaching (e.g. teaching is not a cause-effect relationship). In order to understand this relation (teaching) we need, perhaps, another kind of logic (differently than the classic true-false logic), a logic of the form "may be", i.e., if I teach C to R maybe R will learn C in some given conditions (modal logic, see Bechtel 1988, p.26). In addition, I have been thinking that Fenstermacher's definition has another problem. In fact, it supposes that it is possible to communicate ("transfer") the content "C" to the student R. To be sure there is not such content, nor such transfer process. The separation of the content C is a methodological separation that could produce an idealistic interpretation of teaching. The separation of the content is just a fiction. For

Teaching can be clarified from a historical, sociological, psychological, cultural, philosophical, or ethical perspective. To be explicit about all these components is a task which is beyond the limits of this dissertation. What I clarify now is that from an ontological point of view my model assumes that teaching is an oriented activity in which humans are looking for learning (Cajas, 1995b). Such process, teaching, assumes a specific treatment of knowledge. As I said, Fenstermacher (1986) proposes one. In this chapter, and throughout the dissertation, I suggest others. At this moment it is enough to clarify that I assume that knowledge can illuminate our understanding of teaching, yet teaching is not only about knowledge.

Regarding the knowledge base that I suggest for science teaching, scientific knowledge, pedagogical content knowledge and knowledge about knowledge, **<SK, PCK, KK>**, they should be defined in specific conditions. SK, scientific knowledge, is a specific version of expert scientific knowledge that a community (e.g., scientific community, policy makers community, religious community) agrees on for being taught at schools in a specific era. In the case of Project 2061, for instance, this knowledge is explicit in the panel reports of the Project and mainly in the book *Science for All Americans* (AAAS, 1990). It is important to note that what I call here "scientific knowledge" is a transformation from expert scientific knowledge to the knowledge that should be taught at schools. Usually it is assumed that scientific knowledge (SK) is a representation of expert scientific knowledge (ESK). I do not endorse such an assumption.

The transformation from expert scientific knowledge to scientific knowledge (the planned knowledge to be taught in schools) is affected by several social factors which do

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example, we can read a paper but this paper is just a representation of somebody's thinking, there is not a real separation between the paper's ideas and the person who wrote the paper, so the content is a representation of somebody's thinking process. This idea is hidden in Fenstermacher's definition (in my earlier papers too) because the relation between the teacher and the student should account that "Acquiring knowledge is learning something, i.e. going through a certain brain process, hence not the same as acquiring a book or some other commodity." (Bunge 1983, p.61).

not allow, for better or worse, a representation of expert scientific knowledge in schools. When the knowledge that should be taught in general education is endorsed by scientific communities (e.g. the American Association for the Advancement of the Science (AAAS) with its Project 2061, the Association for the Promotion and Advancement of Science Education in Canada (APASE) or the historical examples of the Physical Science Studies Committee (PSSC) in the 60's), there is more coherence between school science knowledge and expert scientific knowledge, that is, SSK and ESK tend to share structures and key ideas. However, even in these cases, the transformation of expert scientific knowledge to school science knowledge is not isomorphic. In other words, it is possible that such transformation changes the very meaning of scientific theories within school settings (Cajas, 1995a).[4] Think of any scientific concept or theory which is translated from ESK to SK and then SSK, "heat" for example:

> The uses of the 'heat' concept by a teacher solving a problem at high school level, and an engineer calculating in a power station are not the same. The frameworks of use may be calorimetry for the teacher, and the equivalence of work and heat for the engineer. Each of these different persons might not be able to deal with the aspects of the concepts involved in the other situation. In this case, the ways of understanding the knowledge about heat are different..." (Tiberghien, 1996, p. 101)

My assumption is that SK is more than a simple version of the expert scientific knowledge. The transformation from expert scientific knowledge (ESK) to scientific knowledge (SK, i.e., teachers' knowledge of the subject matter) and then to school science knowledge (SSK) is a social and epistemological transformation that I study in depth in a different chapter. For now I focus on a general clarification of the framework of science teacher knowledge. I begin with an illustration of the meaning of "science teacher

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[4] It seems that some scholars tend to break down the distinction between expert scientific knowledge and school knowledge. I think one should be very careful in separating or not these types of knowledge because it has important implications. This separation can be done from different perspectives. For example, I am offering an epistemological separation (see Den, 1997 for an extensive analysis). However, I do not mean that expert and school knowledge are unrelated. In fact the interconnection is complex. Adult scientists and children may share ways of constructing theories as A. Karmiloff-Smith (1988) and D. Kuhn, (1989) have shown. This would be a methodological connection.

knowledge" using information from the Salish Research Project, that is, instrumentation, data, outcomes, experiences.

Science teachers' knowledge: The context of Salish[5]

During our research in Salish we studied the nature and evolution of science teachers' knowledge of new teachers. Teachers' knowledge was explored by interviews and classroom observations (video tapes). For example, teachers' knowledge in the context of the instrument used for analyzing videos was divided in four categories: 1) structure of content, 2) examples & connections, 3) limits, exceptions, & multiple interpretations, and 4) processes & history of science (Gallagher & Parker, 1995). Science teachers' knowledge was defined in relation to teachers' understanding of the content and the way in which it was either presented or explored within classroom activities. In this framework, the structure of the content, for example, can take several forms (from didactic to constructivist). The following table is a reproduction of the first row of the matrix used for analyzing videos which actually has 22 rows and 6 columns. The following row refers to the "structure of the content"[6]

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[5]When I refer to the Salish Research, I use the expression teachers' knowledge (with apostrophe). By doing that I respect the form in which Salish researchers have reported their findings (Salish, 1997). However, when I refer to my framework I use the expression "teacher knowledge" without the possessive. The difference that I find between the term "teachers' knowledge " and "teacher knowledge " is that the former assumes that this knowledge in fact belongs to teachers. Therefore it has more descriptive connotations (performance). The latter, teacher knowledge, has a more normative connotation and is a knowledge which tends to be produced by researchers (competence). See footnote # 1.

[6]The study of teachers' knowledge is only a small piece of the Salish Research Project. Salish was an exploratory research with several components (see footnote #1 Chapter I and Salish, 1997)

Table 3.1 Reproduction of the "structure of the content" row of the Secondary Teaching Analysis Matrix Science Version (Gallagher, & Parker, 1995).

A. Didactic	B. Transitional	C. Conceptual	D. Early Constructivist	E. Experienced Constructivist	F. Constructivist Inquiry
Factual content, *factoids*	Content tends to be *descriptive* with concepts and factoids given equal emphasis	Content tends to be *explanatory* with conceptual content organized around key ideas	Teacher and students negotiate understanding of key ideas with teacher's content emphasized	Teacher and students negotiate understanding of key ideas based on students' ideas & content	Investigation dominate content. Conceptual content and connections embedded into design, implement, analysis, and report of investigation

SK is a transformation from expert scientific knowledge to school knowledge. In general, there are social an epistemological constrains in the process. As I reported in chapter 2, *Dave* mentioned some of them, particularly he follows a textbook and the curricular guides of his State. From the textbook and video observations, one can see that his electricity class includes knowledge of: simple circuits (in series, parallel), electric current, voltage, resistance, electrical energy, electrostatic, etc. In the video analysis of *Dave*'s electricity class (see chapter I of this dissertation for an account on *Dave*'s case), one Salish researcher categorized *Dave*'s content as explanatory (conceptual). A second researcher reported that his content was not conceptually integrated, so it was more "transitional" with some features of conceptual. The means that *Dave*'s knowledge was formed by isolated facts with some conceptual connections.

From a general perspective, science subject matter knowledge is formed by the theories and models that are translated into school knowledge. Think of the case of a simple circuit formed by a battery, a bulb-light and two wires (an activity developed by *Dave*). A potential model that would represent science SK (the knowledge to be taught) is illustrated by the following figure:

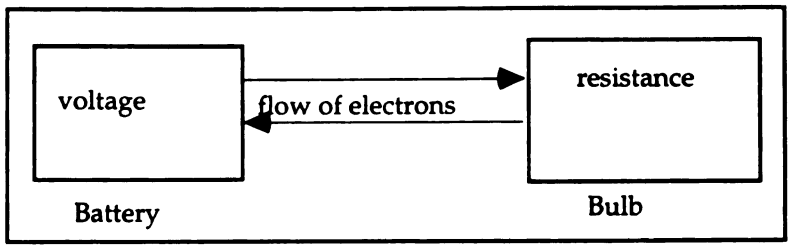


Figure 3.2 Subject-matter knowledge to be translated in the case of electrical circuits.

Note that SK does not only include propositional knowledge (e.g., Ohm's law, i.e. V=IR), SK also includes procedural knowledge such as how to connect the wires with the bulb in electric circuits. We could not assess this knowledge in the case of *Dave*. What is important for my discussion in this section is that subject matter knowledge (SK) includes both substantive and procedural knowledge. The transformation of SK with educational purposes is exemplified by the following row of the matrix.

Table 3.2 Reproduction of the second row of the Secondary Teaching analysis Matrix Science Version (Gallagher, & Parker, 1995). This refers to "Examples and connections".

A. Didactic	B. Transitional	C. Conceptual	D. Early Constructivist	E.Experienced Constructivist	F.Constructivist Inquiry
No examples or interconnections to: a) real world events, b) related ideas, c) key ideas of the subject	Real world examples and/or related ideas separate from other pieces of content	Examples and connections made by teacher to: a) real world events, b) related ideas, c) key ideas of the subject	Teacher leads students in using examples and constructing connections to: a) real world events, b) related ideas, c) key ideas of the subject	Connections constructed by students with teacher's guidance to: a) real world events, b) related ideas, c) key ideas of the subject	Connections constructed by students are related to investigations, data analysis, and concept building.

One can see that here (Table 3.2) the content goes beyond the subject matter. This row refers to the transformation that teachers make of such content using examples, connections, and applications regarding key ideas of the subject-matter (SK). This

transformation has been conceptualized as pedagogical content knowledge (Shulman, 1986). Later I explore the nature of such construct.

In the case of *Dave*'s electricity class video analysis observations reported that he did not integrate content (e.g., scientific models of electricity for circuits) to real-world events (e.g., everyday uses of electricity). However, it was reported that *Dave* gave students opportunities to explore the uses of electricity in everyday situations. Therefore, Salish researchers reported the content of *Dave* as *transitional* and *early constructivist* at the same time without being *conceptual.* As I showed in chapter 2, the connection between the content and its examples regarding students' everyday situations was difficult for *Dave.* However, what is important for this section is that teacher knowledge includes the transformation of the content.

In teaching electrical circuits, or any topic, teachers can use analogies in order to help students to construct their own models. One well known analogy in the case of circuits is to explain electrical current in terms of water analogy. Positive and negative outcomes of such analogies have been widely explored by science educators. These transformations, analogies, are part of the construct pedagogical content knowledge (Shulman, 1986).

A third element of science teacher knowledge is what I call knowledge about knowledge, that is KK. This type includes the conception of science that teachers hold and the use of such conceptions (e.g., philosophy of science, history of science) in teaching science. The Salish research also included an exploration of this important component of science teachers' knowledge. I reproduce the section of the matrix used in Salish to study this component:

Table 3.3 Reproduction of the fourth row of the Secondary Teaching analysis Matrix Science Version (Gallagher, & Parker, 1995). This refers to "processes of science".

A. Didactic	B. Transitional	C. Conceptual	D. Early Constructivist	E. Experienced Constructivist	F. Constructivist Inquiry
No explicit mention on how we know. Scientific method is presented separately as rote procedure	No explicit mention of how we know. Processes of science (observation, inference, experiment, etc.) are not integrated with content	"How we know" included in content. Teacher integrates processes of science with concepts.	Teachers leads students to reconstruct how evidence has been used to formulate scientific ideas and to use scientific processes to formulate and evaluate ideas.	Students, with teacher's guidance, reconstruct how evidence has been used to formulated scientific ideas and to used scientific processes to formulated and evaluate ideas.	Processes of science applied to design of project investigation, data collection, data analysis, and concept building.

This component of science teacher knowledge is more related to epistemological and methodological aspects of science. This knowledge is *about* science (e.g., epistemological issues on how we know that we know or methodological arguments of what is considered as evidence). In the case of *Dave*'s electricity class, we found an absence of this kind of knowledge during his teaching. Although from our interviews we determined a set of epistemological and methodological positions that *Dave* has toward science, the explicit use of such positions in teaching was difficult to asses. Knowledge about knowledge assumes the existence of explanations (e.g., specific models of electricity). For example, one can think of the experiment on simple circuits formed by one battery, one bulb and two wires, the one in which *Dave* asked his students to light the bulb and then make an explanation of such phenomena. In general teachers and students can construct different kinds of explanations to this phenomena as we saw in chapter I (see Arons, 1997; Devi et al., 1996; Tiberghien, Psillos, & Koumaras, 1995 for examples). Think of a preliminary phenomenological model in which the battery is a container of electricity and the bulb is a consumer of electricity:

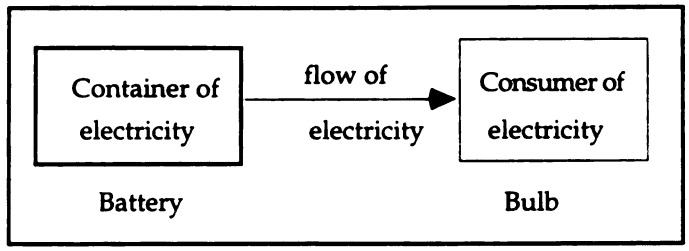


Figure 3.3 Phenomenological model of a simple electrical circuit (This is not a canonical model. Rather, this would be a typical student's model).

Knowledge about knowledge refers to questions such as: How do we know that there is a flow of electricity? How do we find/use evidence in order to support this model? What can the model explain? What is the difference between a model and a theory? What counts as scientific explanation? What counts as scientific evidence? Such potential explanations also have a sort of philosophical assumption which can be important from the perspective of teaching (Duschl, Hamilton, & Grandy, 1992; Cajas, 1995b). Think of the following assumptions: 1) there is electricity (ontological), 2) we can explain how circuits work (epistemological) and, 3) we can plan an experiment and get evidence (methodological). What is important for my discussion here is the potential existence of knowledge *about* knowledge as part of the package of science teacher knowledge.

So far I have illustrated one meaning of the term "science teacher knowledge" using the instrumentation and data from Salish throughout an emergent theoretical model. This model is represented in Figure 3.4. Using this minimal model allowed me to focus on three kinds of knowledge that teachers need to know in order to teach science: Knowledge of the subject matter (**SK**); knowledge of the transformation of the subject matter (analogies, examples, representations, applications, etc.), that is, pedagogical content knowledge (**PCK**); and knowledge about knowledge (**KK**).

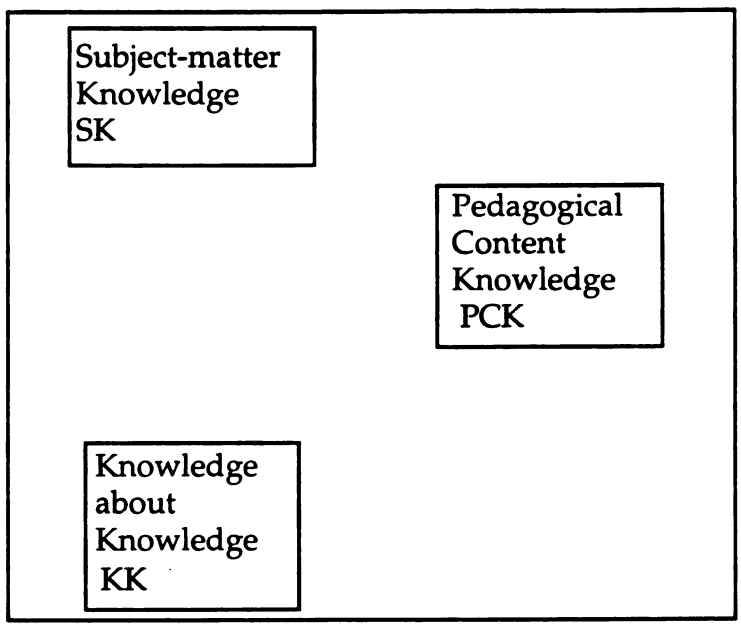


Figure 3.4 Three kinds of knowledge as part of a minimal model of science teacher knowledge.

I have illustrated these three kinds of knowledge using examples taken from video analysis (STAM) in Salish with sporadic comments on the case of *Dave*.[7] These and other components of the teacher knowledge framework have also been explored theoretically and empirically by several scholars. In the following section, I selectively review the literature on science teacher knowledge in order to make sense of my own model. I begin by setting a historical context.

Teacher knowledge: A brief review

Before reviewing the literature on science teacher knowledge, I think that it is instructive to present a brief historical context of the research on teacher knowledge. My starting point will be the 80's given the unprecedented call for reforming education in the U.S. in this decade. The accumulation of psychological research on students' naive

[7]In the context of Salish, the concept of science teacher's knowledge was also explored throughout semi-structured interviews. I do not include this section here given that my interest is only to illustrate the minimal model that I propose rather than presenting a detailed report of Salish (see Salish, 1997 for an extensive report).

conceptions was a key element for understanding the lack of efficiency of traditional instruction. The pioneers of this movement were works from science education, particularly misconception on mechanics such as Newton's Laws, forces, etc. (e.g., Viennot, 1979). A seminal seminar on student misconception was (and still is) held at Cornell University (Novak, 1987; 1993; 1997). At the same time, researchers put attention on students' learning of science from other perspectives such as artificial intelligence (Larkin, et al. 1980), cognitive sciences (Chi, et al. 1981), developmental psychology (Karmiloff-Smith 1988), and epistemology (Carey, 1986, 1992).

The work on students' naive conceptions had as logical consequence research on how teachers could/should face these naive conceptions. The focus of this research was *"students"* rather than *teachers* A very well known work in this direction, in the community of science educators, was the conceptual change model developed by Posner and colleagues (1982).

One of the uses of the research on students' misconceptions was the conclusion that previous educational reforms had almost had no impact on students understanding of science. This, among other political factors, moved the focus of attention from students to teachers. A special interest on how teachers teach emerged in the 80's. Although for several decades the research on teachers was focused on how teachers manage their classrooms, organize actives, etc. (a research done mainly from a behaviorist perspective), in the middle of the 80's there was a turning point which focused on teachers' thinking.

Early in the 1980's, Leinhardt and Smith studied mathematics novices and expert teachers in order to explore their subject-matter knowledge and teacher thinking by analysis, video tapes and interviews, in addition to actual observation of classes. These authors reported the existence of two kinds of knowledge: subject-matter knowledge and lesson structure knowledge. The former was the traditional "content knowledge" which, in the case of their paper, refers to mathematics teachers' knowledge. This knowledge was defined as algorithms, rules, systems number, operations, etc., that is, the traditional

content knowledge (Linhardt & Smith, 1985). In contrast, they also defined the notion of **"lesson structure knowledge"** as the skills needed in order to teach a specific subject matter and to clearly explain the material.

At the same time Lee Shulman reported the lack of research on how teachers teach and mainly on what teachers need to know in order to teach effectively (Shulman, 1986). Shulman questioned the exclusive research on student misconceptions rather than research on teacher understanding of their subject-matter. In two influential papers Shulman mainly expressed that the ***missing paradigm*** in educational research, and also in teacher education, was the study of the understanding of teaching particularly the knowledge base of teaching in specific content areas (Shulman, 1986; 1987). Shulman argued for a stronger relationship between pedagogy and content in the context of understanding teaching. In these papers, Shulman introduced the now well known, yet still controversial, concept of ***pedagogical content knowledge*** as a key element of his notion of teacher knowledge. In addition to the concept of pedagogical content knowledge, Shulman suggested the existence of other kinds of knowledge, such as general pedagogical knowledge, subject-matter knowledge, and curricular knowledge. [8]

Shulman and his colleagues also suggested the notion of pedagogical reasoning which includes the following cycle: comprehension, transformation, instruction, evaluation, reflection, and new comprehension (Shulman, 1987. See also Wilson, Shulman & Ritcher, 1987). In this process, pedagogical reasoning, the category of "subject-matter knowledge provides the focal point" (Wilson, et al. 1987 p.120). Despite the report on the

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[8] As I mentioned, Leihardt & Smith (1985) made a similar distinction; however, they did not introduce the term "lesson structure knowledge" as part of a broader system. In fact, several researchers have "talked" about how to "psychologize" the subject matter (e.g. Dewey, 1902), but the explicit introduction of the term PCK into a conceptual system of teacher knowledge was suggested, I think, by Lee Shulman and his colleagues. According to Shulman (1987), his work is based on the works of several scholars such as Dewey, Brunner, Schawb, Fenstermacher, etc. (see also Shulman, & Quinlan, 1996). What is important here is the distinction between two kinds of knowledge: the knowledge of the subject-matter per se and the knowledge for teaching this subject-matter. The term pedagogical content knowledge is useful in clarifying this distinction.

pedagogical-reasoning framework, the authors themselves have stressed the role of pedagogical content knowledge.

Literature on science teacher knowledge

Regarding the literature on teacher knowledge, one can easily conclude that this is abundant (e.g., Ball, 1989; Ball, & McDiarmid1 990; Cochran, 1992, Cochran et al., 1993; Darling-Hammond, Wise, & Klein, 1995; Karter, 1990; Linhardt,& Smith, 1985; Shulman, 1986, 1987; Smith, & Neale, 1991; Smith, 1996; Tobin, Tippins, & Gallard, 1994; Carter, 1990; Fenstermacher, 1994; Feiman-Nemser, & Remillard, 1996, Grosmman, 1990; Magnusson, 1992; Magnusson, Krajcik, & Borko, 1994; William, 1992; Wilson, et al. 1987; etc.). One observation is that this literature refers -in general- to social studies, mathematics, English, and teacher knowledge. Only a few of them refer to science. From these works, I have identified two basic references on science teacher knowledge: Magnusson's and Smith's pieces (Tobin's piece is a review).

In general the literature on teacher knowledge tends to incorporate several kinds of knowledge in the package of teacher knowledge (e.g., Cochran et al 1993; Darling-Hammond, Wise, & Klein, 1995, Grossman, 1990). [9] For example Magnusson, Krajcick, and Borko (1994) conceptualize pedagogical content knowledge for science teaching using five components: "(a) orientation toward science teaching, (b) knowledge and beliefs about science curriculum, (c)knowledge and beliefs about students' understanding of specific topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science". (p.5) Each of these components has its own division. The components of knowledge of science curriculum, for instance, is subdivided into 1) knowledge of goals and objectives, and 2) knowledge of specific curricular programs.

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[9]An extreme case is the framework of R. Sternberg, & J. Horvath (1995) which includes more than a dozen of types knowledge (p.15).

In contrast to the model of Magnusson et al. S. Wilson, L. Shulman and their colleagues suggest the specificity of pedagogical content knowledge. That is, these authors coined the concept of PCK as a different kind of knowledge in relation to knowledge about curriculum, or knowledge about educational aims or other kinds of knowledge:

> Our preliminary findings suggest that novice teachers, as they prepare to teach their content as well as during instruction, develop a ***new type*** of subject-matter knowledge that is enriched and enhanced by other types of knowledge -knowledge of the learner, knowledge of the curriculum, knowledge of the context, knowledge of pedagogy. We call this form of knowledge pedagogical content knowledge. (Wilson, et al. 1987, p.114. Italics added).

The importance of Wilson's model is that it forces us to study the specificity of pedagogical content knowledge. In contrast, the model suggested by Magnusson and her colleagues tends to explain pedagogical content knowledge in terms of other kinds of knowledge (e.g., curricular knowledge, knowledge about the goals of education).

The second important reference that I use is the work of Deborah Smith and her colleagues (e.g., Smith and Neale, 1991; Smith, 1997). Based on a longitudinal study of primary science teachers, Smith & Neale (1991) studied the nature and evolution of science teacher's knowledge. In line with the work of Magnusson and colleagues, Smith & Neale (1991) identify: substantive content knowledge, pedagogical content knowledge (three varieties), teachers' orientation toward science and teaching and learning, pedagogical knowledge of organization and management . What is important for my discussion is that there is a clear concern in Smith and Neale's report in clarifying the specificity of pedagogical content knowledge. In fact, the authors refers to three specific kinds of PCK:

1) Pedagogical content knowledge of student's concepts;

2) Pedagogical content knowledge of strategies for teaching content; and

3) Pedagogical content knowledge for shaping and elaborating the content.

The connection between the minimal model that I proposed in the beginning of this chapter and the notion of science teacher knowledge of the literature, particularly pedagogical content knowledge, will be explored in the following section. My sense is that

the minimal model that I suggest provides a starting point for analyzing more complex demands of science teachers knowledge. And more important, this minimal model can be used to study the nature of science teacher knowledge that is needed in the context of teaching science for understanding in relation to the science teacher knowledge in the context of applications.

A final comment regarding the literature on teacher knowledge is that it is full of discussions about the problems and the limitations that the teacher knowledge framework introduces (e.g., Cochran et al., 1993; McEwan & Bull, 1991; Tom, 1992). I identify at least two main critiques. One is that this framework does not account for other important characteristics of teaching such as moral values (Tom, 1992; Fenstermacher, 1990). A second critique is that the teacher knowledge framework is too "static" or too "fixed" (see Cochran et al., 1993).

I agree with the comment that the teacher knowledge framework does not account for several factors, particularly the moral aspect of teaching. However, it does not mean that the framework is contradictory to them. Some ethical studies of teaching need clarification of teacher knowledge (e.g., Ball & Wilson, 1996). The second critique is more problematic for me. Although there is a danger in representing teaching by specific categories of knowledge, such as SK, PCK, KK in my model, these knowledges represent only a part of a very dynamic practice (teaching). These knowledges look fixed, but in fact they are not. The subject-matter knowledge SK, for example, changes across time, as do PCK and KK. Fifty years ago, the subject-matter knowledge in K-12 education was different than today's. The same holds for PCK (think of the influence of research on how children learn) or KK (think of research on epistemology of science during the last thirty years). Therefore, there is nothing fixed in this package of teacher knowledge. It does not mean that we have a perfect representation of reality. There is no perfect picture of reality nor need for one. [10]

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[10]For some scholars such as (educational) constructivists, the very notion of "teachers'

Science Teacher knowledge: A theoretical model

In this section, I clarify what I mean by the components of the minimal model of the science teacher knowledge model that I suggest. In the first part of this chapter, I illustrated SK, PCK and KK, that is subject matter knowledge (SK), pedagogical content knowledge (PKC) and knowledge about knowledge (KK). In this section, I present more specific definitions and interpretations of what I mean by these constructs.

Subject-matter knowledge (SK)

In general, I define subject-matter knowledge -SK- as a transformation from expert scientific knowledge to school knowledge. This transformation refers to the substantive and procedural knowledge of natural phenomena that teachers need to known in order to teach science. Substantive SK knowledge tends to be identified with propositional knowledge-that is, facts[11], laws, and theories -while procedural knowledge, from the perspective of my model, is the know-how in the context of experimental science. Think of *Dave*'s electricity class on electric circuits. Substantive SK includes propositional knowledge (e.g., Ohm's law, i.e. V=IR) and procedural SK includes how to connect the wires with the flashlight bulb in electric circuits. A second example is teaching Boyle's law. Substantive SK refers to the law itself (PV= constant) whereas procedural SK refers to experimental knowledge

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knowledge" is problematic because they do not separate the knower from the known (e.g. Tobin, Tippins, & Gallard, 1994). No wonder since contructivists confuse reality with its representations (e.g., Von Glaserfield); that is, they confuse the territory with the map. Therefore, they will see teaching and teachers' knowledge as the same thing. The roots of the problem seem to be in a confusion between epistemological and ontological constructivism. I, for example, consider myself as an epistemological constructivist. But I am not an ontological constructivist in the sense that I am not assuming that I am constructing the external world just by thinking about it.

[11]The term "facts" in my model refers to "knowledge of facts" which is expressed by concepts. Facts are not epistemological entities. They are ontological entities (things or processes, natural or social). Several scholars do not distinguish between facts and knowledge of facts. Given the wide use of the term fact with epistemological purposes, I keep it in my model with the above clarification.

related to this law. For example: the knowledge of how to produce vacuum (e.g., Torricellian method).[12]

From the perspective of my model substantive science teacher knowledge includes a minimal understanding of the mathematical knowledge in which several scientific laws and theories are expressed. Ideal gases theory (e.g., Boyle's law) requires knowledge of elementary algebra. Schools' versions of Newtonian mechanics, another example, requires elementary Euclidean and analytical geometry, elementary logic, elementary set theory, basic algebra, elementary vector space theory. [13] However, my conception of substantive SK goes beyond this formal knowledge. Science teachers, and scientists, develop substantive knowledge of science in other forms such as narratives.

Substantive SK is related to Schwab's notion of substantive structures of the discipline. It is well known that Joseph Schwab made the important distinction between substantive and syntactic structures of the disciplines (1964/1978). The former, substantive structures, refers to the facts and relationships among them (concept, laws, theories) while the latter, syntactic structures, refers to methodological canons of the discipline (e.g., what is evidence?) and how knowledge is evaluated (e.g.. what is valid evidence?). As I said, what I call substantive subject-matter knowledge is partially related to Schwab's substantive structures. However, what I call procedural subject-matter knowledge is not conceptualized in Schwab's syntactic structures.

Procedural subject-matter knowledge refers to the knowledge developed in experimental sciences, that is, the "knowing how". In the case of *Dave*'s electricity class

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[12] Some scholars use the terms explicit/implicit as synonymous of propositional/ procedural. For example, some neuropsychologists and linguistics hold that: "Procedural knowledge is knowledge that cannot be inspected consciously [implicit]..." (Harris, 1996, p.245. See also Ellis, 1994 for an example in linguistic). The dichotomy tacit/explicit does not capture my distinction procedural/ propositional. In my model, procedural knowledge can become explicit, yet usually it tends to remain tacit or missed.

[13] The expression "minimal" understanding of mathematics is tricky because the clarification of the kind of mathematical knowledge that science teachers need to know depends on the knowledge selected and the conception of mathematics, science, and science teaching, among other factors.

this knowledge is connected to the goal of describe, explain and predict how electrical circuits work. This goal assumes that *Dave*'s students, and *Dave* himself, are able to put together the circuit; that is, they have to have a minimal procedural knowledge regarding electrical circuits such as simple connections and troubleshooting strategies.

The case of Torricelli provides an interesting historical context for illustrating substantive and procedural SK. It is well known that Torricelli, a disciple of Galileo and a predecessor of Boyle, faced the problem of explaining why lift pumps (formed by handle, piston, valve) could not lift water to more than 34 feet. According to the Harvard Case Histories in Experimental Science, Torriceli explained that the ascension of water in a pump is an effect of the air pressure rather than being sucked by the vacuum (this, of course, is an oversimplification of the history. See Conant, 1947 or Shamos, 1958 for more details and Shapin & Schaffer 1985 for a different political-historical perspective). This explanation assumes that air has weight. The following narrative, which includes conjectures on how the pressure of the air would produce "the suction" of water, reflects what I am calling substantive SK:

> If air had weight, why might it not exert pressure on the surface of the water in a well and thus force the water up the lift pump as the piston rises and produces suction? The height of the 34 feet of water would thus represent the weight of water which this pressure of the air on the surface of the earth could maintain (Conant, 1947, p.37).

In addition, Conant describes part of the procedural knowledge used in this experiment:

> [Toricceli and Viviani]..took a glass tube about a finger's width in diameter and about 3-feet long, sealed it off at one end, filled it completely with mercury, and keeping a finger over the end inverted in an open vessel of mercury (p.37)

Moreover, Conant explains with more detail the general procedural knowledge of Torricelli's experiment:

> Three new techniques [were] introduced into science; they are still invaluable. The first was the use of liquid mercury in open vessels and the tubes as a medium for experimenting with what we now call gases; the second, closely related, was a

method of producing vacuum; the third was the invention of the barometer... (Conant, 1947, p.39).[14]

Torricelli did not invent only techniques. He developed a theory for explaining natural phenomena. His theory includes substantive and procedural knowledge. Although canonical reconstructions of science tend to make procedural knowledge disappear (Gooding, 1992), procedural subject-matter knowledge is the basic component of experimental science and should be an important component of teacher subject-matter knowledge.

Both substantive and procedural knowledge are related to the frameworks established within academic disciplines, and both are related to expert scientific knowledge.[15] The translation from expert scientific knowledge into SK has stressed substantive knowledge, particularly in its propositional form. This is related to a common conception of science as a body of propositional knowledge.[16] This is somewhat clear when one sees traditional science classes -or even more progressive teaching perspectives- using the matrix developed by Gallagher and Parker in the Salish Research. See for example the row related to teachers' content (Table 3.1) in which didactic, transitional and even conceptual perspectives are centered around substantive subject-matter knowledge (from facts to conceptual understanding, that is, from "factoids" to "key ideas"). Only

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[14]Conant calls "techniques" what I call procedural subject-matter knowledge. The notion of procedural SK in my model goes beyond the common use of the term "technique" which usually is identified with mechanical skills. Donald Schön (1983) calls "knowing in action" the category of know-how, i.e., procedural knowledge. I restrict my procedural SK to scientific procedural knowledge rather than the wide spectrum of knowing-how knowledge (e.g. how to ride a bicycle which -by the way -was the favorite example of Polyani)

[15]Some scholars include in the subject-matter of science "heuristic", that is, ways of solving problems (e.g. H.M. Collins, 1987). Heuristics (e.g., analogies) are an important part of scientific thinking (Polya 1957). They are tools in the production of knowledge. In the context of science teacher knowledge, I conceptualize them as part of the pedagogical content knowledge construct.

[16]It is easier to translate propositional knowledge in contrast to procedural as I explain in chapter 7. However, the reasons of the stress in translating substantive SK are much more complex.

from the perspective of constructivism procedural subject-matter knowledge has a place (Gallagher & Parker, 1995).

In summary, science subject-matter knowledge in my model is formed by substantive and procedural knowledge. Now, let us see its pedagogical perspective.

Pedagogical content knowledge

In this section, I offer a clarification of the construct pedagogical content knowledge. I follow a general direction suggested by Dewey to whom : "Every study or subject thus has two aspects: one for the scientist as a scientist; the other for the teacher as a teacher. These two aspects are in no sense opposed or conflicting. But neither are they immediately identical" (1902/1990, p. 200). In other words, Dewey suggests a separation -and a connection- between the subject for the scientist and the subject for the teacher. A separation on what I developed the meaning of pedagogical content knowledge.

The separation between subject-matter knowledge and pedagogical content knowledge is by its own right, difficult, given the intrinsic pedagogical value of scientific knowledge. In other words, expert scientific knowledge (ESK) has educational characteristics. Needless to say that subject-matter knowledge, SK, the knowledge selected and translated into schools, has mainly educational purposes. Therefore, the separation between subject-matter knowledge and pedagogical content knowledge should not deny that science has a pedagogical component. In fact, any separation between pedagogy and content should take into account the connection between both, that is, the pedagogical aspects of science. However, it is important to clarify that subject-matter knowledge comes from a selection of knowledge which belongs to a specific community, the scientific community, a community with its own goals. The main goal of scientific communities, as far as I understand them, is to produce knowledge about the world. The pedagogical characteristics of this knowledge is not the main concern of such communities (see chapter 7 for an extensive discussion on the topic).

When subject-matter knowledge is re-interpreted with specific educational purposes, there is the emergence of a new kind of knowledge: pedagogical content knowledge, PCK for short. This explains the existence of knowledge that teachers have used, for years and years, to help their students to learn any subject-matter. This emergent educational knowledge has, I argue, two components: substantive (PCKs) and procedural (PCKp).

Substantive pedagogical content knowledge (PCKs), in my framework, is related to substantive subject-matter knowledge (SKs). However, PCKs goes beyond that given the emergence of substantive knowledge which is not conceptualized in the SKs component. Think of the topic of "forces" for example. Expert scientific knowledge can be seen as any of the mechanics that have interpreted (invented) the concept of force (e.g., Aristotelian, Newtonian, Lagragian, or Hamiltonian mechanics). In each framework (e.g., either Newtonian or Lagragian), the concept of force is quite different. The concept of force that has been translated to modern schools has been a version of Newton-Euler mechanics (Trusdell, 1968) in which force is proportional to acceleration of a given body (F=ma with m constant which is a particular case of F=dp/dt in which p is the linear momentum vector). SKs is formed by these academic (i.e., disciplinary-bounded) concepts and theories.

When a given teacher has to teach Newtonian mechanics, she or he uses, re-uses or invents a sort of emergent concepts that go beyond the Newtonian framework, yet they are related to it. E. Smith, for example, has reported a possible pedagogical structure of the Newtonian mechanics.

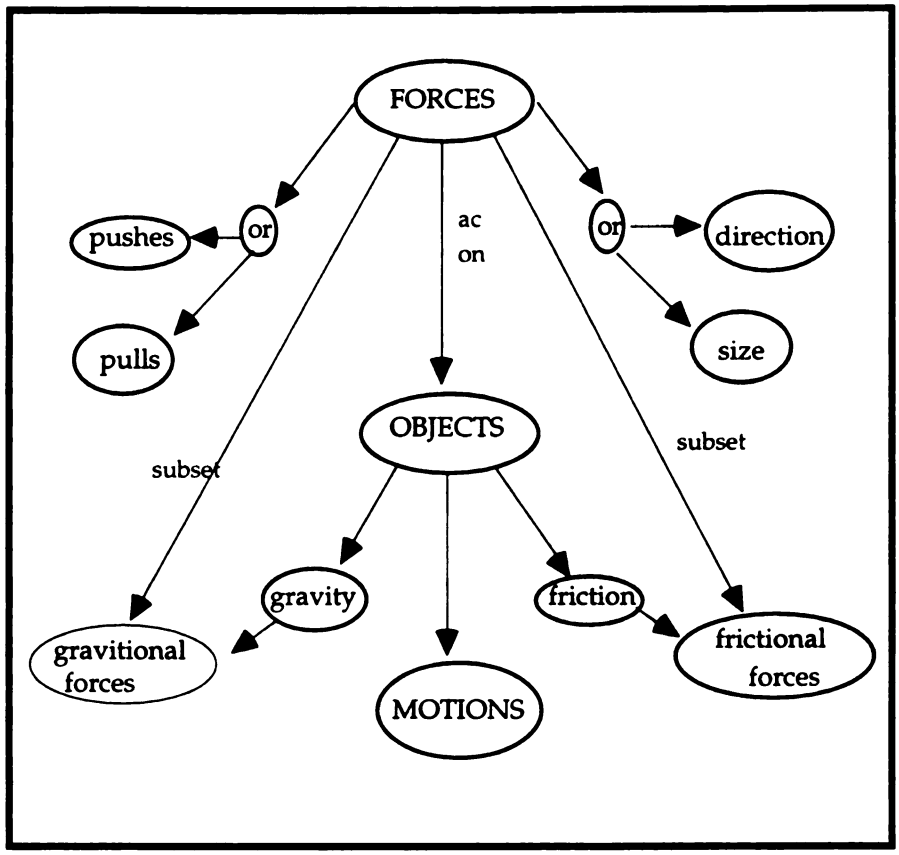


Figure 3.5 Concept map developed by E. Smith for unit on forces (adapted from Smith, 1990, p.48).

This conceptual map illustrates the difference between subject-matter knowledge, SK, and pedagogical content knowledge from the perspective of my model. Concepts such as gravity, gravitational forces, and frictional forces are part of SK, specifically substantive SK. Concepts such as *pushes* and *pulls*, are examples of what I call substantive pedagogical content knowledge when they are intentionally connected to SK in useful pedagogical ways. This point will become clearer later when I present more examples.

The common interpretation of pedagogical content knowledge has been with representations of the subject-matter. Shulman, for example, stresses this aspect of PCK:

> "[the knowledge] which goes beyond knowledge of subject matter per se to the dimension of subject matter ***for teaching***.... [it includes] the most useful forms of representations of those ideas, the most powerful analogies, illustrations, examples,

> explanations, and demonstrations-in a word, the ways of representing and formulating the subject that make it compressible." (Shulman 1986, p.9).

Some of these representations come from the framework of the disciplines (either expert scientific knowledge or subject-matter knowledge) and some of them are teachers' inventions. Several researchers have explored the role of representations in teaching science such as heuristic, analogies, demonstrations, etc. (Ball, 1989; Clemens, 1993; Wong, 1993, etc.). Although I do not describe this research here, it is important to note that representations can be a part of substantive pedagogical content knowledge (see Perkins, and Unger, 1994 for a review and a reconceptualization of the role of representations in science and mathematics education).

Representations, a component of pedagogical content knowledge called "shaping and elaborating the content" by D. Smith and Neale, can be constructed using research in science education. Moreover, teachers can use research in science education in order to develop substantive pedagogical content knowledge (beyond representations). Think of the wide research on Newtonian mechanics since the pioneer works of Viennot at France (1979) to the extensive summary of Driver et al., (1994). Research on the relationship between force and motions suggests, for example, that students tend to believe that:

- If there is a motion, there is a force acting;
- If there is no motion, there is no force acting;
- There cannot be force without motion;
- When an object is moving, there is a force in the direction of motion;
- A moving object stops when its force is used up;
- A moving object has a force within it which keeps it going;
- Motion is proportional to the force acting;
- A constant speed results from a constant force (Driver, et al., 1994, p.149)

This knowledge is not part of expert scientific knowledge nor substantive subject-matter knowledge (SKs). This is the outcome of analyzing Newtonian mechanics from a pedagogical point of view. Teachers can construct substantive pedagogical content knowledge using as a starting point such knowledge. Note that this knowledge becomes substantive pedagogical content knowledge only when teachers actually use that in instruction. Otherwise, this knowledge is general research in science education.

In line with the research tradition on how children learn, I see the emergence of a body of systematized knowledge which is the basis of what I call substantive pedagogical content knowledge. A. diSessa, for example, has suggested the existence of specific phenomenological primitives (p-prims) which can be connected to scientific theories in the course of instruction:

> ... physics-naive students begin with a rich but heterarchical (none being significantly more important than others) collection of recognizable phenomena in terms of which they see the world and sometimes explain it. These are p-prims. Some of them are compatible with formal physics... (diSessa, 1983, p.16). [17]

For example the p-prim called *"force as mover"* -among several p-prims suggested by diSessa- refers to the idea that forces cause motion in the direction of the force. The genesis of this idea is explained by diSessa: "Pushing an object from rest causes it to move it in the direction of the push. The p-prim abstracted from that behavior, at that level of detail, I call *force as mover.*" (1993, p.129). *Force as mover* can be seen as part of *substantive pedagogical content knowledge* if we use that as a bridge between naive conceptions of force and Newtonian forces.

It is important to note that there are different and sometimes competing positions on how people learn science, particularly forces. For example, Bliss and Ogborn (1994) suggest a different set of primitives (they call *prototypes of motions*) regarding the acquisition of the notion of force. In relation to diSessa's framework on force and motion, Bliss and Ogborn assume fewer primitives actions. Table 3.4 is taken from their report.

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[17] diSessa (1989) reported the phenomenology and the evolution of intuition in teaching physics. In this report, he introduced the notion of phenomenological primitives as key percepts or concepts for connecting scientific concepts with students pre-conceptions. Later, in 1993, he presented a work of synthesis in his paper: "Toward an epistemology of physics". Despite this title, what he presented, I argue, is an Epistemology of Physics Education, that is, an epistemology of school physics rather than an epistemology of physics.

Table 3.4 Primitive actions regarding the psychogenesis of motions and forces according to Bliss and Ogborn (1994, p.12). The framework was developed for infants.

Fundamental prototypes	
Level 1	pull
Level 2	fall
Level 3	carry
	move-self
	push/pull
	set-moving
Latter prototypes	
Level 4	lift
	walk/run
	non-living walk/run
	hit/kick/roll/slide/throw
	jump
Level 5	fly
	float

The use of this framework can be illustrated by one example taken from Bliss and Ogborn about a person who goes to the bus stop and catches the bus:

> The trip to the bus stop belongs to the prototype *walk.* It follows at once that the person makes the necessary effort, can control the motion, and won't fall because supported by the ground. When on the bus, the person is *carried* by the bus. We know without reflection that the person, being inside the bus, will behave like a part of the whole and so will move with the bus (*non-living walk-run*)...." (ibid. p.20)

Note that here there is an attempt to provide a theoretical explanation which does not follow a canonical direction, yet it would be connected later. The *phenomenological primitives* of diSessa (e.g. p-prims such as "force as mover") or the *primitive actions* of Bliss and Ogborn (e.g. *walk., carried , non-living walk-run)* are part of theories based on research on how students learn. These theories tend to take into account research on students naive conceptions, cognitive research, developmental psychology, etc. The core of these theories is what I am calling substantive pedagogical content knowledge.

Procedural pedagogical content knowledge differs from substantive PCK. The meaning of procedural PCK that I endorse is the knowing *how-to-teach* a specific content. This is related to what D. Smith and Neale have called strategies for teaching content. In

teaching the Newtonian concept of force E. Smith, for example, has drawn on the conceptual change model proposed by Posner et al (1982). Conceptual change model provides a "procedural" framework for dealing with specific content, that is, 1) knowing common naive conceptions that students tend to have; 2) presenting students with specific questions on the book-on-the table situation, 3) introducing the concept of force using the notion of push and pull, 4) developing the plausibility that the table was pushing on the table, and 5) using the notions of pushes, pulls and interaction among stationary objects to analyze problems (Smith, 1990, p. 50, 51). Although the conceptual change model provides a reference for a general pedagogical knowledge, my interest is in its use for teaching specific content (PCKp).

Procedural pedagogical content knowledge is not directly connected to procedural substantive knowledge (SKp). The former is related to useful pedagogical strategies tied to specific content. The latter, procedural subject-matter knowledge, was defined in terms of the "knowing how to do" in experimental science (e.g. knowing how to produce a vacuum in experiments of hydrostatic).

This distinction that I make between procedural subject-matter knowledge (SKp) and procedural pedagogical content knowledge (PCKp) is important. Such distinction is based on the idea that the knowledge of how to set an experiment is not necessarily the best procedural knowledge of how to teach specific content. The connection between substantive subject-matter and pedagogical content knowledge is stronger than the connection between procedural SK and procedural PCK. Think of the example of *Dave*'s electricity class (basic electric circuits). SKs includes Ohm's law, i.e. V=IR, knowledge of electrical energy, Joule effect, etc. This knowledge is related to expert scientific knowledge (which also includes deeper and more complex models than Ohm's law) such as: Kirchhoff's laws, the free-electron model, in addition to more complex circuits such as RC (resistence-capacitor circuit) and RCI (resistance-capacitor-inductance circuit) etc. Procedural SK includes knowledge of how to connect the wires with the bulb in electric

circuits, basic knowledge of troubleshooting strategies, etc. This knowledge is not directly related to procedural pedagogical content knowledge. In fact, for a given substantive SK and PCKs there is room for several kinds of procedural pedagogical content knowledge.

The meaning of procedural pedagogical content knowledge can be encapsulated by what Shirley Magnusson and her colleagues call orientations toward science teaching. In explaining the nature of the different kinds of pedagogical content knowledge in the topic of electricity, the authors use the following example:

> For the teacher with a "discovery" orientation, the purpose would be to have students discover the relationship that light bulbs in a parallel circuit give off more light than those in a comparable series circuit, and she would expect the students to conclude from this discovery that the amount of current is greater in a parallel circuit. For a "conceptual change" orientation, the purpose would be to have students generate explanations for the result that light bulbs in a parallel circuit are brighter than those in a comparable series circuits....(p.6).

Note that here the discovery orientation suggests a procedural pedagogical content knowledge in which students are allowed to discover differences between proprieties of circuits in series and parallel. In contrast, the teacher with a conceptual change orientation would have a set of different (but perhaps related) procedures.

Magnusson et al. (1994) report other kind of strategies -procedures- from the "guided-inquiry" teacher to whom the goal of teaching science mainly is to engage students in their own research. Students are expected to frame research questions, design an experiment and find a pattern; in this specific case of electricity they are expected to find "...patterns of differences between parallel and series circuits" (ibid.). Here, students study differences in light bulb brightness as part of the research. This category is very similar to the ***constructivist inquiry*** category suggested by Gallager and Parker (1995).

The following table summarizes my discussion on the difference between procedural and substantive pedagogical content knowledge and subject-matter knowledge. I have included the didactic orientation (defined in terms of STAM, see Table 3. 1,3.2 and 3.3 in this chapter). I have also collapsed the inquiry and the discovery orientations into one

given their similarities. Note that substantive and procedural subject-matter knowledge are un-variable. In order words, there are many ways of teaching the same content (i.e., given a selection of knowledge -SK- there are many ways of teaching it PCK).

Table 3.5 Relationship between substantive and procedural subject-matter knowledge and pedagogical content knowledge for different orientations in teaching electrical circuits.

Orientation:	Substantive SK	Procedural SK	Substantive PCK	Procedural PCK
Didactic.	Current, voltage, Ohm's law, difference of potential series and parallel circuits.	1) how to connect the wires with the bulb 2) basic knowledge of troubleshooting strategies	Current, voltage, Ohm's law, difference of potential series and parallel circuits.	1) how to connect the wires with the bulb 2) basic knowledge of troubleshooting strategies
Conceptual	Current, voltage, Ohm's law, difference of potential series and parallel circuits.	1) how to connect the wires with the bulb 2) basic knowledge of troubleshooting strategies	-analogies of flow of water with electrical circuits -powerful representations of electrical circuits -specific pedagogical models to explain flow of electrons in a circuit	1) Determining naive conceptions of electricity 2) Presenting intelligible alternatives 3) Developing plausible explanations 4) Generating fruitful explanations
Constructivist Inquiry	Current, voltage, Ohm's law, difference of potential series and parallel circuits.	1) how to connect the wires with the bulb 2) basic knowledge of troubleshooting strategies	? (Undetermined)	1) Framing a research question 2) Discussing the methodology 3) Designing the research/experiment 4) Reporting the results

Note that I have added the "didactic" orientation in order to illustrate the differences between SKs, SKp, PCKs, PCKp. I suggest that teachers with a didactic orientation do not distinguish between SK and PCK. This is clearer in higher levels in which teachers (e.g., colleges professors) believe that the more you know SK, the better your teaching is. However, what is important for this section is the explicit distinction that I make between SK and PCK in their substantive and procedural forms according the kind of orientation in teaching science.

Knowledge about knowledge (KK)

For knowledge about knowledge, I refer to a philosophical component of science teacher knowledge which takes into account questions of how we know, what counts as evidence, what is a scientific theory, what counts as scientific knowledge, etc. This area has been characterized as nature of science or philosophy of science and illuminated by history and sociology of science (Gallagher, 1991). In the context of my model, this component of science teacher knowledge is related to Schwab's syntactic structures of the disciplines (1964), that is, methodological and mainly epistemological canons of the disciplines.

Knowledge about knowledge in my framework focuses on epistemological aspects of scientific knowledge. However, it includes other philosophical components such as ontological, methodological and ethical assumptions about science. Usually science teachers only have implicit ideas of such philosophical assumptions (Gallagher, 1991). By the same token, science education reforms have traditionally tended to be implicit with their philosophical assumptions of science. In the context of science curriculum policy, R. Douglas (forthcoming) has called these assumptions "companion meanings." One exception is Project 2061 which has been explicit in its conception of science. For example, Chapter 1 of *Science for All Americans* (AAAS, 1990) presents a set of explicit philosophical assumptions of science which would be part of science teacher knowledge.

In order to illustrate what I mean by the component *knowledge about knowledge* in the framework of science teacher knowledge, I briefly comment on the conception of science that Project 2061 has suggested. I use its framework *Science for All Americans* in order to do this illustration (AAAS, 1990).

In an earlier work, I reported a set of philosophical assumptions that *Science for All Americans* portrays (Cajas, 1995a). I identified epistemological (E), methodological (M), ontological (O) and ethical (Eth) assumptions of science that this reform carries. The following table is a summary of these assumptions.

Table 3.6 An illustration of the philosophical assumptions of science from the perspective of Project 2061, particularly *Science for All Americans*. O, E M and Eth mean ontological, epistemological, methodological and ethical assumptions (adapted from Cajas, 1995a, p. 178)

The Scientific World View	**Scientific Inquiry**	**The Science Enterprise**
The World is Understandable (E) Scientific Ideas Are Subject to Changes (E) Scientific Knowledge is Durable (E-M) Science Cannot Provide Complete Answers to All Questions (E-M)	Science Demands Evidence (M-E) Science Is a Blend of logic and Imagination (O-M-E) Science Explains and Predicts (E) Science is not Authoritarian (M-Eth)	Science is a Complex Social Activity (O-M) Science Is Organized Into Content Disciplines and Is Conducted in Various Institutions (O-M) There Are Generally Accepted Ethical Principles in the Conduct of Science (Eth) Scientists Participate in Public Affairs Both as Specialists and Citizens (?)

In order to illustrate how this knowledge can become part of science teacher knowledge let me interpret any of these assumptions. Let us see the epistemological assumption that *the world is understandable*, for example.[18] It seems to me that this principle means that we can have partial knowledge of how the world works (e.g. models of electrical circuits). It does not mean that we can know each part of the world (or each part of the circuit). It does not mean either that the world will be completely understood (any scientific model has limitations). In explaining this principle, Project 2061 stresses the human capacity of knowing from a humble position. That is, it is possible to know the world, but our knowledge is fallible, it is not perfect, it has limitations. From my perspective this philosophical position, fallibalism, does not mean a radical skepticism, that is, that we know nothing. It does not mean either that we know everything (dogmatism).

[18]Such assumption is based on the idea that we know what understanding means. The interpretation that I suggest here of this assumption does not re-elaborate the discussion on understanding that I presented in the first chapter. In addition I explore several meanings of the term understanding in the following chapter. Here I only show a general epistemological interpretation of such principle.

This kind of knowledge is what I call knowledge about knowledge. Project 2061 is only one possible alternative and the above interpretation is my own interpretation. Science teachers should construct their own interpretations in explicit ways.

The separation that I offer between knowledge of the subject matter (SK) and knowledge *about* subject matter stresses the need for being explicit with our conceptions of science (Cajas, 1992a). [19] Perhaps this will pay off if one is interested in the pedagogical values of different conceptions of science in teaching science. It seems obvious that not all conceptions of science have the same pedagogical value. However, we do not know much about the role of different conceptions of science, particularly conceptions of specific subject matter, in teaching science (Cajas, 1995a). Let us think again of the problem of Newton's Laws. From a philosophical point of view, classic mechanics can be understood from several philosophical perspectives. For some philosophers, Newton's laws are mathematical definitions (formalism). For others they are empirical deductions, that is, patterns deduced from empirical observations (empiricism). Others think that they are mathematical universal laws that can be applied to specific cases (a version of positivism).

Ernest Mach, for example, defended the idea that we can reduce Newtonian mechanics to perceptible proprieties (e.g. by experimenting with observable masses). Mach intended to reduce dynamics to kinematics (Mach, 1893). Although I think that Newton's laws are conjectures (hypotheses) of how material objects interact rather than empirical deductions, [20] from a pedagogical point of view, the philosophy of Mach has several things to offer to teacher knowledge given its connection to more concrete assumptions (perceptible proprieties). Therefore, the separation between knowledge of subject matter

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[19]The separation between knowledge of subject matter (SK) and knowledge of knowledge (KK) is problematic. For several scholars, the notion of science also includes ideas about science (Matthews, 1995). I endorse the position that learning science also includes learning about science. However, usually the ideas *about* science are implicit. This is a critical issue in learning how to teach science because in order to improve our teaching, we need to know our implicit ideas (Ball, 1989). Therefore I keep separated SK from KK.

[20]High level of hypothesis, that is, theoretical conjectures. (M. Bunge, August 1995 personal communication).

(e.g., Newton's laws) and knowledge *about* Newton's laws (such as formalist, empiricist, positivist interpretations of the theory) is an important strategy in order to point out potential pedagogical implications of both kinds of knowledge in teaching science.

It is important to note that the component knowledge-about-knowledge in my model, KK, is formed by general assumptions about science (e.g. Table 3.5) and specific assumptions of specific subject-matter. In the case of Newton's law they were mentioned in the last paragraph (see Bunge, 1967; Cajas 1991; 1992b; 1995 for a detailed analysis of Newton's laws philosophical assumptions). Another example is Torricelli's experiment. According to J. Conant, E. Torricelli, a disciple of Galileo, faced the problem of why it was impossible "...to draw up water from a cistern for a distance of more than approximately 34 feet" (p.33). Toricceli's experiment is explained in several sources (Conant, 1947; Shamos, 1958). What is not presented in these histories are the philosophical assumptions of such an experiment. For example: fluids (in this case air) obey the laws of the static of liquids, or, the assumption that the earth is surrounded by air. There are also assumptions related to procedural knowledge. For example, why did Torricelli select mercury for his first experiment? These specific assumptions are examples of what I call knowledge about knowledge.

The role of philosophy of science in science teacher knowledge may have important implications. However, we still need to face basic problems regarding this potential component of science teacher knowledge. In relation to the role of philosophy in teaching science, my position used to be more optimistic (Cajas, 1991). However, after being in the U.S. and learning the lack of impact of philosophy of science in teaching science it has become more critical:

> The quality of the transference of the philosophical principles of science to the school discourse is an open problem because we (teachers, researchers and curriculum developers) still need to answer at least two questions: 1) what is the epistemological status of these principles inside the school discourse?; and 2) what are the pedagogical advantages of introducing these assumptions into the curriculum? (Cajas, 1995a, p.181)

For example, I see basic problems on the relationship between epistemologies within scientific communities and epistemologies within schools settings. One fundamental problem that guides this dissertation is "Should 'understanding' be based on how scholars hold knowledge in a domain or be defined by how ordinary people use knowledge in everyday life?" (Shulman & Quinlan, 1996, p.400). The answers -or proposal of answers- that science teachers can provide to this question and actually their own actions are related to philosophical conceptions of science and their social value in a given society. Such answers -or conjectures- will be reflected in the knowledge-of-knowledge component of science teachers. For example, a revision of current science teacher knowledge shows a concern for cannons and conceptions that come from disciplinary positions. However, with this discussion we are touching the topic of the following section.

Science teacher knowledge: Implications, limitations

When one sees science teacher knowledge from the perspective of my model there are three components: SK, PCK and KK. These three components seem to be in line with the idea that science is to describe, explain and predict natural phenomena. There is a translation from expert scientific knowledge (ESK) to scientific knowledge SK (the knowledge to be taught in schools) with the assumption that science teachers can learn science (SK), reflect on KK (e.g. epistemologies of science) and develop PCK in order to help their students to construct powerful scientific explanations. Here the connection between content, pedagogy, and philosophy is crucial. This raises the question of how much SK, PCK and KK shape each other (Tobin, Tippins, & Gallard, 1994).

The picture that one can draw from my model and from the review of the literature with which I interpreted my constructs is that the goals of teaching science are quite clear: teaching science for understanding in light of disciplinary criteria. This seems to be a translation of understanding of the discipline to schools. The depth of the translation depends on how much understanding teachers want for their students. For example, in

teaching electric circuits one can choose between macro models based on general variables such as current, voltage, resistance or micro models based on electron flow models. The same holds for almost any part of the K-12 science education curriculum. So far, science education has produced knowledge to illuminate teaching science from either macro or micro points of view. At any rate the goal is understanding.

At the same time, we are witnesses of an era in which reforms are also asking for connecting school science to students' everyday lives. Therefore applications of science are, or should be, key components of science teacher knowledge. Applications of school science to everyday life assumes that it is possible to do that. In teaching Newtonian forces, science teachers and researchers assume that we (general public) can use such tools in everyday life. For example, research on naive conceptions assumes that we (humans) are doing explanations of natural phenomena in our daily life (yet we are, usually, wrong!). Think of diSessa's research on the preconceptions of physics (1988, 1993). The p-prim "force as mover" explains (from a naive point of view), according to diSessa, a relation between force and effort. However, in everyday life "...people do not try to explain why you get more results when you expend more effort pushing a big rock. There is no ready explanation or really any need for one" (Ueno, 1993, p.329).

In a study on how people use scientific knowledge for solving real-world problems, Brian Wynne and his colleagues found, among several interesting findings, that

> ...the closer one gets to everyday discussion of apparently technical issues such as those examined in these projects [the research projects carried out by Wynne's team], the more science seems to 'disappear'. This does not deny the importance of science in such contexts but note the extent (and variety) to which it needs translation, or 'reframing'. (1990, p.116).

Teaching electricity, another example, supposes several concepts, theories (SK) and assumptions about such concepts (KK) with which students can describe, explain and predict the phenomena in electric circuits using batteries. Teachers, can help students to construct their own models by using analogies (water pump), models (the container---

>consumer-analogy) or theories (voltage-current, electron flow), that is, knowledge to help students to learn science (PCK). However, some researchers have reported the irrelevance of these circuits in everyday life (Black & Harlen, 1993). How does it affect the science teacher knowledge model that I just described?

The first important element of the model of science teacher knowledge that I developed is that it should help teachers and researchers to understand what teachers need to know to provide students opportunities to use science in meaningful ways. This is difficult because it forces us to think what students can do with science in their lives. For me, such goals shape what we consider SK, PCK and KK. Although it is accepted that applications are part of science teacher knowledge, when one sees the model on teacher knowledge that I developed - and its connection with the literature- there is much more attention to explanations than applications. Teachers and researchers assume that these explanations are connected to students' everyday lives. However, I think that these assumptions and connections deserve to be studied.

In general, I think that there is a basic tension between what is considered science teacher knowledge, at least in the sense described by my model, and the demands of applications that current reforms are asking for. The tension in teacher knowledge is related to the tension that I studied in Chapter 1 and 2 between understanding and applications. In this way, applications of science to the real world in the sense of students' everyday lives require a reconsideration of the knowledge that teachers need to know. This calls for better theories and a richer language to talk about teacher knowledge and teaching.

My position is that we need to study the relevance of school science and develop conceptual systems (theories) to study what science teachers need to know. My sense is that traditional scientific knowledge (SK) has limitations for being used in real-world applications regarding students' everyday lives. It does not mean that teaching science for understanding is impossible. Rather, what I mean is that the epistemological and pedagogical demands that applications -in the sense of real world applications connected to

students' everyday lives- introduce on science teacher knowledge are complex. In order to show that, I think that a re-evaluation of the science teacher knowledge model proposed in this chapter, it is needed. The reason for this re-evaluation is that I see possibilities in using more mundane knowledges, such as technological knowledge, as part of science teacher knowledge in connecting science with students' everyday lives.

CHAPTER 4

SCIENCE TEACHER KNOWLEDGE: APPLICATIONS

Understanding...applications: A clarification of basic terms

The firsts two chapters have set a scenario for analyzing the potential that technology has in teaching science for understanding and applications. Using the case of *Dave* and examples taken from Feynman's physics classes I illustrated different relationships between teaching science for understanding and applications. One approximation to the terms understanding/application was epistemological. I identified understanding with one of its meanings within scientific communities, that is, the use of scientific knowledge to describe, explain, and predict.

A second meaning of the relationship understanding/applications was introduced in the opening chapter with the current concern of science education reforms of connecting school science with students' out-of-school experiences, that is, meaningful applications regarding students' everyday lives. Here, applications go beyond the use of scientific knowledge per se. I used some outcomes of the Salish Research Project along with other references to illustrate the notion of relevance of school science.

During the firsts three chapters I also used other meanings of understanding /application. I mentioned the use of science to solve real-world problems as opposed to academic problems and the role of technology in connecting science to students' out-of-school experiences. Now my aim is to unpack the epistemological demands that teaching for understanding and applications place on science teacher knowledge. Therefore, the several meanings of understanding/applications that I am using need to be clarified.

The multiple meanings of understanding & applications

Looking back I can see that all my interpretations of the terms understanding & application are related to the "solution" of different kinds of problems. So it sounds reasonable to clarify what I mean by the term problem. My general assumption is that a

problem is a difficulty which requires some degree of challenge in order to be faced. Problems have many purposes, roots, colors, flavors, etc. according to their creators and their affiliations. Therefore, I begin my clarification on the multiple meanings of the terms understanding/applications by analyzing the meanings of *academic problems* in the context of teaching science.

Understanding/applications: Academic problems

One meaning of the term "scientific problem" can be analyzed from the perspective of disciplinary knowledge in which problems are a special kind of conceptual difficulties developed within the tradition of academic disciplines. Such problems require the "application" of scientific knowledge in order to be solved. Of course, I do not mean that academic problems are solved by a simplistic application of knowledge already made. The problem is much more complex than that (see Popper 1996 for a discussion). What I want to point out is that from this perspective, understanding/applications means to solve theoretical difficulties framed by scientists. The assumption is that these problems address features of reality, that is, *Nature* poses the problems. The common assumption is that scientific problems are discovered. Here the meaning of understanding/application is to discover the secrets of the Universe. I do not share this philosophical position, but I think this assumption is widely shared within scientific communities in which scientific problems are supposed to be given by *Nature*.

Scientific problems can also be seen as special kinds of difficulties which are posed within a scientific paradigm shared by a scientific community (Kuhn, 1970). The epistemological conditions for accepting scientific problems change from author to author and from time to time yet they share some features. For example, some people tend to agree on the need of a specific body of knowledge to be applied (scientific theories). Others ask for well-formulated problems (e.g., Reif & Larkin, 1991). Understanding and application here is the use of such a paradigm to solve problems. Note that although the notion of

scientific problems is tied to the paradigm, understanding/applications is the use of canonical knowledge to solve specific difficulties.

One fundamental paradigm has been identified with Galileo's contributions. This paradigm has supported the development of modern science. One line of interpretation of Galileo's work, and perhaps the only one, has stressed the process of idealizations and abstractions in the explanation of natural phenomena (Matthews, 1995). Think of the case of a simple pendulum (which is the problem usually presented as an example). Galileo developed, among several other contributions, a theory for explaining a) how the period of a pendulum changes with its longitude, b) the relationship between period and amplitude (actually no connection), and c) the relationship between period and mass (also independent). In this theory, Galileo reduced real events into abstractions. The "simple" pendulum is not a real pendulum; this is an ideal pendulum whose mass is an ideal point.

Based on this general paradigm (reductionism into abstract ideas) scientists have invented several "scientific problems." Note that from this perspective, in order to be "scientific," the problem should be posed within this specific paradigm. This is one meaning of the term "scientific problem", that is, those problems which make sense within these conceptual frameworks (Kuhn, 1970).

There is a parallel process in school settings. Contemporary science education reformers are also asking for teaching science in line with the above conception of understanding. This is not only the position of scientific communities or the position of science education reformers, but it is also a general movement for reforming education (e.g., O'Day & Smith, 1993; The Holmes Group, 1990). The following case taken from one of the Holmes Group reports is an interesting example: "In a school where students are taught for understanding: Fifth graders may experiment with pendulums and refine contrasting hunches about timing and length into testable theories" (1990, p.17). Here, understanding and applications for these fifth graders is the reconstruction of this Galilean experiment. Their hunches about timing and length of the pendulum will refer to ideal

types, that is, an ideal pendulum. The problem will be scientific because it belongs to the organized tradition of scientific communities. Note that I am not criticizing such positions. Rather, I am illustrating one meaning of students' everyday lives which is related to the solution of academic problems in school settings.

A second meaning of understanding as application is its concern on developing mathematical models. The problem of the pendulum, for example, would be seen as the justification of using mathematical tools, such as differential equations or algebraic equations in the case of K-12 science education. Using again the potential interpretation of understanding as explanation and prediction based on mathematical models, one can see that, from this perspective, the deeper the theory the better the understanding. The more formal the mathematical apparatus the better the understanding.

What is important for my analysis is that the focus of attention changes from the natural phenomena to the mathematical apparatus. Think of the case of the pendulum which consists of a small mass (m) suspended by a light inextensible cord of length l. If $\propto$ is the angle between the cord and the vertical, one can develop the following equations of motions of the particle m:

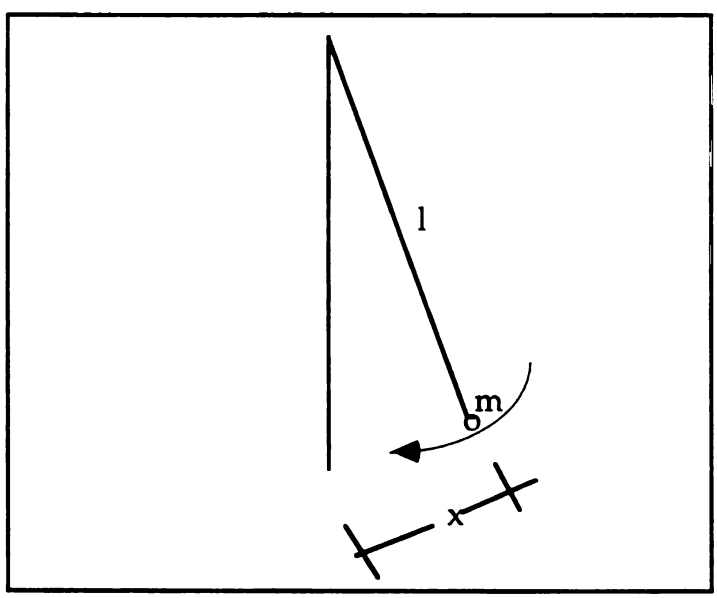


Figure 4.1. The simple pendulum.

(1) $SF=ma$

(2) $ma= mdx^2/dt^2=-mg \sin\alpha$

$dx^2/dt^2=-g \sin\alpha$

or in terms of the angle (where $x=l\alpha$)

(3) $lda^2/dt^2=-g \sin\alpha$

with approximations of small angles one can assume that sina is more or less α, therefore the differential equation becomes

(4) $da^2/dt^2=-g/l\alpha$

What is important from this perspective of applications is not the natural phenomena. What is important is the mathematics. Followers of this perspective would argue that the natural phenomena is embedded in the differential equation (4). The solution of the equation for specific conditions is one meaning of application. However, the tendency in theoretical mechanics, for example, is to value the formal apparatus rather than the natural phenomena. In this way, the natural phenomena (real-world event) is an excuse for developing formal models (e.g., Lanczos, 1970). In other words, the concern is the mathematics.

For better or worse this meaning of understanding/applications has its existence in school settings. Take the same example of the pendulum suggested by the Holmes Group (1990). One plausible interpretation of this suggestion is that students will develop or simply use mathematical models such as the formula of the period of the simple pendulum, that is, $T= 2p \sqrt{l/g}$ (with l the longitude of the pendulum, p the irrational number 3.14..., g the acceleration due gravity, and "$\sqrt{}$ " the symbol of square root) -which by the way is one solution of equation (4)- in order to make predictions. [1]

When the mathematics has the objective of describing, explaining, and predicting I refer to the notion of internal relevance, that is, the first meaning of understanding/ application that I suggested. However, when the phenomena is only one excuse to develop

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[1]For greater amplitudes, the expression of period of a pendulum becomes the following: $T= 2\pi \sqrt{l/g} (1 + 1/4 \sin^2 \alpha/2 + 9/64 \sin^4 \alpha/2+....)$ If one wants to take into consideration the form of the pendulum, i..e., the real interaction between the mass of the pendulum and the air, the problem is much more complex (Reference: any college physics textbook).

mathematical models, I refer to a different meaning of understanding/ application. Although the mathematical model can be used for understanding, the second meaning of applications that I am pointing out is the very use or creation of mathematics for its own sake.

Solving real-world problems

A third meaning of the word application, according to my clarification, is the use of science for solving real-world problems. The meaning of the term *real-world problem* is tricky. On the one hand, "real world" would mean the phenomena itself; for example, the pendulum with its movement. On the other, hand real word problems could mean problems that refer to real objects and events rather than abstractions or idealizations. One special kind of these problems are everyday phenomena. Both meanings of real-world problems are quite different notions. The idea that science refers to real-world events is a general ontological assumption. However, not all real-world events are approached in similar forms. The example of the pendulum-problem can be seen as a real-world event (ontological assumption), but it is also an idealization (methodological strategy).

The ontological assumption that science is about real-world events is problematic only for some philosophers (idealists such as the case of Plato and several contemporary constructivists who are also idealistic). However, the idea that one can apply scientific knowledge to real-world problems is more problematic because it depends on the kind of real-world problems that one is talking about. Real-world problems in everyday life tend to be ill-structured, confusing, outside of specific disciplines, etc. (Lave, 1988; Schön, 1983). Therefore the assumption that canonical scientific knowledge can be applied to real-world problems, in the sense of everyday problems, requires more than a clarification.

When scientists refer to real-world problems, they talk from their own experiences. When science educators talk about real-world problems, they refer to common experiences that can be approached by scientific knowledge. In teaching my own classes, particularly in topics such as forces, energy, and momentum, like many science teachers I frame "real-

world" problems with common examples such as climbing a rope, accelerating a car, pushing a box along the floor, filling with air the tires of the car, etc. Nobody denies that they are real-world problems (ontological assumption). However, these problems become scientific (academic) problems after a huge process of transformation such as idealizations (methodological strategies) or after changing the very nature of the problem. In other words, they become scientific, and also much more manageable, after one eliminates all their mundane characteristics.

The nature of real-world problems is problematic by its own right. Such problematic nature and complexities transcends disciplinary boundaries. In a recent presentation at Michigan State, Richard Lesh, for example, suggested a separation between traditional textbook problems and real real-world situations in the context of mathematics education. The following table represents his conception of real-world problems in relation to traditional textbooks problems:

Table 4.1 Real life situations and traditional textbook problems in the context of mathematics education according to Richard Lesh (1997).

Traditional Textbooks & Test	**Real-life Situations**
Problem: What's problematic is to make meaning of symbolically stated situations.	Problem: What's problematic is to make symbolic description of meaningful situations.
Products students produce includes simple answers to questions	Products students produce include constructions, descriptions, explanations, justifications, predictions.
Focus on numbers and operations	Focus on quantities, relationships, and transformations.

I see a small difference between Lesh's conception of textbook problems and his idea of real-life situations. It seems to me that what is a real-life situation for Lesh is still an unproblematic description of a very complicated issue. Perhaps in a community of mathematicians, descriptions, explanations, justifications and predictions are part of their real life. After all, real-life problems are relative to the life of the people. However, if one

is thinking about common people (just plain folks, **jpf**, is the expression coined by Lave), real life problems tend to be ill-structured, confusing, outside of specific disciplines, and several times they are more practical rather than cognitive.

In an interesting paper, Reif and Larkin (1991) have analyzed cognition from the perspective of everyday and scientific domains.[2] The authors attempt to show continuities and discontinuities between science and everyday life. Reif and Larkin's analysis is important because it points out the difficulties of using school science in everyday life. The meaning of understanding in both domains is of special importance in my discussion. According to them, understanding in science "...is a working goal pursued deliberately in the service of the central goal of explaining and predicting...the criteria of scientific understanding are well specified" (p.741). In contrast, according to them, there are not well defined criteria of what constitutes understanding in everyday life.

Although the separation between scientific and everyday life domains is important, the business of science education is to connect both. The discontinuities between science and everyday life according to Reif and Larkin would have important consequence in teaching science (in fact it has had implications given the popularity of this vision). The authors make the case that being aware of these differences is important for students given the fact that they commonly import into science problem-solving strategies used in everyday life with negative consequences. It seems to me that the authors make an important contribution to the (lack of) research on the use of science in everyday life. However, the assumption behind the argument is that science is going to be useful in everyday life if we

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2 The authors refer to "knowledge domain" following the language of research in cognition and computers. There are other meanings of domains even within this line of research. R. Schank, for example, defines a domain as "...an area of interest that can be used as background for the acquisition of skills and cases while one engages in tasks that teach processes used with a subject area" (1993/1994, p. 433). Therefore, physics is a domain in Schank's sense and also a knowledge domain in Reif and Larkin's sense. It is problematic to talk about everyday domain because the area of interest is not limited. When one says that everyday knowledge is knowledge that one use in everyday life, one does not say anything. Delimiting and clarifying what everyday knowledge is seems to be a super complex problem. Despite that, I keep talking about the two domains suggested by Reif and Larkin with the clarification that we are in a fuzzy, uncertain and complex area.

are aware of the differences/ similarities between science and everyday life knowledge. The conception of science that is behind this argument is the idea that scientific problems can be solved by general theories. The role of students is learning such theories and how to use them in "real" life situations. The importance of these theories was already built by scientists; that is, it is a general assumption that these theories are important and useful in every day life.

The meaning of real-world problems, which ultimately is related to the meaning of understanding and applications in everyday life, is important given the stress that contemporary educational reforms are putting on this goal. However the implications of such a goal and its relation with the scientific knowledge that is taught in school is still unclear to me. To complicate matters, real-world applications in the context of current educational reforms are not only in the sense of real stuff, but also in relation to students' experiential worlds. This is a matter of the following section.

The relevance of science

Another meaning of the word application in the context of my work is its connection with the concept of personal relevance introduced in the first chapter. The reader may recall that in the exploratory study of Salish, personal relevance was used in order to know how teachers make use of students' everyday experiences as a meaningful context for the development of student's scientific knowledge and, mainly, how students perceive such relevance (Taylor, et. al, 1995). However, the concept of relevance of science goes beyond personal relevance. The relevance of science in personal life is not only connected to utilitarian reasons. There can be cognitive, aesthetics, social, and other reasons that are included in this kind of application.

Educational reformers are asking for meaningful applications of science to students' everyday lives (e.g., Project 2061, the National Science Education Standards). As I pointed out in the last section, this assumes that scientific knowledge can be used in meaningful

ways in real-world problems and everyday life. The advantages and limitations of this assumption should be analyzed taking into account the kind of relevance that one is talking about. Traditionally the notion of relevance has been approached from a cognitive point of view. From this perspective, the idea is that scientific knowledge can be used in students' personal lives with meaningful, i.e., cognitive, purposes. However, the relevance of science from a cognitive point of view is not necessarily the same as the relevance of science from a social point of view (see chapter 7 for a discussion).

Another meaning of the term understanding application I have used is the design of artifacts. This is the perspective of technology. In the following section I clarify this meaning.

The design of artifacts

In the first chapter, I used the meaning of application in the sense of the design and creation of artifacts. This is the perspective of technology in which knowledge has practical value (e.g., for designing and/or transforming artifacts). Here applications do not only have the cognitive goal of understanding (as describing, explaining and predicting). Rather, knowledge, from this perspective, makes sense if it can be used with practical goals (designing, creating or transforming). This meaning of application of science is presented in the two leading science education reform proposals: Project 2061 and the National Science Education Standards.

We can start with the general statement that technology is a problem-solving activity (Allshop, 1981) or the very first definition that the Panel Report of Project 2061 suggests: "Technology is the application of knowledge, tools, and skills, to solve practical problems and extend human capabilities" (Johnson, 1989, p.1). Although both definitions of technology, problem solving activity and application of knowledge are broad descriptors of a complex activity, they illustrate (with the danger of a mis representation) the meaning of

applications that I want to point out here. That is, the idea that science can be related to the solution of practical problems.

Of particular interest in this meaning of application is one branch of technology: engineering. To some extent, engineering is a representative of technology and its relation with science is important to science education. In general, one can assume that "Engineers spend their time dealing mostly with practical problems, and engineering knowledge both serves and grows out of this occupation" (Vicenti, 1990, pp. 200-201). Practical problems in the context of engineering and the existence of engineering knowledge are key terms that are related to the meaning of application as design of artifacts. In fact, the meaning of application that I want to clarify in this section is related to the use of science to deal with "practical problems" in the sense of designing, creating or transforming things. Later, in a specific chapter, I clarify the meaning(s) of technological knowledge and its potential connection with science education.

From a cognitive point of view, Leona Schauble and her colleagues have analyzed how children's understanding of experimentation changes when they are exposed to scientific (understanding) and engineering (applications) types of experiments. The features of children's engineering and science models of experimentation used by Schauble and her colleagues is important to clarify one meaning of applications in the sense of the design of artifacts.

Table 4.2 Features of children's engineering and science models of experimentation according to Schauble et al. (1991, p.861).

	Engineering model	Science model
Goal:	Make a desired or interesting outcome occur or reoccur	Understand relations among causes and effects
Strategies:		
Procedures:	Compare highly contrastive instances	Establish the effect of each potentially important variable
Inferences:	Emphasis on making inclusion, or causal, inferences	Emphasis on making exclusion or non causal inferences of indeterminacy
Search:	Focuses on variables believed to cause the outcomes	Seek to test all combinations, if feasible
Stop rule:	When the desired outcome (or acceptable approximation) is achieved)	When systemic test of each manipulable variable is completed

Applications in the context of the engineering model are better characterized by practical, utilitarian and pragmatic reasons: "We refer to the practical approach to experimentation as the engineering model of the process. The main objective of engineering practice is to optimize a desired outcome, and much of engineers' experimentation is organized around this objective" (ibid, p.860). In contrast, the scientific model stresses understanding (describing, explaining, and predicting using causal models).

From this cognitive perspective, the domain of knowledge and experimentation strategies (either scientific or practical) affect how children learn science. For my argument the very existence of engineering problems, as part of applications of science, places new demands of knowledge in science teachers. Perhaps these applications will pay off if they can be connected to other goals of science education such as everyday applications. This argument is implicit in Schauble's report: "'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).

The argument of Schauble has important implications for science education and reflects a specific meaning of understanding/application that I have used. I am particularly interested in this notion of understanding/ application. Therefore, I will study the role of

technology as content knowledge in science education. This implies a careful study of the notion of design in some technological fields (e.g., engineering) and how this can have implications in the science curriculum. At this moment, the goal of my discussion is to clarify the multiple meanings of students' everyday lives have used in the first chapters of this dissertation.

Problems

So far I have illustrated five generic meanings of the terms understanding and applications that I have been using during the first chapters of this dissertation. At this moment, the reader can see that the tension understanding versus applications of which I am talking about is not a simple dichotomy between a single meaning of understanding and a single meaning of application. Rather, it reflects a complex interaction among several potential and actual meanings of these terms. The following table summarizes these different meanings.

Table 4.3 The multiple meanings of the term application.

Application 1 **The use of scientific knowledge to solve scientific problems**
Application 2 **The use of science to solve mathematical problems**
Application 3 **The use of science to solve real-world problems**
Application 4 **The relevance of science in everyday life**
Application 5 **The design of artifacts**

I call "application" each of the meanings that I am using, yet sometimes I refer to understanding. Application 1, for example, does not separate understanding from application. Here, understanding and application mean the use of scientific knowledge to describe, explain, or predict. The meaning that I stressed was the use of science to solve academic problems. This meaning was also called internal relevance given its concern on the use of knowledge for cognitive reasons usually in line with the key ideas of the discipline.

Application 2 refers to the concern of the use of mathematical tools to solve scientific problems. Application 2 also has its representation when school science tends to stress the use of mathematical models rather than the understanding of the natural phenomena. Application 3 is a goal in contemporary science education. There is a great concern in approaching real-world problems within school settings (Resnick, 1987; AAAS, 1990). Application 4, relevance of science in everyday life, is another current goal of schooling and usually is mixed with application 3 (e.g., Nagel, 1996) . However, the relevance of science in personal life is a somewhat different goal than the solution of real-world problems, yet they could be related. Application 5 refers to the uses of science to design, change, and control artifacts.

All these meanings represent general categories that are interconnected and overlapped among them. For example, for some people, mathematical models are related to real-world problems such as the case pointed out by Speiser and Walter: "The message of this article is that if we take real-world modeling seriously, then we need to introduce the basic concepts of calculus with much more subtlety and depth" (1994, p.135). Therefore, for these authors, application 2 is related to application 3. The same holds for applications of science to real-world problems or the notion of personal relevance. If one of the goals of science teaching is to give students opportunity to use science in the real world in relevant contexts, application 3 is mixed with application 4. In this way, the meanings that I have pointed out are not pure goals of science and mainly science education. Rather, they are terms that I use in order to explore what the kind of knowledge is that science teachers need to know that they are going to teach for understanding and applications. My interest is on applications that go beyond the discipline; that is, applications 3, 4 and mainly 5 because they are more important from a social point of view. It does not mean that I am not interested in applications 1 and 2. Certainly, I think that in order to know what the role of science in everyday life is, or what the relevance of science is, we need to know more about the role of science as institution, that is, know more about how scientific communities

actually work, what count as knowledge and evidence and mainly what is the meaning of understanding and applications within these communities.

When one sees Table 3 with its different meanings of understanding and applications, one also sees different conceptions of the nature of the problems. For example the use of science to solve academic problems assumes that problems exist somewhere; therefore, their ontology is already established. This is not the case for the creators of such problems, but this is the case for the re-creators of these problems. For example, for Galileo, the problem of the pendulum was his creation. However, the transformation of this problem and its incorporation within the discipline of physics illustrates the existence of academic problems with their own ontological status. On the other hand, when one sees what a problem is from the perspective of students' everyday lives, the relationship between the problem and the "solver" (the person who intends to solve the problem) becomes more complex. Here, the very ontological status of problems changes from something already made (disciplinary problems) to something with less clear ontological status (Roth, 1995b). The notion of "problem" moves from the discipline to students' everyday lives. This movement introduces new demands of teacher knowledge.

At this moment my interest is on the clarification of the kind of knowledge that science teachers need to know in order to teach for applications in general. In doing so I suggest the following two steps. First, I want to explore those Salish teachers who were perceived with high personal relevance by their students. I mainly use the example of one teacher (*Judy*) who was consistently rated high on the personal relevance scale of (CLES). I also mention the examples of other Salish teachers. Second, I present an extension of the model of science teacher knowledge developed in the second chapter in light of my discussion of those Salish teachers who made science relevant according to their students and in light of the several meanings of understanding and applications that I pointed out in this section. These two steps will prepare my specific discussion on technology to be presented in the next chapter.

Personal relevance: A kind of application

The Salish Research Project explored the relationship between personal relevance and teachers' knowledge and beliefs. The Project also studied potential connection with teachers' actions, students' outcomes and program (teacher preparation) features, that is, characteristics of the program of these science teachers that would affect the relevance perceived by students and by the teachers themselves. A general finding of the Salish Research was that few science teachers were rated by their students with high personal relevance. In other words, students did not perceive the relevance of science out-of-school. In addition, science teachers agree with their students, yet they tended to rate higher the relevance of their classes (see Figure 1 in Chapter 1).

In this section, I use the case of *Judy* in order to set a preliminary scenario on the demands that applications place on science teacher knowledge. As I just said, one interesting set of teachers are those Salish teachers who were rated by their students with high scores on the scale of personal relevance according to the Constructivist Learning Environment Survey (CLES), that is, those students who perceived their science classes highly relevant to their personal lives. In the context of Salish, we found that only a small proportion of teachers (10% approximately) were seen as highly relevant by their students (personal relevance scores > 25). Relevance according CLES is defined as the meaningful uses of science out-of-school (Taylor, et al. 1995). *Dave* was not viewed as a very highly relevant teacher by his students. He was in the middle of the scale like most of the Salish teachers of the national sample (68 science teachers in this case).[3]

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[3]When we wrote the final report of Salish (chapter 5 on linkages of Salish Final Report, 1997) in December 1996, we used a sample of 68 science teachers. Later more data was added. Chapter 2 of the final report of Salish includes data from 116 new teachers. Data from CLES now is avai;able from 241 classes taught (we have some data of the same teachers for different years, i.e. multiyears teacher), 207 of these were science and 34 were mathematics. The CLES data was used with more or less 5,000 students (Salish, 1997).

The case of *Judy*

Judy is a new science teacher who consistently was rated with high personal relevance scores by her students. She seems to help students to see the relevance of science. In the following paragraphs I explore some general aspects of *Judy*'s knowledge, beliefs, and actions that would illuminate a future analysis on what teachers need to know for making science relevant to students. I use the case of *Judy* as an example of those teachers who were rated as having high personal relevance by their students. I sporadically introduce references from other Salish teachers such as the case of *Dave*. [4]

From the very beginning of the Salish research, *Judy* showed several interesting characteristics that would explain why she was seen by her students with high relevance. In the first year of the research, 1994, Salish researchers asked *Judy* how she knows when she has learned something. She answered in the followings terms: "If I can explain it again, you know, to somebody else or use it either to apply it or explain it to somebody else...apply it...like if learned how to measure something I would be able to go into a room that I was going to wallpaper and determine how much wall paper I needed....If I learn I solve a problem with it" (Interview, 6/28/1994). This conception of learning tied to applications is also present in her concern for external relevance: "We do a lot of human biology and there are limits to what you can do in the class because you do not have the equipment like a lot of diagnostic equipment. But a lot of times it is just giving examples of something that is happening to people like diseases" (ibid.) This was confirmed by video tape observations (Tapes 101 # 1, 2, and 3)

The concern of *Judy* is not only on the applications of science but also in teaching science itself. In this first year of teaching, she seems to use the following pedagogical structure: **basic science ---› complex systems ---›applications**:

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[4]Salish researcher divided CLES scores in two groups: high (more or equal than 25) and low (less than 25). Given the high numbers of scores in the interval between 20 and 25 scores, I decided to include a medium scale between 20 and 25. Therefore, I interpret low scores as those which are less than 20. High scores are > 25.

> Because we really do try to build upon basics we start off with the cell. We do some genetics, and then so many of the human systems we go through. You have to understand what cells are and then we go into describing how cell are different by getting into viruses and bacteria. And then I try to get into more of that later with applying it to what some of the human system of specific diseases and problems and plants. (Interview, 6/28/1994)

She also showed a critical position toward the knowledge that her students need in order to learn about complex biological systems from the basics.

> When I looked at ... the textbooks, so much is explained in terms of biochemistry and I do not see how they could ever give the books a reference or read anything in detail without having some of that background. So I did take some extra days to go through just the basics- here is a carbohydrate, here is a protein, a lipid...(Interview, 6/28/1994)

Judy holds a position which goes beyond the uses of this pedagogical chain (from basic to complex systems). In answering the question of what learning in her class she values she said:

> I think it does not have to do with the topic of science. A lot of it is study habits, being organized, and just thinking of defining a problem or thinking. It does not often necessarily relate to science. Questioning, not believing everything. Looking further into something. I think a lot of those things are far more important than knowing how many hydrogen will be on the terminal end of a carbon, you know, carbohydrate or something. A lot of facts, yet facts where they apply to keeping them healthy and safe too. With the human biology, you know, them knowing what diseases are out there, how to protect themselves, the importance of immunization (Interview, 6/28/1994).

Therefore, knowledge is important; however, it has to have some personal implications on students' lives. This partially explains why *Judy* was consistently scored high by her students on the personal relevance scale of CLES.

When we asked *Judy* directly what some of the things that she values about science are, her answer was coherent with what we have already seen: "It would have to do with health and technology. I'm really in biology. Things that it is done for, how science is applied to better people's health and the technology. And again, my bias is toward human biology. So I really think a lot in terms of medicine and disease..." In this quotation, there is the emergence of the technology component which was also pointed out early in the

interview when *Judy* answered the question on what she decides to teach or not to teach in a school year: "A lot of it I go by what is current and important. Biotechnology...They [students] are going to have to make far more decisions with genetic testing and things like that than we ever did." Therefore, biotechnology (e.g. genetic engineering, medicine) are clear concerns of *Judy* as well as their connection with students' health.

In her second year of teaching, *Judy* also shows high concern for relevance and applications. The first question on the TPPI interview of the second year of teaching was how she describes herself as a teacher: "I feel that the subject I teach is relevant and important to all the students" (3/28/1995), which is the belief of almost all teachers, I think. However, in contrast to several teachers *Judy* is trying to connect her subject(s) with students' interests.

In answering how she decides what to teach or not to teach, this year she responded:

> I look at what units have been taught in the past in the subject in high school...for example in physical science we are doing a unit on alternative energy...There is hardly anything in the textbook...so a lot of it I go by what is current in society or...in a current area of research. In biology...we hit DNA really, really because of the O.J. Simpson trial. So, I think any time that there is something outside the classroom that might help interest the students and show the relevance of it, I think it is important to seize that opportunity (ibid.)

This second year, *Judy* was also teaching physical science. Here her approach of teaching science seems to differ in relation to her teaching of biology. In physics, she seems to be more conservative. I mean, it is not clear to me the kind of relevance that she is presenting because in her physical science classes she uses a quite different approach. It would be clearer if we listen to what she says is important to her students: "In physical science, they need to understand what measurement is about, things like density, and math..." (Interview 3/28/1995). This is reinforced by an interview in her third year of teaching. In answering how she decides to move from one concept to another, *Judy* reports:

> Say we do Newton's first law lab with cars and collisions and all that. After they work a few problems and answer some questions, you see degrees of what they have

> obtained from it...After we have covered some content, usually through lecturing or reading, hands-on, there is some follow up...We look at a textbook and we draw out some critical chapter [because] we do not cover an entire textbook in the year of physical science (Interview 4/20/1996).

This seems to be a different approach than her biology class. Although class observations in a unit on fluids (Tape 101-2) showed that she tried to connect as much as possible the topic of forces, pressure and fluids with students everyday life experiences, observations in biology showed that in this subject, her classes are more relevant regarding to student's questions and discussions. Therefore, the subject matter seems to make a difference in the relevance that *Judy* can or cannot accomplish with her students. It seems to me that biology is more relevant to students' everyday lives than traditional physics classes. However I cannot make any final claim regarding the role of the specific subject-matter and personal relevance. In addition, the Salish questionnaire used to measure personal relevance, CLES, does not discriminate the specific subject-matter that was taught. Salish data on CLES only provides a general average score of personal relevance without having information on the role of the specific subject-matter (see chapter 1).

The third year of classes shows an evolution of *Judy*'s pedagogical thinking. In answering a question about her philosophy of teaching she seems to be more concerned about all students: "You need to look at a body of knowledge within a subject area and figure out what is going to be useful for the majority of the students" (Interview 4/20/1996). This is coherent with the following answer on the question about what she decides to teach or not teach:

> For example, I spent more time on genetic engineering than I did on some of the older like Hardy Wineberg rules of gene pools and all that. Because I think they [students] need to know what scientists are really doing and what's going on in the field because they are going to need to narrow down their career choices...I look a combination of what some of the college-bound students will encounter in physics and chemistry that they really need to be prepared for and what is relevant. There is a lot of content that is relevant...(ibid.).

The case of *Judy* can illuminate part of the problem of teaching relevant science to students lives. According to Salish reports (e.g. video analysis observations, information

of teachers' academic background, etc.), *Judy* has a solid subject-matter knowledge. She holds a degree in biology. In addition, the subject-matter knowledge that she reports during our research goes beyond traditional biology subject-matter knowledge. She is helping students to see the relevance of science by moving her knowledge beyond the science territory and traveling to areas less explored, such as biotechnology (testing using DNA, genetic engineering, health, etc.)

The introduction of this kind of knowledge is nothing new. In a study of biology teachers, Zesaguli (1994) reported these kinds of approaches in the teaching of science of some of the teachers of her research sample (see Lock, 1996 for a survey on the implications of teaching genetic engineering in middle school). The topics covered in these classes were -along traditional topics of biology, such as DNA, cellular biology; etc., -the following: " 'Drug and Alcohol Abuse', 'Genetic Engineering,' and 'Applied Genetics,'...[and]... 'Biological society' and 'Biological Seminars' (1994, p.343). Although Zesaguli did not report what the specific knowledge that teachers needed to know for dealing with these generic topics is, she points out that: "The students were not enacting the role of knowledge consumers. Instead they were provided with an opportunity in which they made use of knowledge that they learned and also to reflect critically on their espoused view..." (ibid.).

The topics reported by Zesaguli are illustrations to support that *Judy*'s approach is not new as one can see by reviewing the literature (Lock, 1996, Kille, 1985, Johnsen, 1985). What is new is the explicit clarification of the role of technological knowledge in these approaches, that is, biotechnology, applied genetics, genetic engineering, etc. This clarification is important given the potential relation between relevance and technological knowledge.

Note that I am not arguing that technological knowledge is producing high personal relevance in students' perception of science nor the inclusion of "current" issues (social problems as part of the subject-matter). The problem is much more complex than that. I am

pointing out *Judy*'s epistemological and pedagogical positions toward knowledge. For example, *Judy*'s relevance seems to be supported by her experience in several mundane works and her preparation on science and science education. She worked as a medical technologist and then with health care, computers, florist, etc. as she explains:

> I think having done several different types of work has given me a good background. I have worked in business, in hospitals, with computers. I have a real varied background. In fact, towards the end of the year, one student told me he did not really believe that I had every job that I described. When we talked about plants, I talked about working in a florist shop and he goes, no, you did not work in a florist shop. You told us you worked in a glass factory once and you told us you worked with computers once. How many things have you done? But I think it helps, because you are always fishing for any example or an illustration... (Interview, 6/28/1994)

In addition, she reports a clear concern on biotechnology (e.g. genetic engineering). This is partially supported by external conditions such as the connection between science and technology within professional communities: "Biotechnology is an interesting case in point because the boundaries between science and technology appear particularly indistinct in this field" (Faulkner 1994, p.439).

In the case of *Judy*, one could speculate that external situations provided conditions for meaningful discussions such as the O.J. Simpson trial in 1994 and 1995 - the first two years of *Judy*'s teaching. This trial could introduce an authentic context for discussions on DNA testing, evidence, instrumentation, technology, etc. The creation of such contexts is a critical problem in education (Lave & Wenger, 1991). David Susuki, for example, sees the relevance of science education from this perspective, that is, the creation of meaningful contexts according to students' lives:

> Science education in high school should be designed around sex and human biology...By starting their instruction with human sexuality and reproduction, teachers will be able to go on to practically every other subject in science" (1989, p.213).

One can speculate that *Judy* is approaching problems that keep the interest of students. Although she did not report human sexuality as part of the content, in her human

biology classes, and in general in all her classes that we had access to, she found ways to help students to see the relevance of science. What is interesting of the case of *Judy*, for my argument, is that *Judy*'s knowledge seems to differ from the model that I presented in the last chapter because of the emergence of other kinds of knowledge such as mundane experiences and technological knowledge. How does it differ? This is a matter of the following section.

Demands of science teacher knowledge in the context of applications

I assume that science teacher knowledge can be represented by the minimal model I suggested in the second chapter, that is, subject-matter knowledge, (SK), pedagogical content knowledge (PCK), and knowledge about knowledge (KK). Remember that in this model, subject-matter knowledge has two generic components: substantive (SKs) and procedural (SKp). The same holds for pedagogical content knowledge, yet there is not a one-to-one relation between SKs and PCKs nor between SKp and PCKp (See Table 4 Chapter 3 for a summary). The relationship between SK and PCK depends on the kind of teaching (orientation). Now I study the demands of knowledge that applications (in general) place on science teacher knowledge. In doing so, I present a first extension of my original model. I begin with an illustration of the three generic components of my model in light of *Judy*'s case. For the purposes of this illustration, I do not get into details of the original model (for details see chapter 3). Rather, I prefer to illustrate the extension of the model.

Subject-matter knowledge. Subject-matter knowledge includes what *Judy* calls the basic, that is, scientific knowledge (SK) of natural phenomena (e.g., basic biology: cell, viruses, bacteria; basic biochemistry: carbohydrate, protein, lipid; basic physics: density, Newton's laws; basic mathematics: arithmetic, measurement, graphics, etc.). I conceptualized science subject-matter knowledge as a part of the transformation from expert scientific knowledge to science school knowledge. SK includes theories, laws of nature, theoretical tools,

substantive and procedural knowledge. At this level the goal of SK is understanding (describing, explaining, predicting). As I said, *Judy* calls this knowledge "basic".

> Interviewer: In general, what science concepts do you believe are most important for your students?
>
> *Judy*: It depends on the subject...In biology they get an idea of some basic bio-chemistry, metabolic process, genetics, DNA. In physical science the big things we hit usually are basics...some main things like math. There might be two or three in each unit that we hit heavy like the unit on forces, Newton's first and second law. We have just done simple machines. We just want them to get an idea of efficiency and work and what might be some of the goals of people designing machines... (3/20/1996)

This comment has two important parts. The first part stresses the basic nature of SK (particularly substantive SK). The second goes beyond the knowledge of natural phenomena. Here, *Judy* introduces the goals of *efficiency, design, and transformation.* During the three years of Salish data available from *Judy*'s teaching one sees that she presented several examples of this kind of goal in the context of biology, particularly biotechnology (including genetic engineering). I will call this knowledge technological knowledge (TK).

In the case of *Judy,* TK mainly seems to refer to knowledge of biotechnology. There are several definitions of biotechnology. For example, R. Kille suggests that biotechnology is the

> ...application of biological organism, systems and processes to manufacturing and service industries. In particular it is the expansion of use of microbial and other cell, together with the demands these new manufacturing processes will place upon close relation and understanding between biologists, chemists and engineers (1985, p.67)

Although this definition tends to connect biotechnology with industry more than what one can (should) do in general education, there is also a clarification on the role of biology, chemistry and engineering. These areas are unconnected and mainly missed in traditional science teachers subject-matter knowledge.

The potential use of technological knowledge also appeared in some of *Dave*'s classes, particularly during the task of designing a bridge. This task requires knowledge of materials for the construction of a bridge, that is, proprieties of materials (natural or artificial). It also requires knowledge about stability of structures (e.g., triangles for forming bridges), fatigue of materials, and knowledge of how to construct a structure (procedural technological knowledge). Therefore, technological knowledge also comes in two forms: substantive and procedural. As we will see in a later chapter, procedural knowledge in technology is much more complex than in science. This explains the difficulties of using technology in teaching science. Moreover, the very existence of technological knowledge is, by it own right, problematic and it is a matter of discussion of a specific chapter of this dissertation. For now, it is enough to illustrate the general characteristics of this knowledge rather than doing a detailed epistemological surgery of technological knowledge.

Pedagogical Content Knowledge.

There is a qualitative difference between *Dave*'s knowledge and *Judy*'s. *Judy* has integrated several mundane experiences and has also developed a level of awareness about the role of technology in society (e.g. genetic engineering). *Dave*, in contrast, intends to present the relevance of science anchored in traditional scientific knowledge: "...the next unit is motion, forces and energy...and this is an excellent one for real-world applications. How fast can you run? How much power can you generate? (Interview, 4/22/97). In contrast, *Judy* was always aware of the potential uses of important problems from the perspective of students and the uses of areas of applied biology (e.g. genetic engineering). Therefore, one can conclude that *Judy* has developed pedagogical content knowledge which is richer than *Dave*'s in the context of applications, mainly application types 3, 4 and to some extent 5 (see Table 4.3).

In relation to *Dave*, *Judy* has integrated (rather than added) her knowledge using applications in more efficient ways. This would be related to the construction of her pedagogical content knowledge which went beyond canonical knowledge. Although both *Dave* and *Judy* were concerned with including applications as part of their science teaching, the very notion of applications differs in both cases. This implies that the notion of relevance differs, too. In addition, and more important for my argument, *Dave*'s students did not perceive the relevance of science in the same way than *Judy*'s. Although I can not present any final claim regarding the reasons of that, I suggest some conjectures. One potential reason would be that *Dave*'s subject-matter knowledge is connected to traditional science (describing, explaining, predicting in the context of applications type 1 of Table 3). *Judy*, in contrast, has a more integrated subject-matter knowledge which allows her to include several mundane experiences in her pedagogical content knowledge. What is important to note is that the kind of pedagogical content knowledge that *Judy* holds is quite different than *Dave*'s mainly in the case of applications.

The kind of pedagogical content knowledge that applications of knowledge requires depends on the conception of the application that one is talking about. Science teachers and science education researchers have studied and developed applications of science in the sense of describing, explaining, and predicting natural phenomena (applications type 1 according to Table 4.3). For this kind of application, there is a body of knowledge that suggests analogies, representations, and examples that teachers use (or should use) in order to teach science (e.g., all of the research on misconceptions, theories such as diSessa's work). A movement from understanding (internal relevance) to external relevance, that is, applications to a) real-world problems (type 3), b) personal relevance (type 4) and c) design of artifacts (type 5) will change important aspects of teachers' knowledge in general and pedagogical content knowledge as well. Needless to say, these applications produce or affect what is traditionally considered subject-matter knowledge. The case of *Judy* illustrates how her subject-matter knowledge also includes knowledge of applied science

and biotechnology which at the end allowed her, I suspect, to develop a different pedagogical content knowledge than *Dave*'s.

From a theoretical perspective it is important to know whether or not the construct pedagogical content knowledge changes with the introduction of applications. It is obvious that it changes, but how does it change? What is the kind of knowledge that allows teachers to construct pedagogical content knowledge for applications types 3, 4 and 5? We know, for example, that applications are already part of pedagogical knowledge of science teachers. Applications have been means and ends. That is, applications have been essential for meaningful uses of science and also are means for presenting the importance of science. What is new and needed is the explicit clarification of the knowledge for applications and mainly applications which go beyond the discipline (types 3, 4, 5). In fact, I argue that knowledge for applications (e.g., knowledge for solving real-world problems or technological knowledge) produces changes in our conception of pedagogical content knowledge.

Researchers have reported that there is a relation between pedagogical content knowledge and the kinds of problems that science teachers are incorporating in their classes (Magnusson, et al. 1994). Moreover, there is a relation between teachers' pedagogical content knowledge and students' content knowledge (Magnusson, 1992). However, the changes that real-world problems, personal relevance goals, and mainly the inclusion of technology introduces in pedagogical content knowledge have not been explored.

If one buys Shulman's notion of pedagogical content knowledge (analogies, representations, illustrations), substantive pedagogical content knowledge for this kind of teaching is also related to canonical representations which include, I suggest, "... the notations for algebra and calculus, the Cartesian coordinate system with its numerous applications, various kinds of diagramming, such as free body diagram in physics, and so on" (Perkins and Unfer, 1994, p.9). In chapter 3, I discussed the nature of pedagogical content knowledge in the context of my framework and its relation with the literature. In this

context, representations, analogies, examples, etc. are an important part of pedagogical content knowledge. However, the connection of this kind of pedagogical content knowledge in the context of applications beyond the discipline, such as to everyday life, is problematic.

If one accepts *Judy*'s case as an example, teachers would need to have more mundane experiences and more opportunities to use science in meaningful ways. Although *Judy*, for example, did not work from the perspective of students' everyday lives problems, she did set a meaningful context for discussions. In this context, students perceived the relevance that *Judy* was presenting, One would say that she invited her students to connect their everyday lives with canonical knowledge and applied experiences. She did that by constructing a context for the discussion. This is clearer if one reads what she answered regarding a question on how she assesses learning in her class:

> You go by the questions...assessing their [students'] discussions, how well they can discuss, what they do when you throw out a question, what kind of response you get. You can show them a real current video or something that gets into an application or the idea or something. I showed them a video of some genetic engineering and only part of the video and then had them write their opinion (6/28/1994).

Note that this quotation reflects procedural pedagogical knowledge. In this case, *Judy*'s procedural pedagogical content knowledge which together with her substantive knowledge allowed her to construct meaningful scenarios for her students.

In the case of *Judy*, one sees that her pedagogical content knowledge seems to be integrated in light of both: canonical knowledge and mundane experiences. From a canonical point of view, she reflects a common pattern of the Salish Science teachers that were perceived relevant, that is, these teachers framed what is relevant for students. The way in which such a process takes place is usually by word problems or setting context for discussions, as in the above example. Even in the case of laboratory work, word

problems, that is, verbal presentations of difficulties, were the core of the instruction. Within this mix of canonical versions of word problems and mundane experiences *Judy* seems to have called the attention of her students to the use of science in everyday life.

Taking into account the above discussion one can see that pedagogical content knowledge for teaching science tends to be connected to the capacity of teachers to present *word problems* rather than *world problems,* particularly real-world problems. There are, perhaps, differences in the kind of knowledge that both approaches require. Word problems tend to have their roots in disciplinary traditions. Real-world problems are elusive problems that depend on the interest of individuals. Moreover, the knowledge that teachers need to know for helping students to face real-world problems will depend on the kind of real-world interest that students have. Despite these limitations, one can explore a distinction between word problems and real-world problems in the construction of pedagogical content knowledge.

My general position is that in constructing pedagogical content knowledge for real-world problems, teachers need to be aware of the advantages and limitations of using canonical knowledge to solve ill-structured problems. Teachers need to learn how to approach the complexities of real-world events. That is, the question is how to help students to solve problems beyond traditional disciplinary boundaries. For example, teachers will need to be ready to accept students' problems as an important part of their teaching.

Using the Salish Research as a general referent, I can say that science teachers seem to assume that problems already exist and they [the problems] are looking for "solvers," "[but] with this emphasis on problem solving, we ignore problem *setting*, the process by which we define the decision to be made, the ends to be achieved, the means which may be chosen. In real-world practice, problems do not present themselves to practitioners as given". (Schön, 1983, p. 40). Therefore, problems, if they are so, should be invented and delimited by their creators. Teachers need to know how to help students to invent, frame,

and face their own problems. This is not the case of *Dave* and only appears sporadically in *Judy*'s classes. One of the reasons, I argue, is that school science is framed in terms of word problems rather than real-world problems. A second problem, I argue, is that we still do not know what kind of science people need to know in everyday life.

The case of *Dave* and *Judy* reflect what seems to be a common practice in teaching science: solving word problems. Applications of science from this perspective tend to be conversations about what is relevant from the perspective of disciplines. Yet, there are cases of teaching science in which students moves from teachers' explanations to their own explanations. Even here, the notion of application is still in the sense of word problems or disciplinary problems. However, if one wants to move to more relevant science teaching, such as meaningful uses of science in everyday life, I think we need to re-examine the knowledge behind these real-world applications (types 3,4,5). My suggestion is that technological knowledge can play a middle ground role, that is, a conceptual bridge between canonical knowledge and real-world applications.

When one thinks of technological knowledge as a means for doing real-world applications, the very meaning of science teacher knowledge, in general, and pedagogical content knowledge, in particular, should be analyzed further. One way of doing that is by using research on students conceptions of technological tasks. For example, I showed in the last section that Leona Schauble and her colleagues have studied how children approach engineering tasks in relation to scientific tasks. Based on this kind of research and other such research on engineering design (e.g., Bucciarelli, 1994) or epistemology of engineering (e.g., Vicenti, 1990), one can show how the introduction of technological tasks would require the construction of a different pedagogical content knowledge, that is, different representations, different analogies and quite different subject-matter. The task is to connect that with teaching science. This moves my discussion to the last component of the extension of the model of science teacher knowledge, that is, knowledge about knowledge.

Knowledge about knowledge (KK).

Traditional science teacher knowledge has had for referent scientific knowledge in contrast to other kinds of knowledge (e.g., practical knowledge). In relation to the model presented in the second chapter, the big difference here is the introduction of more mundane knowledges. For more mundane knowledges, I refer to a) the knowledge needed to solve real-world problems as opposed to "academic" problems, b) the knowledge related to relevance of science in everyday life, and c) the knowledge needed to deal with technological tasks (e.g., the design of artifacts). These three generic "applications" of science also carry different epistemologies, methodologies, and ontologies. In other words, applications of science beyond scientific knowledge requires a re-examination of new epistemological territories, methodological rules and ontological worlds.

My concern is with technological knowledge. Although the other applications are important, I tend to think that technology can provide conditions to use science to solve real-world problems, to increase the relevance of science in everyday life and to use science in specific and concrete conditions (e.g., by designing artifacts). The introduction of technological knowledge will require a reconceptualization of the nature of science which takes into account the nature of technology. From an epistemological point of view, I expect important differences given the positions that science and technology have toward the world. However, from a methodological point of view, it is possible that both nature of science and nature of technology will be similar. Being aware of the similarities and differences between science and technology, and its potential use for teaching science, is part of this extension of my model of science teacher knowledge, particularly its component KK.

This component of science teacher knowledge, KK (knowledge about knowledge), is intrinsically related to our beliefs of what counts for knowledge, that is, the criteria of validation of knowledge that teachers translate to schools. For example, science education

has stressed a conception of knowledge based on universality :"Science also assumes that the universe, as its name implies- a vast single system in which the basic rules are everywhere the same" (AAAS, 1990, p.2). The basic rules of the universe are a basic referent of science education. More examples of this perspective can be found in the previous chapter, chapter 3, in which I studied some assumption of Project 2061 regarding the knowledge-of-knowledge component (see also Cajas, 1995a). However, other goals of science education, for example, everyday life applications of science regarding students' interest, move the attention to more local and mundane phenomena. Technological knowledge, for example, tends to be more local rather than universal. Therefore, knowledge about practical knowledge would differ from knowledge about universal knowledge. Being aware of this distinction is partially what I mean by this component of science teacher knowledge.

Extension of a theoretical model for science teacher knowledge

I have discussed some implications that the introduction of applications would produce on science teacher knowledge. I began with a clarification of the multiple meanings of the terms understanding and applications that I used in the first three chapters. After that, I explored some characteristics of a Salish teacher whose students perceived science relevant to their lives. This teacher, *Judy*, is representative of a group of Salish teachers who were perceived highly relevant according to their students' rate on the Constructivists Learning Environment Survey (CLES). Using the case study of *Judy*, I explored her knowledge, beliefs and actions using the tools of my preliminary model of science teacher knowledge. I reported some changes on the connotation of some elements of my original science teacher knowledge model which allowed me to illustrate a potential extension of my first model. The following figure illustrates such changes:

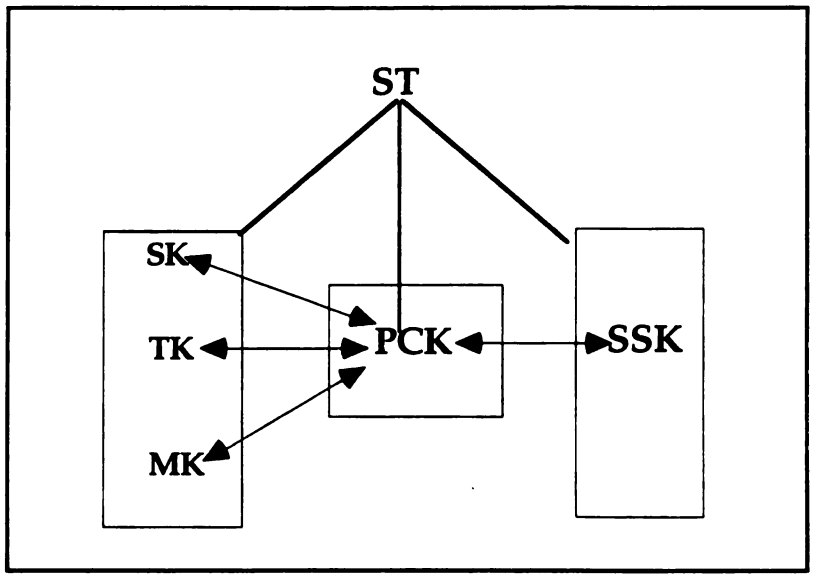


Figure 4.2 An extension of the science teacher model in which SK is the traditional subject-matter knowledge, TK is technological knowledge and MK represents other mundane knowledge.

In principle, subject-matter knowledge in the context of applications goes beyond traditional specific disciplines. Think of the case of *Judy* in her biology class. When she teaches biology, there is an integration of canonical and mundane knowledge (SK and MK according to Figure 4.2). Yes, *Judy* teaches biology; however, the relevance of biology is not limited to biology itself (internal relevance). Biology is one part of her knowledge. There is evidence that she consistently includes important applications of biology regarding students' lives (health, food production and consumption, etc.). In addition, biotechnology plays an important role of her teaching (e.g., genetic engineering). Therefore, the case of *Judy* illustrates one option in which students saw science relevant to their lives.

Subject-matter knowledge in the case of *Judy* is a mix of SK (defined in the last chapter) with TK (technological knowledge) with other mundane knowledge MK (knowledge of how to use biology in a florist shop). Therefore, subject-matter knowledge, SK, can be represented by **<SK, TK, MK>** as it is illustrated in Figure 2.

Pedagogical content knowledge for applications seems to includes a new set of demands. The case of *Judy* also helps to illuminate potential scenarios. One important factor is the creation of contexts in which students can use science in meaningful ways. In an earlier chapter I pointed out that research in science education has developed knowledge on how students learn. This knowledge would be used to develop both substantive and procedural pedagogical content knowledge. The case of misconceptions (naive conceptions) of science was an important part of that. The importance of this research should be analyzed further in light of the relevance of this knowledge to develop pedagogical content knowledge for applications to: a) real world problems, b) everyday life or c) design of artifacts. From the case of *Judy*, and also from my general discussion, one can expect that pedagogical content knowledge for applications (types 3, 4 and 5) differs from PCK from understanding (e.g., types 1 or 2). Therefore, the demands of knowledge that applications introduce in science teacher knowledge should be reconsidered.

Knowledge about knowledge in the context of my framework should open possibilities for other kinds of epistemologies, methodologies and ontologies that can help us to teach science in meaningful ways. As I have pointed out, technological knowledge has some potentialities for being used in teaching science because it can provide opportunities to a) work with real-world problems, b) increase the relevance of science, and c) connect science with society as a whole. Of course, science teacher knowledge would need to change. In order to describe and explain these changes I propose to study in depth the role of technology in science education.

Technology has been introduced as part of the leading science education reform proposals, Project 2061 and the National Science Education Standards. However, its role in teaching science is still unclear. One of the first reasons is that the very notion of technology advanced in Project 2061 and the National Standards needs to be unpacked. In fact, the relationship between scientific and technological knowledge in the context of general education needs to be clarified. This is one goal of this dissertation. A second

reason for unpacking this relationship is the complexity of the social scenario, particularly the social status of technology as subject matter (Lewis, 1993). Both problems, the meaning of the term technology in the context of science education reforms and the potentiality of being used as a bridge between understanding and applications in teaching science are the core of this dissertation.

In the following chapter, I approach the first of these problems, that is, I clarify the meaning of the term technology and technology education. I re-study the notion of teaching science for applications in light of the potential use of technological knowledge. I also clarify the very notion of technological knowledge and how it is (or would be) related to scientific knowledge in the context of teaching science in K-12 education. The goal of this discussion is to explore the role that technology would play in connecting understanding with applications in the sense of connecting internal with external relevance in teaching science. I am particularly interested in what knowledge science teachers need to know in order to connect both domains of teaching science, understanding and applications.

CHAPTER 5

A FRAMEWORK FOR TECHNOLOGY: INTRODUCING TECHNOLOGY INTO THE SCIENCE CURRICULUM

During the first four chapters, I have insinuated that technology should have a place in general education. I have proposed that technological knowledge can and should be part of science teacher knowledge. One of the reasons for that is the potential that technology has to provide meaningful contexts for teaching and learning science. Particularly, technology can be seen as a domain of practical applications of science. Therefore, technology would reduce the tension between understanding and applications that I have pointed out.

One of the first problems in suggesting technology as a bridge between understanding and applications is the general conception of technology in society at large and academic in circles. In fact, the term technology is mainly used for referring to artifacts, computers for example. This connotation limits the epistemological richness that technology, as a way of thinking, would provide to teaching science. Consequently, the first step in suggesting technology as part of the science curriculum is to clarify the concept of technology and its connection with science. In this chapter, I offer a clarification of the term technology in light of current and relevant work in philosophy of technology.

A second problem in suggesting the use of technological knowledge for teaching science for application and understanding is its connection, or potential connection, with traditional science curriculum. Therefore, a second step is to identify some of the technological knowledge, i.e., the specific technological theories, that have potential for being used in school curriculum. In this chapter, I explore this possibility. In doing so, I first develop a framework for technology based on a general discussion of the meanings of the term *technology*. I offer a framework for analyzing technology as artifact, knowledge and social practice. This framework provides analytical tools for studying different

conceptions of technology and their implications in science education. I illustrate my argument using examples from the topic of energy.

The term technology.

We all seem to agree that we live in an era dominated by technology. However, there is least agreement on the meaning of the term technology. As the *Benchmarks for Science Literacy of Project 2061* acknowledges: "***Technology*** is an overworked term. It once meant knowing how to do things -the practical arts or the study of the practical arts. But it has also come to mean innovations such as pencils, televisions...or manufacturing..." (AAAS, 1993, p.43). In fact, the term technology is used with several meanings. One of the most common meanings of the term is related to the idea of artifact, that is, the object (usually seen as material) which can perform an activity. Within educational circles when one talks about technology, people immediately think of computers and their applications in classrooms. Moreover, given the revolution of the electronic communication era people do not see problems in identifying technology with CD-ROM, Internet, etc. This extentionalist conception of technology is also found in society at large. Common citizens tend to think that the television, car, highway, factory, or the atomic bomb are technologies. To some extent, this is one meaning of the term technology. However, it is necessary to clarify what people mean when they say that the computer or the television, for example, are technologies. And more important, it is necessary to clarify why one should care about this meaning of the term technology.

Technology as artifact

From a general perspective there are, at least, two ways for identifying technology with artifacts. In either way, what is interesting is the object, that is, the artifact that can solve a problem or perform an activity. The first identification comes from the perspective of the general public, the common user of the artifact (technology). From this perspective,

the internal way in which a given artifact (technology) works does not seem to be important. Think of the computer. When one person is working on a computer, what usually matters is the things that the computer can or cannot do. We can call this perspective a kind of "black box" model perspective. Black-box models do not take into account internal mechanisms. They stress inputs and to a greater degree outputs.

The lack of interest in the internal mechanism of the artifact is justified for practical reasons. One does not need to know how a car works (internal mechanism of the car) in order to drive it. One needs general ideas about some inputs (gasoline, starting, skills for driving, etc.). The picture is quite different when one is thinking of the design (art) of the artifact (e.g., the car) or about the preparation of technologists (education of designer and constructors of cars). In this context, technology as artifact has an important place. Traditional engineering education has stressed the study of artifacts as part of the preparation of their students. For example, the mechanical dissection of a structure (examples: a bridge, an engine of internal combustion, etc.) is a pedagogical strategy for teaching the function of each part of the artifact (the bridge or the engine). This is a widely used pedagogical technique for teaching engineering. In this case, it is assumed that the study of the artifact will provide knowledge of the form in which the artifact works. This is also a first attempt to open the black-box model of technology as artifact.

Focusing on the artifact is a methodological strategy for understanding technology. The concept of artifact that I use has a general philosophical base on the works of Mario Bunge to whom artifacts are "...anything optional made or done with the help of learned knowledge utilizable by others" (1985, p.222). The ontological status of artifacts depends of the kind of creation. They could be material or conceptual. The most common meaning of the term artifact is its material connotation such as the computer (its monitor, mouse, keyboard, i.e., the hardware). However, the computer is not a computer without some conceptual features (e.g., the software that I'm using: *Microsoft Word*). In addition, the concept of artifact that I endorse (Bunge, 1985) includes social artifacts (*artifacts states*), for

example, the internet (that is, a network of computers users made by intentional human actions or a plan for increasing the level of literacy of a given country).

The ontology of artifact raises important questions. What I present is a distinction between artificial and natural objects. This is a distinction between the mouse that I am using to control the computer and my hand. The former is the product of an intentional action, a design which included a blueprint, specifications, negotiations (Turckle, & Paper, 1990; Buciarelli, 1994). The latter, my hand, is not the outcome of a specific intentional human action nor a blueprint. The separation should not be seen in the sense that artifact are part of an unnatural world (either Platonic, magic, or Popperian World 3). What I want to point out is that both, the computer and my hand have different ontological histories. Such history, the connection between nature and artifice, is the very history of technology which dramatically changed with the creation of new products (e.g., organic products developed by chemists), control of energy (invention of the steam engine, electrical motor), invention of new materials (e.g., steel) and control of time (popularization of mechanical clocks).[1]

[1]Historians identify the 17th century as the beginning of the scientific revolution and later (18th and 19th) the industrial revolution. The connection between both revolutions is complex. For example, according to D. Cardwell, "Indisputably, in popular opinion and in economic fact, the single most important technological agent over the greater part of the nineteenth century was the ever-triumphant steam engine" (1995, p.306). The creation and improvement of the steam engine is related to the names of Joule, Carnot, Clausius, etc. (17th century). However, a new historical report shows that Papin already had a proposal of a steam engine 100 years earlier. Philip Valenti recently developed a case study of sabotage by the Britsh Royal Society which delayed the steam power 100 years (Valenti, 1997). At any rate, the steam engine is the symbol of the industrial revolution. However, it is hard to deny the importance of other technological advances such as the mechanical clock and mainly its popularization which has had an incredible impact on society, perhaps deeper than the steam engine. Just think of the omnipresence of the clock in our life and how society became structured in relation to time. However, the steam engine and the clock are not alone. I am sure that a chemist would develop an argument to support that the industrial production of sulfuric acid was the most important technological agent for the scientific and industrial revolution. Therefore, there are no simple factors to explain the industrial revolution.

Technology as knowledge

Opening the black-box model of technology, that is, an artifact that perform activities, leads us to see a second meaning: Technology as knowledge. The explanation of how a given artifact actually works requires a specific knowledge. Moreover, the *design* of the technological artifacts supposes the existence of a specific knowledge. Design, in the framework that I use, is a previous representation of a thing or process. Particularly, technological design is a representation of an artifact with the help of scientific knowledge (Bunge, 1985). The nature of this knowledge has been a matter of long debate and is related to the way in which people have seen the connection between science and technology. The range of interpretations varies from one that indicates there is no such thing called technological knowledge to another extreme position, which indicates that there is a body of knowledge independent from science, technological knowledge.

Early conceptions on the relationship between science and technology tended to see a hierarchical relationship between science and technology in which technology was subordinated to science (see Barnes, 1982 for an account). Another saw a cause-effect relationship between science and technology. From this perspective, technology is an outcome of science. These linear models also made a clear distinction between science and technology. Science provides the knowledge and technology the artifact. The model, which seems to have positivistic roots, is still used. Think of traditional curriculum in technological fields (e.g., engineering, medicine). The way in which future technologists (e.g., engineers or medical doctors) are generally prepared is the following. Students first take science classes with the assumption that such classes can be applied to specific technological problems (e.g., engineering problems, medical problems). The justification of taking science classes (physics, for example, in the case of engineers or physiology in the case of medicine), is that these classes are the bases of their future professional work (this

justification is used within engineering colleges, but it also appears in medical schools and several professional careers).

The idea that scientific knowledge is the basic knowledge and its applications are what make the technology has been challenged. Studies of how technologists actually work have shown that technologists (e.g., engineers) do not go to the real world with their general scientific theories and solve practical problems by applying them (Buciarelli, 1988, 1994; Simon, 1969; Schön, 1983, 1987). Donald Schön (1983), for example, has shown that in fact technologists, "practitioners," develop contingent theories at the level of their actions. Any experienced technologist knows that the relationship between science and her/his own work is more complex than a simple application of basic science. And several technologists complain about the lack of applications they see between their basic science courses and their professional career as H. Simon recognizes: "Engineering schools have become schools of physics and mathematics; medical schools have become schools of biological science" (1977, p.56)

[One more example comes from teaching. There was/is the assumption that you can teach how to teach by teaching general theories of learning . There are programs in which future teachers learn general theories of learning (e.g., Ausubel's theory) with the purposes of learning how to teach. The assumption is that one can learn basic science (psychology) and then apply that to specific conditions (practice of teaching). However, nobody uses such general theories of learning in specific classrooms situations, not even the same teachers that are teaching such general laws (Edward L. Smith, personal communication, July 1997). The contexts of real classrooms are too complex for being captured for such theories (Schön, 1987). These general theories are -usually, if not always- unpractical. The nature of the connection between these general theories of learning and the practical needs of teaching is in the core of what I call technological knowledge (Cajas, 1993a, 1993b)].

In challenging the linear model of technology as a simple application of science, Edwin Layton advanced an influential discussion in which he suggested the existence of specific technological knowledge. Such knowledge is quite independent of science, yet somewhat related to it. Working from a historical perspective, Layton showed that the relationship between science and technology is more complex than the linear model, that is, the cause-effect model. What Layton suggested is a kind of two-way model in which there is the emergence of a specific technological knowledge as part of the practice: "We might restate the matter by noting that laws of science refer to nature and the rules of technology refer to human artifice" (Layton, 1974, p.40). The human artifice seems to be the referents of technological knowledge. Unfortunately, E. Layton did not present in his paper examples of what he called "rules of technology", that is, technological knowledge. However, the importance of Layton's paper is that it opened a fruitful discussion on the very existence of technological knowledge. I do not discuss here the debate (see, for example, *Technology and Culture* Vol. 29, No.1). What is important for this general introduction is the possibility of having a meaning of technology that is related to knowledge.

The philosopher Mario Bunge provided a specific definition of technology in line with Layton's conception. According to Bunge: "A body of knowledge is a technology if and only if: (i) it is compatible with science and controllable by the scientific methods, and; (ii) it can be employed to control, transform or create things or processes, natural or social, to some practical and deemed to be valuable" (1976, p.154). The first criterion assumes a relationship between science and technology. Bunge asks for compatibility with science. From this perspective the knowledge which was used in *designing* and producing the chair in which I am sitting now would be technological only if it is coherent with science. This definition is useful in the sense that it makes a distinction between technique and technology. A carpenter, for example, could create this chair without taking into account any scientific canonical knowledge. In this context, the knowledge that the carpenter has, technique, only satisfies the second of Bunge's criteria, that is, it is being used to create a

thing (chair). Artisans and technicians would produce technological artifacts only if they use canonical scientific knowledge in the design or construction of the artifacts. This is a problematic distinction because, in principle, it will depend on one's conception of science. If one thinks that science is a body of knowledge which is expressed in the form of canonical theories, e.g., Newton's laws, a carpenter hardly uses this canonical knowledge and consequently she/he does not produce technological artifacts. However, do we know, for example, what is the kind of geometrical knowledge that carpenters use in the design of chairs? I think that we do not even know what the role of creativity is in the work of carpenters in designing chairs. For some people, creativity is the core of science. Consequently, Bunge's definition is an alternative, but one has to be aware of its limitations.

The basic problem in identifying technology with knowledge is the clarification of the knowledge needed for the design or the solution of practical problems (e.g., design of an artifact). It is difficult to be specific with the knowledge because it is not so universal. There is a huge amount of tacit knowledge in the process, too (Polyani, 1958, Sørensen, & Levold, 1992). Although there are people who defend the idea that it is possible to have a universal science of design, the challenges of such a proposal are enormous. In his exquisite book, *the Sciences of the Artificial*, Herbert Simon defends the idea that this universal method is not only possible, but it is also desirable. Despite that, the existence of this kind of universal knowledge has been challenged empirically and theoretically. Regarding this point Bunge says: "Given the large variety of design problems, it is doubtful that a unified science of design, capable of tackling any design problem -as imagined by Simon (1977) could ever be built..." (1985, p.228).

Bunge's critique is not alone. Layton, Barnes, and others have suggested the limitations that a potential universal method of design would have. These limitations seem to be related to the nature of the "technological knowledge." One of the problems of such critiques is that they tend to leave the reader with the idea that although there is something

called technological knowledge, its nature is unknown. It seems to me that the literature available does not help to clarify what technological knowledge is. Yet, one can go to the engineering building and check out the disciplinary autonomy of engineering by taking a look at the specific engineering courses, labs, journals or hand-books. In general, one will find that technological disciplines have their own departments. However, the nature of the knowledge that these departments are teaching is another problem.

In order to clarify one meaning of the term technological knowledge, I invite the reader to take a short epistemological trip. I suggest using the example of engineering, a special kind of technology. The reason for that is double. First, I have more familiarity with this epistemological territory. Having been trained as an engineer and having worked with them for several years, this territory is more familiar to me than other technologies (e.g., medicine). I have also spent time thinking about the role of technology in education (Cajas, 1992, 1993a, 1993b, 1996, 1997a, 1997b). And second, the epistemology of engineering is a pioneer area of research within the emergent philosophy of technology (Bunge, 1985; Herrera, 1989, 1996; Vicenti, 1990).

The trip I propose requires some clarification. I will begin with a typology of technological knowledge given a priori (a map). I draw the map from two kinds of works: research on the knowledge needed for industrial innovations (Faulkner, 1994) and epistemology of engineering (Vicenti, 1991). Although both sources have empirical evidence, I use them as preliminary analytical tools in the sense of the Deweynian connection between map and territory, that is, a tool to order experiences (1902, pp. 197-200). Such typology is a preliminary picture (map) of what I call technological knowledge. As in the case of my study on science teacher knowledge, the clarification of what counts as knowledge is not only a problem of definition (just drawing a map). There should be a relation between knowledge (model) and reality (practice).[2]

[2]Of course I am not building a descriptive model of technological knowledge. I am not analyzing any engineer's actions. At this level I present a map of the epistemological territory of engineering informed by the literature. However, my analysis is enriched for my experience.

Drawing on the demands of knowledge required by industrial innovations Wendy Faulkner has proposed five types of knowledge regarding: 1) the natural world, 2) design practice, 3) experimental R&D, 4) the final product, and 5) knowledge itself (1994, p.449). This is related to the epistemological work developed by Walter Vicenti who, drawing on cases of study of aeronautical engineering between 1900 and 1950 suggests the following characterization: 1)fundamental design concepts; 2) criteria and specification, 3) theoretical tools, 4) quantitative data, 5) practical considerations, 6) design of instruments (1991, p.208). Both typologies overlap. However, one should be aware that they come from different kind of research. Given my interest on the clarification of the meaning of technological knowledge, rather than an extensive report on such typologies, I illustrate my point using few elements of both taxonomies. I particularly use Faulkner's types of the natural world and design practice knowledge which are related to the theoretical tools and fundamental design concepts of Walter Vicenti.

What is considered knowledge of the natural world includes, according to Faulkner, scientific and engineering theories, "laws" of nature, and proprieties of materials (natural and artificial). [This is something that we already explored with the notion of expert scientific knowledge ESK and substantive scientific knowledge SK, see chapter 2.] Now, let us first explore the nature of scientific theories within engineering knowledge. It seems to be obvious that engineering requires some kind of basic science: "Concepts of broadest applicability include basic ideas from science, like force, mass, electric current, and so forth..." (Vicenti, p.217). The question is how do these theories look like in the context of engineering?

Think of the epistemological background of Newton's laws. As scientific laws they are to describe, explain and predict movement of objects (material bodies). All the scientific versions of Newton's second law (F=ma, F=dP/dt) are descriptive. For example, the following well known version of Newton's second laws asserts that: "The net (external unbalanced) force [**F**] acting on a material body is directly proportional to, and in the same

direction as, its acceleration [**a**]" (Holton, 1985, p. 118). An engineer interested in using such law -to design a bridge, for example- would read this descriptive statement with normative lenses such as: "To cause a material body an acceleration **a** exert on it a force **F**" or :"to prevent a body to get an acceleration **a** exert on it a force **F**"(adapted from Bunge, 1985, p. 244). In the hands of the engineer, the descriptive character of the scientific law becomes normative. The scientific law is called either causal-mechanists or descriptive explanation, whereas the other (the engineering version) is a teleological "explanation" (finalistic, using a differentiation suggested by George H, von Wrigth, 1979). My argument is that even scientific knowledge in the hands of engineers (technologists in general) tends to be more teleological, finalistic, normative (utilitarian) rather than descriptive, mechanist.

What engineers use in most of the cases are specific technological theories which refer to specific devices. Vicenti, for example, suggests something like that:

> Farther in the direction of engineering are theories based on scientific principles but motivated by and limited to a technologically important class of phenomena or even specific devices...examples of such essentially engineering theories centered on a class of phenomena are those dealing with fluid mechanics, heat transfer, and solid-body elasticity... (p.214).

Therefore, the notion of "scientific knowledge" within the epistemology of engineering suggests the specific nature of technological knowledge (theories about "specific devices") and the complex relation that this knowledge establishes with scientific knowledge (teleological position rather than causal).

The teleological position that engineers, and in general technologists, have toward the world is exemplified with the relation that they establish with artifacts. Machines, for example, are understood as a special kind of artifact and are defined for what they do rather than for what they are. Using Simon's words: "Artifact things can be characterized in terms of functions, goals, adaptation" (1969, p.8). Moreover, the artifice -the term used by Simon to situate the world of artifacts- brings with itself the emergence of new otolological status which is not explained by natural science (e.g., physics, chemistry, etc.):

> All machines have technological proprieties, such as maneuverability, versatility, and safety, as well as economic proprieties, such as high or low production or operation cost. These proprieties are neither physical nor chemical: they are emergent proprieties resulting from the particular interplay between machine and user. (Bunge, 1985, p.244)

From the perspective of technology as knowledge the connection between scientific knowledge and technological knowledge becomes clearer given the fact that the design and also the explanation of artifact require an emergent knowledge. As Polyani has pointed out several years ago:

> Suppose you are faced with a problematic object and try to explore its nature by a meticulous physical or chemical analysis of all its parts. You may thus obtain a complete physico-chemical map of it. At what point you would you discover that it is a machine (if it is one), and if so, how it operates? Never (1958/1962, p.330).

The reasons for that, according to Polyani, are that: "The complete knowledge of a machine as an object tells us nothing about it as a machine" (ibid. p. 330). In other words, what Polyani says is that scientific explanations of artifacts do not help to understand their technological properties. Although my position is less extreme than Polyani's, I think that his point is valuable. In fact, teleological explanations (finalistic, i.e. one which answers the question: for what?, what are the purposes of this artifact?) does not follow from a scientific explanation ("a complete description"). In order to design a machine, it is important to know for what, that is, the purposes of the machine while in order to explain how an artifact works (causal explanation), one does not need to know what the purposes of the artifact are. The design and eventually the explanation (when it is needed) of artifact require a specific kind of knowledge: technological knowledge. This is related to the second kind of knowledge suggested by Faulkner: knowledge of design practice.

Both Faulkner and Vicenti point out the importance of a specific kind of knowledge to design artifacts. Polyani has stressed the importance of tacit knowledge (procedural) in the process of constructing -interpreting the behaviors of- machines (a special kind of

artifact). However, Polyani did not develop an epistemology of engineering nor an epistemological study of technologies. Recent studies on engineering reflect that procedural knowledge is not always tacit (Shapiro, 1997, Vicenti 1990 partially develops this point). Procedural technological knowledge for the construction of artifacts has its roots in experience, research and failure (Petrostki, 1985) and it has been partially codified in the form of standards.

Standards of engineering practice refer to the physical (in the case of physical engineering) properties (minimum or maximum) that the components of the artifact should have:

> Procedural standards of technological practice which indicate how one should go about designing and implementing technological artifacts...they often specify minimum and maximum values of physical quantities- strength of steel rods in tension, for instance, or the means by which they should be calculated (Shapiro, 1997, p. 291).

Such standards are formulated by communities of practitioners (e.g., the National Association of Engineers in the X field which for consensus develops their practice based on a set of standards). Standards play a critical role in the design of artifacts not just from the knowledge they embody, but also because they play the role of connecting local contingencies with more universal knowledge. In the words of Shapiro:

> There are many degrees of freedom available to the designer and builder of machines and processes. In this context, standards of practice provide a means of mapping the universal onto the local...Local contingencies must govern the design and construction of any particular bridge [for example] within the frame of relative universals embodied in the standards. The point is not to maintain universalism as is the case with physical laws and constants. Rather, the point is to localize the artifact. A volt must mean the same thing regardless of where it is used. A bridge that functions successfully (with respect to multiple criteria including aesthetics) in one place need not have the capacity to function successfully in another place (pp. 293, 294. See also Petrosky, 1997 for a beautiful example on how contemporary design competition takes place).

Standards are key elements for understanding contemporary engineering. Design philosophers are just in the beginning of the analysis of these components of what may be an emergent epistemology of engineering. Note the role of standards in connecting science with design. This peculiarity of engineering has important implications for science education. However, standards are only a small part of what is called procedural technological knowledge (Vicenti, 1990, Herrera 1996). For the purposes of this clarification of technology as knowledge, I think we already have a general picture of the epistemological territory of engineering. At this moment, I do not engage in any deeper discussion on epistemology of engineering . What is important for now is to note that the framework of technological knowledge I endorse is formed by substantive and procedural knowledge. The role of procedural knowledge in technology is much more important than science (Sørensen, & Levold, 1992). As I show later, technology is mainly based on procedural knowledge, yet there is an important amount of substantive knowledge. In contrast, science is based mostly on substantive knowledge.[3] Clarifying the interaction between substantive and procedural scientific knowledge in relation to technological knowledge is a fundamental task to appreciate the potential uses of technological knowledge in science education.

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[3]I do not mean that procedural knowledge (e.g., tacit) is not important in science. History and philosophy of science have shown that procedural knowledge is important in science (Conant, 1947, Gooding, 1992, chapter 3 of this dissertation). However, I argue that the role of substantive knowledge is much more important than procedural in scientific communities (this accounts for a smooth "translation" as I discuss in chapter 7). Although some researchers have argued that modern science is an outcome of technology, such as the case of Traweek (1988) in her studies of particle accelerators or the works of Latour (1987) in biological laboratories, they seem to confuse the instrumental (technological artifacts) with the research. Moreover, they defend the idea that scientific research constructs facts by its instruments (e.g., particle accelerator) therefore they do not distinguish science from technology. These conclusions may be right in the sense of the high technological dependence of modern science. However, such technological artifacts are means rather than ends. An account of research on particles suggested by Wilson (1958, 1980) is more realistic and preserves the intrinsic scientific nature of this research rather than its technological mis-connotations suggested by Traweek and others.

In short, the relationship between science and technology that I endorse reflects a complex interaction between them. Such interaction was illustrated using the case of engineering. The typologies suggested by Faulkner and Vicenti have been useful to draw a general picture of what technological knowledge means. The problem is much more complex than this preliminary description; however, it is enough, at this moment, to provide a general meaning of the term technology as knowledge. As the reader can see, there is no simple relation between scientific and technological knowledge. In addition, the very meaning of the term technology as knowledge has its own history. The following table summarizes my discussion.

Table 5.1 Relationship between science (S) and technology (T).

Model:	**Relationship:**	**Description:**
Subordination	T | S	S is the base of T (S creates knowledge while T applies it)
Cause-effect	S ---> T	S provides knowledge T the artifact
Two-way	S <---> T	S refers to natural world T refers to artificial world. S affects T, but T also affects S.
Specificity-of-T		There is specific technological knowledge (T) which would be related to S. T creates specific knowledge. S is reinterpreted.

Technology as social practice

Both generic meanings of technology, artifact and knowledge, are concerned with changes, that is, control, transformations, creations of things and processes. The creation or transformation of processes assumes the existence of knowledge (whatever its nature). The possible outcome of the process is an artifact (material as a bridge or social as a plan for improving literacy). However, artifacts and knowledge do not exist by themselves in a Platonic world (or a Popperian world 3). Both artifacts and knowledge are human

constructions. The nature of the construction can be understood by looking for the kind of social practice which produces a given artifact or the knowledge which supports this construction. Again, E. Layton enriched the discussion on the social and epistemological nature of technology: "What is needed is an understanding of technology from inside, both as body of knowledge and social system" (1977, p.198). This was the context of the emergence of the Science Technology and Society movement, usually called STS (Spiegel-Rösing, & Solla, 1977).

The STS movement has its roots in an interest in the social aspects of science and technology, and it was an important movement in the 1970's. Ina Spiegel-Rösing (1977) traces back the roots of this movement to the Second Word War as a reaction to the use of science (technology) for military purposes. In the 1970's, there was a similar movement. This time in the context of the unpopular war with Vietnam and the effect that technology was producing on the environment (DeBoer, 1991; Spiegel-Rösing, & Solla, 1977). The STS movement has had, according to Spiegel-Rösing, several tendencies (such as the humanistic, cognitive normative, relativistic which, by the way, became the constructivist). And one should be aware that the educational branch of the STS is only one tendency (see examples of education versions in Yager, 1996 and Aikeheand, & Salomon, 1994). It is also important to note that the roots of the STS movement are connected to external factors (e.g., political, economic factors, i.e., macro factors) rather than the epistemological demands of the design process.

A parallel movement regarding studies of science and technology from a social perspective emerged in the 80's with the social studies of science (e.g., Barners and Edge, 1982; Knorr-Cetina, and Mulkay, 1983; Shapin, 1985; Bijker, Hughes, and Pinch, 1987; Gooding, 1990; 1992; Knor-Cetinna, 1990, 1992; Latour, 1987; Traweek, 1988, and others). This approach has taken over the studies on how scientists and technologists actually work in laboratories (e.g., Latour, 1987; Traweek, 1988). In contrast to the roots of the STS movement, the social studies of science have stressed micro analysis, that is,

they have studied scientific and technological researches in terms of individual actions within specific laboratories.

The social studies of science and technology are important references for analyzing the meaning of technology as social practice.[4] They have shown that: a) the connection between design and knowledge is not linear, and b) negotiations play important role in the design process (particularly Buciarelli, 1988; 1994). However, one should be careful in interpreting their frequently radical conclusions. For example, researchers in science and technology studies working within the "constructivist" or "relativistic" positions tend to argue that scientific and technological knowledge are socially constructed and are undistinguisble from other forms of knowledge: "The treatment of scientific [and technological] knowledge as a social construction implies that there is nothing epistemologically special about the nature of scientific knowledge. It is merely one in a whole series of knowledge cultures..." (Pinch, & Bijker, 1987, p.19). I do not share this radical conclusion. In principle, the slogan "socially constructed" has been used to justify almost everything, so much that the term has become almost empty. And secondly, I think

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[4]The notion of social practice is taken for granted in the social studies of science and technology. This is in part because of their philosophical positions regarding the role of theories in scientific and technological research. The typical researcher in this line (e.g., Latour) goes to scientific laboratories, i.e. researchers make a field trip (like anthropologists) in order to describe what they "see", usually without conceptual tools (theories). In contrast, social practice is a key concept in sociology (a domain formed by theories), particularly in the works of Marx, Althusser, and Bourdieu, (alternative versions can be found in Coleman, 1990 in which the key concepts are "action", "actors", "transaction", etc.). The notion of social practice that I assume is related to the idea of *intentional action*. From a general perspective there are three basic social practices: economic, political and cultural. According to Althusser, any social practice is composed by four elements: human work force (**w**), means of production (**m**), the object of transformation (**o**) and the final product (**p**). The structure of any social practice is represented by **< w, m, o, p >** (Herrera, 1989). For example, think of the production of a wood chair done by a specific social practice (carpentry). Carpentry can be seen as a social practice which has the purpose of the production of material goods (furniture for instance). The four elements of this social practice are: work force (labor of the carpenter), means of production (tools, materials, knowledge, etc.), the object of transformation (the wood) and the final product (the chair). When I refer to technology, as social practice, I am thinking of a specific practice which has the purposes of transforming a thing or process with the help of scientific and technological knowledge (Herrera, 1989; 1996; Cajas, 1993, 1994a, b). The practice can be conceptual (design of a bridge) or material (the actual construction of the bridge).

that science and technology are quite different enterprises but they are connected in complex and contextual ways. Moreover, they are both special kinds of knowledge that we can distinguish from other kinds of knowledge.

My comments on the STS movement are related to the third meaning I propose for the term technology. Technology can be seen as a social practice, that is, an oriented activity which has the purposes of changing, controlling, or transforming material or social things or processes with the help of scientific knowledge. The kind of transformation the social practice makes is partially based on a special kind of knowledge. The nature of the knowledge that a technological practice uses is determined by how one sees the relationship between science and technology. So far we have explored some of them. Bucciarelli, for example, has explored others.

Drawing from traditional models of engineering design, such as those found in engineering textbooks, Bucciarelli reports that design is usually thought of as a practice that are based on models like the following: Definition of the Problem---->Development of a Plan---->Model Formation--->Applications of Physical Laws--->Computation---->Checking-->Evaluation--->Solution. However, what Bucciarelli found in his anthropological studies on how technologists actually work is that design takes place in complex social settings in which the very "Definition of the Problem" is by its own right a problem. Problems are not always well-understood, so the social practice of design becomes complex (see also Schön, 1983; 1987). At this moment, I do not engage in any discussion regarding the simplistic models criticized by Bucciarelli. What is important for my discussion at this level is the intrinsic social character of the design process reported by Bucciarelli.

The meaning of technology as a social practice also has a wider connotation. This is its connection to economic, political, and cultural factors of a given society. Perhaps this meaning is even more complex than the meaning of technology as social practice

regarding the nature of the design (knowledge base, negotiation, etc.) The problem is complex as Bijerker and Law acknowledge:

> What do we mean when we write of the "social"? Do we mean social in "sociological"? The answer is we do, but only in part. For the sociological is not exclusively sociological. In the context of technology and its social shaping it is also political, economic, psychological - and indeed historical (1992, p.4).

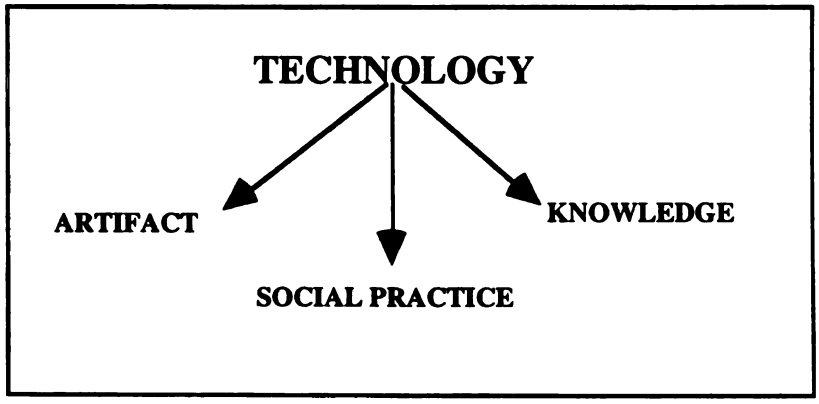
I agree with these authors in the sense of the multiple meanings of technology as social practice. However, different from them, I assume a conception of social practice which allows me to construct conceptual tools (theories) to explain such phenomena (technology). Therefore, technology can be seen as a social practice with two aspects. First, the general ontological assumptions that social practices are the basic realm of social interactions, that is, individual interactions (micro-level). Such practice, technological practice, has its own specificity. Particularly, it has the purposes of changing or transforming, natural or artificial processes or states with the help of relevant scientific and technological knowledge. I already showed that such practice is based on the concept of design which ultimately requires a specific kind of knowledge. Second, I also refer to the intrinsic social nature of the technological practice in the sense of its economic, political and cultural connotations (macro level). I use both senses of the term "social practice" when I refer to technology as a social practice (see footnote #4 for a definition of social practice used in this chapter).

When I say that technology can be seen as artifact, knowledge and social practice, I am trying to capture a huge complex phenomena with a sort of ontological assumptions (what is an artifact?), epistemological positions (is there technological knowledge?) and social peculiarities (what is the social nature of the design process? what are the political assumptions of the practice?). The notion of artifact is connected to the meaning of social practice. Artifacts were defined as objects that are made with the help of shared knowledge (Bunge, 1985) . In this way, there is no artifact without "shared" knowledge and there is no shared knowledge without communities.

A framework for technology

Given this short discussion on the multiple meanings of the term technology, I re-frame the three general uses of the concept: 1) technology as artifact (a concrete system) 2) technology as knowledge (a conceptual system), and 3) technology as social practice (an activity). I argue that these three generic meanings are important elements for a general framework for technology. I do not mean that they are the only meanings of the term. The term carries other meanings, such as technology as a way for solving practical problems (methodological definition of technology), technology as a tool for educational purposes (educational technology) or even technology as an ideology. The French philosopher Jaque Ellu, for example, argues that the term technology ("La Technique") has mainly political and ideological connotations; particularly, it is related to a new kind of society (technological society). In the same line of thinking, technology is usually identified with destruction of the environment and so on and so forth. I argue that these are social implications of technology rather than specific meanings of the term. The framework I suggest can be used for further analyses of such social implications. And more important, this framework on technology can be used for studying some characteristics of technology education and its potential connections with science education. The following figure summarizes this framework.

Figure 5.1 Three different meanings of the term technology.



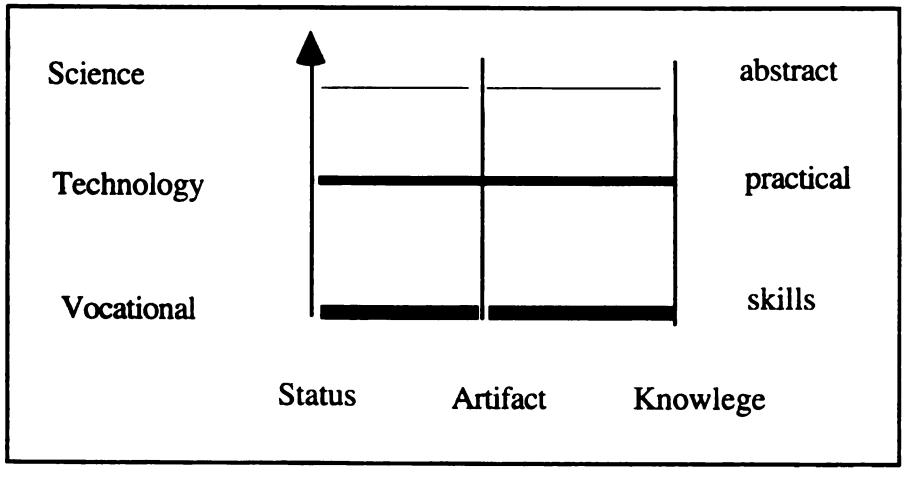
The framework on technology that I propose has immediate applications. Vocational studies, for example, stress a conception of technology as artifact (hands-on occupational oriented experiences). In the United States, vocational studies do not focus on technology as a special kind of academic knowledge. Although American vocational studies include general knowledge, they stress the acquisition of actual job skills, such as repairing televisions, or washing machines (see Evans, Hoyt, & Mangum, 1973 for an example). In contrast, when one thinks of the preparation of engineers, technology stresses a specific kind of professional knowledge. Engineers do not lead with the humble work of fixing televisions, repairing cars, etc. They design "better" televisions, "better" cars and "new" technological artifacts. Their preparation stresses the acquisition of high academic knowledge which is connected, at least formally in the curriculum, with science.[5]

The interaction between technology as artifact and technology as knowledge is also an interaction between status. The emphasis of vocational studies on artifacts and job skills contrasts with the preparation of technologists (e.g., engineers) whose preparation stresses more academic knowledge, a knowledge that goes beyond job skills. Contemporary departments of technological fields (e.g., engineering. biotechnology, medicine, etc.) have an intense connection with science. For real or artificial reasons, science is the referent of the knowledge taught in academic disciplines which is actually a higher status. I argue that the relationships that science, technology and vocational practices (both: the preparation and the practice itself) establish with artifact is a representation of the different status that each has in a given social structure. If one draws a graphic representing the hierarchy of status of these three social practices (science, technology and vocational practices), one would draw in the top of the status-arrow (see Figure 2) the name science, and then technology in

[5]This is something relatively new. In the American context after World War II there was an attempt to redefine engineering as an applied science rather than art. The tension between art and science has important implications for the preparation of professionals (Schön, 1983).

the middle, and finally vocational practices at the bottom. In the case of vocational studies, there is a strong relation with the artifact. However, the relation is from the perspective of the keeper, that is, the maintenance of the artifact. The emphasis is on the "fact" rather than the "art". The case of technology changes this relationship with the artifacts. Here the emphasis is on the "creation" of the artifact. The stress is in the "art". The artifact is seen from the perspective of the "creator". The knowledge can or cannot be academic, but usually there is emphasis on academic knowledge (technological knowledge). Science, in contrast, has a different relation with artifacts. Although contemporary science is very dependent on instruments (artifacts), the goal of science is not the construction of these artifacts (think of a particle accelerator or an optical microscope). The artifacts in these contexts are seen as tools which mediate research activities. The position that scientists have in relation to artifacts is similar to the position the general public has in relation to technology -both do not care much about how these given artifacts work. There is a weak relation with the artifact and a strong relation with knowledge (high abstract and general knowledge). The following figure illustrates this discussion.

Figure 5. 2. Relationships between science, technology and vocational practices with status, artifacts, and knowledge.



It is important to note that the framework I propose only illustrates a general tendency. The status that technicians, technologists and scientists have in a given social structure and how it is related to the kind of practice they develop is a complex issue.[6] What I want to emphasize is the derogation that technical skills and technological knowledge suffer in relation to science. As I show later, this has implications in science education. Even in contemporary scientific laboratories, the status of technologists is lower than theoretical scientists which is explained by Chandra Mukerji in the following terms: "This has a long history and stems in part from the seventeenth- and eighteenth-century tradition of gentlemen scientists hiring technicians as a kind of servant" (Mukerji, 1989, p.15. See also Shapin, 1985 for specific examples). The assumption is that technology does not have epistemological value, so why should one care of its translation into science education? My position is that we have to explore what the potentialities of technology in teaching science are. So, far I have shown that technology has epistemological value (specific technological theories). In the following section, I am more specific in relation to the potential that technology has in the science curriculum. In order to explore that, I propose to study a specific topic which is part of contemporary science curriculum: energy.

Teaching science...teaching technology: The case of energy

In this section, I study how the approach of teaching energy changes or would change when one sees it from either the perspective of science or from the perspective of technology. In other words, I attempt to show how the meaning of teaching energy would change when one sees it from the perspective of traditional science education and technology education respectively.

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[6] For example, there are theories about instruments such as simple theories about how an Ampere-meters works. These theories are used by scientists in order to contrast their data with what they expect, i.e. for making corrections. However, the goal is not the understanding of the instrument. The position that they have with the artifacts (instruments) is still utilitarian.

Energy is a fundamental concept within scientific and technological communities. It has a place in the K-12 science curriculum. Although I focus my analysis on secondary science curriculum, it is important to note that in elementary education, students are usually expected to develop qualitative approximations to the several kinds of energy concepts, such as knowing about: sources of energy (e.g., the Sun, batteries, wind, etc.) and transformation of energy (e.g., from chemical to electrical). The National Science Education Standards (National Research Council, 1995), suggest specific themes about energy, particularly the study of energy in relation to movement of objects, light, heat and electricity. Although I present my examples from the perspective of the movement of objects, my argument can be developed using any of the other topics (i.e. light, heat, electricity).

Teaching science: Energy

Given the high order of generality of the concept of energy, teachers and students can use these concepts for making connections with almost all kinds of science school knowledge. From the physical science perspective, one can develop basic concepts of energy from the perspective of the movement of objects (dynamics) or from the perspective of heat and temperature (thermodynamic), as well as from electricity (electrokinetic) and other alternative themes. From the perspective of dynamics, for example, there are two general approaches. The first focuses on the notion of force and how forces act on objects. This approach is based on contemporary interpretations of Newtonian mechanics in which forces are treated with their vectorial proprieties. The general idea is to isolate the object and to consider it as an individual. The changes of velocity of the object are explained for the existence of unequilibrated forces. The connection between force and energy is made by the concept of work (W), which in the school science context is defined as the force acting on an object multiplied by the distance in which the force has been acted. For the particular case in which both vectors, force (F) and distance (d), have the same direction, the expression of work is W= Fd. From this perspective energy is work.

It seems that the objective of introducing the concept of work is for preparing the scenario for the concept of energy (see for example the high school text book" Conceptual Physics", Hewitt, 1997). This introduction is done by explaining certain transformations related to two different kinds of forces: "conservatives" (e.g., gravitation) and "non conservatives" (e.g., friction). When there is work done by a given conservative force there could be changes in the velocity of the object. This is explained introducing the concept of kinetic energy. In the case of gravitational forces, some work is not transformed in changes of velocity but in possibilities of producing these changes. This is explained with the concept of potential energy. For conservative forces, one can *deduce* that there is a relation between kinetic and potential energy, i.e. that the sum of both is constant. The point of the approach is to explain movements of objects starting with the concept of force and finishing with ideas about work and energy.

The second approach has a different starting point. Here, one *defines* two quantities: kinetic and potential energy and *postulates* that the sum of both is constant. The quantity most important here is not force; the important quantity is energy. Changes in kinetic energy ($1/2\ mv^2$) are related to changes in other kinds of energy. Although the approach does not start with a specific description of movements, it can be used for solving problems of movement. The approach requires the introduction of several kinds of energy. In the school science curriculum, the concept of kinetic and potential energy (mainly gravitational and elastic) tend to be the most commonly used concepts, yet there are references to other kinds of energy (chemistry, electric, etc.). Students are invited to understand the principle of conservation of energy. Traditional high school physics, for example, includes experiments for helping students understand the transformation of one type of energy into another.

From the perspective of a physicist, both approaches are different alternatives for solving problems, such as problems of movement of particles or analysis of more complex systems. However, from a pedagogical point of view, they are very similar. In fact, they

both are concerned with the traditional goal of science education of solving textbook-based problems. In both cases, students are expected to use some general principles for solving specific problems (e.g., predicting the final velocity of an object given its initial velocity and other conditions). In other words, both approaches provide students analytical tools for dealing with physics problems. As I just said, traditional science education has stressed solving specific textbook-based problems using both approaches (e.g., the problems used in the classical study on experts and novices presented by Chi, Feltovich, & Glaser, 1981). A more interesting way for acquiring these tools is by doing experiments. Paul Robinson, who is the author of the Laboratory Manual of Hewitt's book "Conceptual Physics," suggests the following experiment for investigating the relationship between work and force: "In this experiment, you will investigate the relationship between the initial height of a rolling ball and the distance it takes to roll to a stop" (Robinson, 1987, p.87-90. Experiment #1 in Table 1). It is intended that students develop the notion of work by analyzing the forces that act on the rolling ball (Newtonian approach) and the work that the friction does. The point is to be able to predict movements. The second approach is exemplified by another experiment taken from the same manual (Robinson, 1987, pp. 77-79. Experiment # 2 in Table 5.1). The objective here is to measure the potential and kinetic energies of a pendulum in order to see if there is conservation. My last example is an experiment on solar energy (p.195. Experiment #3 in Table 5.1). Here the goal is to calculate the rate of energy that the sun emits. These three experiments are examples, to some extent, of the use of energy in school science. What is important for my account is the idea that these conceptual tools (different kinds of energy and their transformation, definition of work, etc.) are important for students to make descriptions, calculations, explanations and predictions.

The models that students are expected to develop are usually causal models (Devi, Tiberghein, Baker, & Brna, 1996). In the case of the experiment of the rolling ball, it is expected that students conclude that the rolling ball stops because of dissipation of energy

(friction), for example, **"loosing energy" ---> "lack of movement"**. The fundamental principle of conservation of energy, together with specific proprieties of different kinds of energies such as kinetic, potential, etc., should be the essential components of the expected student models. Students should develop models of transformation of energy (causal model such as the potential energy of the rolling ball is transformed in kinetic energy and then it is partially transformed in "heat" because of the friction). The goals of such models are descriptions and mainly predictions of movements using both analysis of forces and energy studies.

Table 5.2 Concepts and goals of teaching energy from the traditional science education perspective.

Concepts	**Goals**	
Force Work	Predicting movements of isolated objects Developing an expression between energy and force	Experiment # 1
Energy Kinetic Energy Potential Energy Fundamental Principle of Conservation	Explaining transformations of energy Predicting movements	Experiment # 2
Solar Energy Flux Area, Volume, Temperature, Units of energy	Calculating the amount of energy the sun emits	Experiment # 3

What students usually gain from these experiences is a mixture of outcomes (Tamir, 1991). Research in naive conceptions has clearly shown that students have problems in distinguishing between energy and force. The pioneer works of Laurence Viennot (1979) in France demonstrated that the notion of energy is problematic for students. Joan Solomon (1994) in England also studied how students understand the concept of energy. Her

extensive report indicates the problematic connection between everyday notions of force, work and energy with scientific canonical definitions.

Teaching technology: Energy

From the perspective of technology, the picture of teaching energy is quite different. One can analyze the introduction of the concept of energy using the framework for technology I proposed earlier. As I said, technology can be seen from three different perspectives: as artifact, as knowledge and as social practice. In looking at Table 5.1, the first comment that comes to mind is that traditional science education stresses knowledge rather than artifact or social practice. Focusing on knowledge within school settings is nothing new. However, one would ask if there is any relationship between scientific and technological knowledge in the case of teaching energy in school settings. In other words, do the general concepts of energy change when one moves from the context of science to the context of technology? In any case, does it matter?

From a historical point of view, several of the concepts of energy have their roots in technological processes, such as the case of the development of stream engines. This is the origin of thermodynamics. In this context, the goal of the knowledge developed was to control, transform or create things or processes. This is one of the meanings of technological knowledge that I explored earlier. From the perspective of science education this goal is not presented, or at least it is not stressed. Consequently, if there is a difference between scientific and technological knowledge, it would be in the goals of the use of knowledge. These differences in goals have, I argue, important implications for teaching science. The experiments already cited about energy (work-energy, conservation, and solar energy) are experiments for understanding, that is, for describing, explaining or predicting. As one can see in Table 5.1, no goal for transforming, controlling or developing artifacts was presented.

One way for understanding the role of technology in teaching science is by re-framing the two science education experiments in the context of technology education. The first experiment had the purposes of investigating the relationship between the initial height of a rolling ball and the distance it takes to roll to a stop. In the context of technology education, one can transform it, among other alternatives, into a research project for investigating different materials that could produce ***less*** friction. Using the same structure, students would test different materials in order to determinate the ***"best"*** material for reducing the friction. Students would investigate the positive and negative implications of friction. The goal of this experiment goes beyond explanations and predictions. The introduction of this utilitarian goal has the potential positive effect that students can see some uses of scientific and technological research. The potential negative implication is that people do research not only for utilitarian reasons. In any case, from this general example it is difficult to distinguish between scientific and technological knowledge. What is making a difference is the general goal of the experiment (Experiment # 1 according to Table 5.1 and Table 5.2).

From the perspective of science education, the experiment on solar energy presented earlier (Experiment #3) has the goal of calculating the amount of energy that the Sun emits. From the perspective of technology education the focus of attention shifts somewhat. What matters here, for example, is how to use this energy. Energy becomes a resource rather than only an object of study. A possible technological problem is to design a solar collector for capturing this energy and using it in some way. Think for example of the approach reported by Wolff-Michael Roth and his colleagues when they were working with grade 10 students and asked them: "What is the rate of energy delivery from the sun per square meter at the Earth's surface: your task is to design and build a solar heat collector which will enable you to answer the question" (1992, p.22). The construction of the collector here is very related to the notion of technological task. However, the artifact is being used for answering questions related to understanding. I argue that generally technological

approaches go beyond this epistemological position. Although knowing the amount of energy that the Sun emits is an important goal from the traditional position of science education, from a technological point of view, one should ask: ***for what?*** One possibility is for heating water or for determining better material for building the collector. From this perspective, the artifact has an intrinsic value. These utilitarian goals are behind any technological design. Although conceptual understanding would be important, the goal behind technological problems is related to the solution of specific problems or more efficient uses of resources. This is perhaps the first difference between teaching technology in relation to teaching traditional science. It does not mean that some science teachers have not approached practical problems. What I mean is that traditional science education tends to focus on conceptual understanding by using canonical knowledge in predetermined problems. Technology education, in contrast, suggests more real scenarios in which students and teachers can engage in approaching specific technological problems as the following table shows.

Table 5.3 Teaching energy from the perspective of technology education. The concepts in italics tend to have more technological connotations.

Concepts	**Goals**	
Work Force *Efficiency*	Finding materials with less friction.	Experiment # 1
Energy Solar energy *Heat Transfer* *Thermal Conductivity*	Designing and building a solar collector. Selecting materials for building the "best" collector. Using the solar energy for heating water.	Experiment # 3

In thinking about the possibility of using technology as an alternative way for teaching science the first meaning of technology that comes to my mind is technology as artifact. Unlike traditional science classes, teaching science through technology will require a more intense contact with instruments and with the production of artifacts. Given the role that technology can play in teaching science, the second meaning that follows is technology

as knowledge. The distinction between scientific and technological knowledge should be approached with prudence. In the case of teaching science, it is important to stress the epistemological richness of technology. The design of a solar collector requires a sort of scientific concepts (energy, work, area, flux, etc.) in addition to specific technological knowledge (about transfer of heat of the specific collector). As I pointed out, the relationship between technological and scientific knowledge is complex. The same complexity, and perhaps more, will be translated to the classroom. If students will be engaged in solving technological problems, such as the case of the design of a solar collector, according to some initial conditions, it is expected that they will generate specific knowledge (situated knowledge). Think of graphics of velocity of heating different material as a function of time or temperature. It is possible that students will construct knowledge for designing specific kinds of collectors. Therefore the construction will be material and conceptual. This is what I am calling teaching science via technology. In the case of teaching science, this specific and perhaps local knowledge should be connected to some extent with school science knowledge.

Technology: Social practice

So far, I have discussed two meanings of the term technology: technology as artifact and technology as knowledge. The educational implications of the meaning of technology as social practice have not been discussed. There are at least two ways for analyzing this meaning. The first focuses on internal social interactions in classrooms situations, particularly on the social interaction of students when they are engaged in technological tasks. The second, is the social reasons that we have for teaching technology which has been a concern of the STS movement (Yager, 1996). In this section, I analyze the meaning of technology as social practice in relation to the social implication of technology. I do that from the perspective of the topic of energy.

There are several potential reasons why we teach energy from the perspective of its social implications. One of the most accepted goals is that students should be aware of the consumption of energy in their homes, in their country and even on the planet. Scholars have suggested that "...conservation [of energy] must be our highest priority throughout the rest of the twentieth century" (Olsen, & Joerges, 1981). This concern is an outcome of the energy crisis of the 70's. In fact, the educational branch of the STS movement has been suggesting this direction for almost twenty years (Layton, 1994. R. Yager, personal communication, September 1996).

Teaching science and particularly energy from the perspective of its social implications is a complex task. It requires some understanding of basic scientific concepts. Gerald Davis, an expert in energy consumption, suggests that: "...it helps to understand where energy comes from and the purposes that it serves in our lives" (Davis, 1990, p.55). This emphasis in understanding basic concepts is important. However, if one wants to understand what the status of the demands of energy of the planet is or how people use or misuse energy, one has to go beyond these basic concepts. This will require technological concepts such as efficiency, optimization, invention of better ways of consuming energy, etc. Given its utilitarian connotations, these are technological rather than scientific concepts. Looking for better uses of energy, developing alternative sources of energy, designing new systems of recycling, creating more efficient artifacts, etc. are activities which have more technological connotations. However, these concepts are only technical approximations to the social core of the problem. From a social point of view, the problem of the uses of energy in the world is a problem of power and stratification.

Teaching the social implications of the uses of energy is a very complex task. It requires the integration of social with technological concepts in addition to scientific concepts. Concepts such as energy policies and relationships of lifestyles to energy consumption, that is, conservation versus consumerism, are social concepts that usually are not connected to traditional approaches of teaching science. The introduction of these

concepts into the traditional science curriculum is not only complex but also ideologically problematic. Think, for example, of the complexities that the following information would introduce into the classroom: "The average person in a developing country eventually uses the equivalent of one or two barrels of oil...In contrast, the numbers jump to between 10 and 30 barrels in Europe and more than 40 in the U.S." (Davis, 1990, p.58) From the perspective of science education, these are important goals for teaching science. However, their connections with traditional science curriculum is still unknown.

I suggest Table 5.3 as a way of summarizing the three approaches for teaching energy that I have discussed. The first kind of concept is related to the traditional way of teaching science. The second is the technological approach that I defend. The third approach stresses social implications of science and technology, a movement that has its roots in the educational branch of STS (Yager, 1996).

Table 5.4 Three different approaches for teaching the topic of energy in high school.

Science	Technology	Society
Force, work , kinetic and potential energy, principle of conservation of energy	Efficiency, quality of energy	Differences of consumption of energy between poor and developed countries
Specific kinds of energy (solar, chemical, etc.) Transformation of energy, e.g., from kinetic to heat. Thermal conductivity	Specific knowledge about transfer of energy e.g., knowledge about transfer of heat in specific artifacts Knowledge about the design of artifacts	Social implications of alternative sources of energy (nuclear plant, solar, firewood) Relationship between petroleum dependence and environmental impact

I think that these three approaches reflect different conceptions of teaching science. I also think that there is a progress in the complexity of each approach from the scientific to the social approach. Usually, the scientific approach for teaching science is the simplest approach (simplistic) given its relation with didactic approaches, which tend to be identified with telling and remembering facts. However, it is important to note that there is an enormous effort for teaching science for understanding in authentic way which is a complex task. At any rate, the most complex approach is the social, but only if one wants to go

beyond simple and general descriptions of the implications of science and technology in society. I think that this perspective of teaching science is very important. However, we still do not know how to connect social concepts with scientific concepts in the context of teaching science.

In a middle position, I see the introduction of technology as a way for teaching science. This approach can be analyzed using three meanings of the term technology: a) as artifact, b) as knowledge and c) as social practice. The role of technological artifact in teaching science is fundamental. The status of the artifact depends on the perspective that one uses for teaching science. From a technological perspective, artifacts are very important. They are means and mainly ends; that is, they can be used for solving some practical problems, but they are also expected outcomes of a given learning process. The relationship that scientific approaches have with artifact is interesting too. Traditional science classes use artifacts developed by other people (instrumentation such as laboratory equipment). From the technology education perspective, the design of artifacts is an important goal in which students should be involved (Raizen, et al. 1995). However, the emphasis on teaching science through technology should be, I argue, in the technological knowledge that is used for designing a given artifact or for solving practical problems. This knowledge, technological knowledge, represents an opportunity for learning basic scientific concepts, but it is also the arena for designing and developing artifacts based on research projects. My concern is on the lack of research that we have for understanding the role of technological knowledge in the teaching and learning of science.

Technology has been introduced as part of the leading science education reforms proposals, Project 2061 and the National Science Education Standards. However, its role in teaching science is still unclear. One of the first reasons is that the very notion of technology advanced in current reform proposal such as Project 2061 and the National Standards, needs to be unpacked. In fact, the relationship between scientific and technological knowledge in the context of general education needs to be clarified. This is

one goal of this dissertation. A second reason is the complexity of the social scenario, particularly the social status of technology as subject matter. Both problems, the meaning of the term technology in the context of science education reforms and the potentiality of being used as a bridge between understanding and applications in teaching science, are the core of this dissertation. The following chapter studies the position of technology in Project 2061 and the National Science Education Standards.

CHAPTER 6

TEACHING SCIENCE, TEACHING TECHNOLOGY : PROJECT 2061 AND THE NATIONAL STANDARDS

In this chapter, I analyze the introduction of technology into the school curriculum according to the two leading reform proposals in America: Project 2061 and the National Science Education Standards. I attempt to describe the nature of technology portrayed in both proposals. I use the conceptual tools that I developed in the previous chapters. Although my analysis accounts for the general assumptions regarding teaching and learning, I stress the position technology has in the school curriculum. In others words, I study how the nature of technology, as it is presented in Project 2061 and the National Standards, would shape our conception of science education. This chapter is descriptive in the sense that it attempts to provide the reader with a general idea of the role of technology in these proposals. In addition, this chapter is critical in the sense that it is looking for the specific technological knowledge that would connect science and technology.

The perspective of Project 2061

In this section, I explore the meaning of the term technology in light of Project 2061. The Project has reported its conception of technology across three documents. The first is the *Panel Report on Technology* (Johnson, 1989). This document was produced by experts who were asked to select the knowledge that schools should teach for technological literacy. This suggestion was enriched and translated into the framework of the Project: the book entitled *Science for All Americans* (SFAA). The preparation of documents for developing curriculum was a different phase. This phase is mainly represented in the *Benchmarks for Science Literacy* (AAAS 1993), and the *Blueprints for Reform* (e.g. National Center for Research on Teaching and Learning, 1994). All these documents have information about technology and technology education. However, for the purposes of unpacking the conception of

technology, in this section, I will focus my analysis on SFAA and the *Panel Report on Technology* (AAAS, 1990; Johnson, 1989).

SFAA presents a set of recommendations on what knowledge about technology is required for scientific literacy. In fact, the text dedicates two chapters to exploring the concept of technology: Chapters 3 and 8. In this context, the term technology is used beyond its traditional meaning of artifact or even beyond the notion of educational technology. In a broad sense, SFAA claims that:"...technology extends our abilities to change the world, to cut, shape, or put together materials, to move things from one place to another, to reach farther with our hands, voice, and sense" (p. 25). This wide conception of technology is refined introducing three general ideas: he connection between science and technology, the principles of technology itself, and the connection between technology and society.

The relationship between science and technology is seen in SFAA as a two-way route. In other words, the authors describe how science produces some basic knowledge for technology and how technology produces tools for science. The existence of technology is justified as more than a producer of tools. SFAA claims that technologists work with epistemological motivations, i.e. research for knowledge. In this way, the connection between science and technology includes the production of knowledge because of technological problems: "The theory of conservation of energy was developed in large part because of the technological problem of increasing the efficiency of commercial steam engines " (p. 26, 27).

The relationship between science and technology is enriched in SFAA by illustrating how some classical technologies such as engineering have scientific characteristics: "...the use of mathematics, the interplay of creativity and logic, the eagerness to be original..." (p.27). However, these similarities do not mean identity. In fact, according to SFAA: "Scientists see patterns in phenomena as making the world understandable; engineers also see them as making the world manipulable" (p.27). These different epistemological positions have tremendous implications on the nature of technology suggested by Project 2061.

Scientists, according to SFAA, assume that ***the world is understandable*** while technologists assume that ***the world is manipulable***. The motivations behind science and technology are partially different. In this sense, whereas for scientists knowledge is an end, for technologists it is a mean in dealing with practical goals. As I will show later, this conception of technology has important implications for developing curriculum.

The second general topic that SFAA suggests as part of the nature of technology is *Design and Systems.* This topic is identified with the principles of technology itself and includes four areas (pp 28-32):

- The Essence of Engineering is Design under Constraint
- All Technologies Involve Control
- Technologies Always Have Side Effects
- All Technological Systems Can Fail

In light of SFAA, the concept of ***design*** is the essence of technology. Although engineering is used as an example, the text goes beyond classical engineering. The authors describe general characteristics of technological design such as: flexibility, constraints (social and natural), testability, multiple options, etc. However, this description is poor in approaching the epistemological demands that technological designs would require. For example, there is not any discussion on the possibilities of using technological methods of design. The substantive knowledge that supports the technological design is not clear either. This is understandable given the fact that SFAA is not a treatise on engineering or philosophy of technology. In addition, only recently philosophers and ethnographers of technology have studied the concept and use of design and the demands of technological knowledge within technological communities (Bucciarelli, 1994).

Although SFAA does not present in an explicit way its conception of design, the general idea seems to be in line with planning the creation of artifacts. Within the context of science and technology education, Wolff-Michael Roth has recently suggested that : "[Design] includes creating artifacts, specifying how a system should be organized, or specifying how a

process should be executed. Design constitutes one form of situated learning in which students appropriate practice co-incidentally in the pursuit of a purposeful goal..." (1996, p. 108). Although Roth's definition of design is much more specific, it seems to be in general accordance with the implicit conception of technological design of SFAA.

The other section on the area of *Design and System* presents a description on the nature of technological systems. SFAA introduces concepts such as "control", "unexpected outcomes", "technological failure", etc., in order to show general characteristics of technological systems. Drawing on examples taken from classical technologies, SFAA describes the importance of understanding intended and unexpected outcomes of technological design. The text not only points out examples of intended outcomes, but it stresses the complexities of unintended outcomes: "Some side effects are unexpected because of a lack of interest on resources to predict them. But many are not predictable even in principle because of the sheer complexity of technological systems..." (p. 30). This position recognizes that technology is not the simple positivistic application of scientific knowledge to practical problems. In contrast, there is an intrinsic level of uncertainty in the design and control of technological systems. This idea is coherent with current works on philosophy and ethnography of technology. For example, drawing from an anthropological study on the production of solar energy cells, Louis Bucciarelli reports that: "...ambiguity and uncertainty are essential to design [engineering design]" (1988, p. 120).

The final section of SFAA on the nature of technology refers to issues of technology and society. In this section the authors present a general description of the social matrix in which technology is embedded. For example, SFAA shows how the human presence has changed our earth and the living organism in part because of technological innovations. The text draws on examples taken from environmental problems. Although SFAA tackles delicate problems on environmental and related issues, its position is not alarmist. In addition, the authors of SFAA display an optimistic position on the uses of technology in society, such as their industrial and commercial advantages. In this way, they explain how technological

systems interact with social systems and recognize that these interactions are usually complex. Although SFAA is the most well-known report that Project 2061 has published, it is important to review other reports of the Project in order to unpack its notion of technology. In fact, there are two more documents that I analyze below: the *Panel Report on Technology* and the *Benchmarks for Science Literacy* (Johnson, 1989; AAAS, 1993).

The panel report is an important source for summarizing the conception of the nature of technology in Project 2061. This report suggests a framework for technology which is coherent with the image presented in SFAA. This framework can be explained using some of its questions: "What knowledge and know-how are needed? What materials will be used to construct the artifacts of technology?..." (Johnson 1989, p.3). These questions are a sample of some "technological" questions that are in accordance with the principles of technology suggested by SFAA. In addition, the panel report introduces other kinds of questions which should also be familiar to the technologically literate citizen:

> -What are the mechanisms by which the technology enters [to the] social system?...
> -Does the technology put at risk the users, or other people who are not beneficiaries?...
> -Will the technology have long-range effects on the course of human history?"
> (Johnson 1989, p. 3, 4).

These question are meta-technological questions in the sense that they do not address just technical problems. They address social problems, that is, problems related with technology conceptualized as a social practice. The conception of technology of the panel report is coherent with SFAA and both suggest a conception of technology which goes beyond the traditional notion of artifact, as I pointed out above. They both stress technology as knowledge and technology as social practice. In fact, I argue that Project 2061's conception of technology includes the three general meanings of the term suggested earlier: a) technology as artifacts (tools, special artifacts such as the computer, x rays, etc.), technology as knowledge (e.g., technological knowledge for solving problems), and c) technology as social practice (relationship between technology and social issues).[1]

[1]From a general perspective, these three meanings of the term technology are also useful for understanding how researchers have studied the process of engineering design.

In the context of teaching and learning science, one basic meaning of the term technology is its epistemological connotations, that is, technology as knowledge. I argue that in order to clarify the role that technology would play in teaching science it is important to study the relationship between scientific and technological knowledge in the context of teaching science. This seems to be (obviously) an essential step in clarifying the potential introduction of technology as part of the science curriculum. This task was done in the last chapter from a general perspective. Now, I specifically examine the technological content knowledge suggested by Project 2061 and its relation to teaching science.

Teaching technology, teaching science: The perspective of Project 2061

In order to unpack the relationship between teaching science and teaching technology in light of Project 2061 I propose to follow the study on the topic of energy that I initiated earlier (chapter 4). That is, I study how energy is treated from the perspective of both science and technology education.

In the context of science education, SFAA suggests an academic approach in which energy is understood using mainly atomic and molecular models. For example, the process of transformation of heat from "warmer" places to "cooler" is explained in the following terms:

> Heat energy in a material consists of the disordered motions of its perpetually colliding atoms or molecules. As very large numbers of atoms or molecules in one region of a material repeatedly and randomly collide with those of a neighboring region, there are far more ways in which their energy of random motion can end up shared about equally throughout both regions than there are ways in which it can end up more concentrated in one region (p. 51).

Traditional research has focused on the product of the design, i.e. artifacts, machines (e.g. Aglan, & Ali, 1996; Koen, 1994). A second line of research has focused on the knowledge behind the design process (e.g. Eder, 1994; Fricke, 1996). A third approach has studied the social context of design in which talking, negotiating and communicating are important activities of engineering design (e.g. Bucciarelli, 1988; 1994).

In line with this conception of energy, the "Benchmarks" suggests to develop curriculum toward atomic models. In grades K-2 it, is only expected that students become aware of some sources of energy (e.g. the sun). For grade 6-8 , the reformers upgrade their expectations. For example, by the end of the 8th grade, "students should know that:

- Heat can be transferred through materials by the collisions of atoms...
- Energy appears in different forms. Heat energy is in the disorderly motion of molecules ..." (p.85).

For grades 9 to 12 the situation is even more demanding. In the case of heat energy, student should know that: "...it consists of the disordered motions of its atoms or molecules. In any interaction of atoms or molecules, the statistical odds are that they will end up with less order than they began- that is, with the heat energy spread out more evenly..." (p.86). Moreover, the final section on energy is dedicated to the introduction of quantum ideas, i.e. more abstract ideas.[2]

The topic of energy introduced within the context of technology (chapter 8 of SFAA and *the Benchmarks*) receives a different treatment. The emphasis here is that students can obtain a sense of the process of transfer of energy from a macroscopic perspective. For K-2, students the Benchmarks suggest that: "the emphasis should be on familiarizing them with a

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[2]The use of atomic and molecular models in school science has its advantages and limitations. One problem, for example, is the common idea that temperature (T) is a measure of kinetic energy of the molecules or atoms in a substance. This idea seems to have its roots when people began to identify the works of J. Bernoulli (1738) and L. Euler (1729) [both developed an expression for the pressure (P) of a dilute gas in function of the volume (V), mass (m), velocity (v) and number of moles (N)] with empirical results of gases. Euler suggested the following expression of the pressure of dilute gases $P=(1/3)(N/V)\ mv^2$ (Trusdell, 1968, p. 274). People, perhaps physics textbooks writers, have put together this expression with the empirical results that connects pressure, volume and temperature, i.e. Boyle's Law: $P= (N/V)kT$), in other words: $(1/3)(N/V)mv^2 = (N/V)kT$. From this expression, one can deduce that $(1/2)mv^2=(3/2)kT$. This mathematical expression, although logical, does not provide meaning for temperature. Several textbooks use this mathematical expression to make the case that "temperature is a measure of kinetic energy of the molecules or atoms in a substance". However, this expression confuses two different models: the kinetic theory of ideal gases and the kinetic theory of matter (J.L. Sanchez-Saenz, personal communication, November 1995). In this specific example, school science seems to present a trivialization of a microscopic model.

wide variety of phenomena that result from moving water, wind, burning fuel, or connecting to batteries and wall sockets"(p.193). The idea seems to move students from these early experiences to design energy-conversion systems using available material. In line with the general conception of technology education, design, testing, measuring, and problem solving, seem to be the base of this kind of literacy.

The topic of energy seems to receive two different treatments in Project 2061. One is in the context of teaching science and the other is in the context of technology. One could argue that this only reflects how project 2061 faces this specific topic of energy. Although a comprehensive study will be needed, I argue that in the context of Project 2061, there is a clear distinction between teaching science and teaching technology. The difference can be partially explained given the epistemological position of science and technology endorsed by Project 2061. However, this difference does not mean that teaching technology should deny teaching science. What is clear in this context is that both are different; however, science and technology education share many characteristics such as: logical thinking, testing, measuring, problem solving, and using mathematical models. The most important difference that I observe between both kinds of "standards", within the context of Project 2061, is related to two aspects. First, the goals behind teaching science are different from the goals behind teaching technology. Teaching technology is more related to applications, transformation, problem solving, and mainly ***designing.*** Teaching science is more connected to understanding, explaining, and ***knowing***. Second, the knowledge behind teaching science is partially different from the knowledge behind teaching technology. In the case of my example of energy, in the context of Project 2061, teaching science is more related to atomic models. Teaching technology, in contrast, is related to general ideas of transfer of energy, particularly it is related to the design of artifacts.

Technological content knowledge: The missing element

If one asks about the demands of knowledge that Project 2061 introduces in teaching energy according to its vision of science education, there will be few problems. SFAA and the Benchmarks present a set of recommendations on what specific knowledge students should learn. As we saw, both documents stress scientific models of energy, particularly atomic and molecular models. On the other hand, if one asks what the demands of knowledge that a movement toward technology education creates, there will be several problems. SFAA and the Benchmarks present general explanations on the kind of teaching and learning that reformers expect. However, the knowledge that students should learn, from the perspective of introducing technology, is not explicit. Developing projects, solving problems, measuring, testing, etc. are activities rather than specific kinds of knowledge.

In this section, I re-analyze the topic of energy using the basic principles suggested by Project 2061. I study the kinds of knowledge that students and teachers need to know in teaching energy from the perspective of technology.

In line with the framework on technology constructed in the first part of this chapter, it is necessary to have a specific practical problem in order to teach technology. This is the first difference with the traditional way of teaching science. Teaching technology will require teachers to engage their students in solving practical problems and designing artifacts. *The Benchmarks* of Project 2061 for example suggests that for grades 6-8 : "...students [should be] making and testing simple energy-conversions devices as tabletop wind generator and ***model solar collector***...the data that they gather can inspire hypotheses..." (p. 194). Let us think about making a solar collector. The first problem that a given teacher will have to face is the ***WHY*** of building such an artifact. As we discussed earlier, the design of artifact (e.g., machines) requires functional questions (e.g., for what?). In addition, and in contrast to traditional science and school science problems, technological problems have their roots in practical situations which are usually ill-defined. Let us assume that the teacher and students

agree on designing a solar collector for heating water. Let us also assume that we are talking about students who can be engaged in developing alternative ways of using energy (in contrast to traditional ways such as combustion which produces pollution). What is important for my account is that in teaching technology, the selection of the problem goes beyond traditional disciplinary knowledge.

Within the context of the classroom, the problem of heating water will not be determined until the teacher and students discuss the social reasons for thinking in alternatives ways of using energy. In addition, they have to talk about conceptual and material resources available. Materials for building the collector (metal, wood, etc.) will be needed, in addition to tools (e.g., hammer) and instruments (e.g. thermometers). Moreover, specific information will be needed. For example, the amount of water to be heated and the initial and final conditions of the water. Consequently, traditional scientific knowledge is not enough. However, what is the kind of knowledge required for carrying out these activities?

Rather than presenting a general discussion of the potential technological knowledge suggested by Project 2061, I choose to focus my analysis on the specific technological knowledge which is behind the potential design of a solar collector.

In designing a typical solar collector (e.g., a simple box -with a window- which can contain a fluid), engineers do not use atomic models. [3] They do not even use classic thermodynamics because"...it simply prescribes how much heat to supply to, or reject from, a system during a process between specified end states without taking care of whether or how this could be accomplished" (Kreith, 1973, p.2) which is in line with my discussion on the descriptive character of scientific knowledge. Moreover, this general theory does not include time as an important variable (time is a very important practical variable). What engineers use, or construct, is a specific kind of knowledge developed by the demands of the specific

[3]The distinction between micro and macroscopic models is also presented in technological knowledge. There are specific technological theories which are by nature microscopic, for example, a theory of construction of solar cells based on the quantum theory of solids. However, technologists will not use microscopic (deeper) theories from the very beginning. The typical attitude of technologists is pragmatic, so if macroscopic theories work, why should an engineer, for example, use more complicated theories?

design and the constraints of reality (e.g. kind of materials, costs, engineering standards as Vicenti, 1990 and Shapiro 1997 eloquently have shown). In the specific case of our collector, "...the determination of the rate of heat transfer at a specified temperature difference is the key problem" (Kreith, 1973, p.2). This information and the desirable outcomes provide the bases for calculating costs, size, feasibility, etc. I do not discuss all these complexities here. I am interested in the specific technological knowledge which has potential connection with teaching science in K-12 education.

In designing a collector, the models that engineers tend to use are macroscopic which can be based on either conduction, radiation or convection. Although each of these mechanisms has its own theoretical support, in order to simplify my example let us think of conduction as the mechanism that a teacher wants students to use in designing their collector (yet radiation is the "source" or energy). J. Fourier developed, in the early 1800's, a model for conduction which assumes that heat flows from higher to lower temperatures. He suggested that the rate of heat flow is equal to the product of three quantities: 1) the thermal conductivity of the material (k), 2) the area of the section through which heat flows (A), 3) the rate of the change of temperature (T) with respect to distance in the direction of heat flow(x). [4] Within the classroom, this theoretical explanation of the process of transfer of heat can be the basis of the design of the collector or goals for teaching science. In teaching technology students would change areas of contact (A) or materials (k) in order to design different kinds of collectors. In teaching science, the goal can be to understand processes of transference of heat using macroscopic models (e.g., Linn, & Muilenbegur 1996). What is fundamental for my point is that this kind of knowledge, technological knowledge, is not explicit in Project 2061.

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[4]The analytical modern view of heat transfer assumes differential equations; for example, a modern interpretation of Fourier's law for one-dimensional conduction is q=-kAdT/dx. However, if one approaches more complex problems (e.g. three-dimensional conduction, radiation and convection), "the solutions" go beyond the analytical methods and other methods are needed, for example, graphical, analogical, and numerical methods (Kreith, 1973).

So far I have shown a general conception of the nature of technology suggested by Project 2061. I also illuminated the problems of the lack of clarity with the technological knowledge that teachers and students should learn. At this moment, the image of Project 2061 seems to reflect a high concern for the introduction of technology as part of K-12 education; however, its connection with science is still problematic. Now I analyze the National Science Education Standards (National Research Council, 1995) given that this is a very important document which is shaping current science education reforms. I study the position that technology has in this proposal.

The position of technology in the National Science Education Standards[5]

Project 2061 has had an important impact on the National Science Education Standards, NSES (Bybee, 1997). For instance, the emphasis of the *Standards* on deeper content knowledge and unifying concepts and processes seems to have its roots in the work of Project 2061. However, Project 2061 and the National Standards are quite different enterprises, yet they both share the goal of reforming science education. In fact, the *Standards* document has several components which provide guidance in many specific areas of teaching science such as professional development, assessment, teaching, content, etc. In contrast, Project 2061 is better known for its work on curriculum and mainly content (*Science for All Americans* and the *Benchmarks for Science Literacy*).

Although Project 2061 is publishing materials in areas different than curriculum, for example, the *Teacher Education Blueprint* (National Center for Research on Teacher Learning, 1994, see also AAAS, 1997), the documents that seem to identify Project 2061 are related to content, that is, what students should learn. Given these differences between Project 2061 and the National Standards, I approach the study of the position of technology in the *Standards* analyzing mainly the content area.

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[5] Througgout the text, I refer to the National Science Education Standards in different forms. I use the expressions: "the *Standards*" or the National Standards and mainly the NSES.

In general, technology has a more important position in Project 2061 than in the NSES. As I analyzed earlier, Project 2061 dedicates an entire section of its framework, *Science for All Americans,* to clarify the nature of technology and several other sections to introduce technology as part of K-12 education (e.g., activities on engineering design according to the Benchmarks for Science Literacy, in addition to a chapter on the Designed World). Although the National Standards recognizes the importance of technology: "Everyone needs to be able to engage intelligently in public discourse and debate about issues that involve science and technology", the "weight" of technology in the *Standards* is minimal. Even in the case in which some technological tasks are introduced, there is a tendency to be very careful with its presentation: "Because this study of technology occurs within science courses, the number of these activities [technological tasks] must be limited" (National Research Council, 1995, p. 192).

Regarding the general nature of technology endorsed by the *Standards*, this seems to be in line with Project 2061's : "As used in the *Standards*, the central distinguishing characteristic between science and technology is a difference in goals: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs" (p.24). In addition, the *Standards* recognizes the epistemological richness of technology: "Technology as design is included in the *Standards* as parallel to science as inquiry" (ibid., p.24). Therefore, the general conception of technology in the *Standards* goes beyond the notion of artifact that we explored earlier as the document clarifies: "The use of 'Technology' in the *Standards* is not to be confused with 'instructional technology' which provides students and teachers with exciting tools - such as computers...to conduct inquiry and understand science" (p.24).

The first substantive appearance of technology in the context of the *Standards* is in the Standard E. According to that, K-4 students should develop:

> Abilities of technological design,
> Understanding about science and technology,
> Abilities to distinguish natural objects and objects made by humans (p.135).

The concern of this standard is on developing students' abilities and understanding about design, technological solutions, constructions of artifact, etc. It seems that the *standards* are calling for familiarity with some technological strategies, that is, to identify a problem, propose a solution, implement a solution, or evaluate a design. At this level, some of the technological tasks suggested are:

> ...making yogurt and discussing how it is made, comparing two types of string to see which is the best for lifting different objects, exploring how small potted plants can be made to grow as quickly as possible, designing a simple system to hold two objects together, testing the strength of different materials, using simple tools, testing different designs, and constructing a simple structure (p.137).

From the point of view of teaching science, these experiences should be related to the goal of understanding. To some extent, in the context of the *standards* understanding science is in line with the notion of internal relevance that I developed earlier (chapter 2), that is, describing, explaining and predicting using canonical knowledge:

> Understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events (p.23).

However the NSES does not provide guidance on how to put together this conception of understanding with technological tasks such as making yogurt or designing a simple bridge (structure).

As one can see in the context of the NSES, teaching science tends to stress questions like: How can microorganisms produce yogurt? What kind of biochemical reactions take place? What kind of forces act on a structure (e.g. a bridge)? Why does the bridge support a given charge? From the perspective of technology, what matters is the very construction of useful artifacts (a plan for making yogurt, an efficient bridge). The question is: What is the knowledge that students should learn after designing and

constructing such kind of artifacts? Moreover, what is the knowledge that teachers should know in order to help students with technological tasks. The potential answer to this question is related to the clarification of the technological content knowledge behind the design process. So far, the standard E on technology does not clarify the nature of this knowledge. It does not even mention its potential existence. Despite the critique that I presented on the lack of clarity on the specific technological content knowledge needed to introduce technology in the context of teaching science, Project 2061 has a more developed conception of technology than the National Standards.

Although the National Standards do not clarify the potential existence of technological knowledge, they do suggest the need of introducing technology into the teaching of science. The next level of the standard refers to students in grades 5 to 8. Here, the NSES stresses the relationship between science and technology: "The [technological] tasks chosen should involve the use of science concepts already familiar to students or should motivate them to learn new concepts needed to use or understand technology" (p.161). At this level (middle-school years), technological tasks are more demanding; "...experiences could include making electrical circuits for a warming device, designing a meal to meet nutritional criteria, choosing a material to combine strength with insulation..." (p.165).

The stress in connecting science with technology in the middle-school according to this standard does not mean a clarification of what scientific concepts should be used or how to make the connection between scientific concepts and design. Any of the activities suggested (e.g., making an electrical circuit for warming a device, designing the components of a meal, selecting materials on the bases of heat transference and strength proprieties) require a specific kind of knowledge, *technological content knowledge*, a knowledge which is absent in the NSES. My argument is that without having an idea of the kind of knowledge required for dealing with these activities, the National Standards are

asking teachers for something unknown. Think, for example, of the task of making an electrical circuit for warming a device.

Although the problem of designing an electrical circuit for warming a device is similar to the design of a solar collector (examined in chapter 1 and re-examined in chapter 5), it is instructive to point out the need of clarifying what the knowledge required to carry out this activity is. The problem of design should start with the specification of: what device needs to be heated, what changes of temperature are needed and what the general conditions of the material to be heated are (static, dynamics). In short, for what is the artifact needed. The *standards* call this starting point the clarification of the technological problem. It is important to note that technological problems differ from scientific problems. The former tend to be practical while the latter cognitive. Being practical does not mean that these problems do not have cognitive demands. The very epistemology of technological problems is tied to actions (rather than only analysis). So, one can assume that the solution of practical problems will present cognitive demands for teachers and students.

The most advanced topics of the standard on technology in K-12 education appear for grades 9 to 12. Here, the situation is similar to the sections already examined with the addition of more stress in the design process and the connection science/technology: "This standard has two equally important parts [1] developing students' abilities of technological design and [2] developing students' understanding about science and technology" (p. 190). The standard also suggests some general guides on the choices of technological tasks which should take into account issues like "...whether to involve students in a full or partial design problem; or whether to engage them in meeting a need through technology or in studying the technological work of others" (p.190). Although the general advice is important, the criteria that teachers need to know in order to make a decision on whether or not to involve students in a full design process should be illuminated by the kind of knowledge that they (teachers and students) are persuading and the material conditions for

developing technological work (e.g. materials, instrumentation, laboratories). It is impossible to make a reasoned decision on these aspects of teaching without having ideas of the knowledge that teachers and students will need, the interconnection between knowledge and artifacts, and the conditions that teachers and students will need for developing these projects. The National Science Education Standards do not approach this important problem.

Personal Relevance: The case of the National Science Education Standards and Project 2061

Although the explicit technological knowledge that students should learn is a missing element of the *standards*, one should note that *Personal and Social Perspectives* of science are important components of this reform initiative. It is true that the NSES show few aspects of technological knowledge in the section on technology. However, the section of the relevance of science, *Personal and Social Perspectives* , is full of technological assumptions. In fact, this section is characterized for K-4 grades in terms of:

- Personal health
- Characteristics and changes in populations
- Types of resources
- Changes in environments
- Science and technology in local challenges

For grades 5-8 the topics are similar with the addition that students should take a more global perspective (changes in society as opposed to local challenges).

In these two levels, from K-4 to 5-8 grades, there is a clear concern on the personal uses of science. I do not report in detail all the standards here, in part, because only some of them are directly related to technology. However, it is important to note that the construct Personal Relevance -as a meaning of application- explored earlier (chapter 1 and 2), accounts for this tendency of the *Standards*. Although the connection between personal relevance and technology is a difficult one, the *standards* provide help in clarifying

important relevant aspects of science and technology that students should know. Think of the case of health care.

The demands of the standards can be illustrated by the case of *Judy* already studied in chapter 4. As we saw, Judy is a science teacher who values the personal uses that students can make of science. Health was a constant concern of *Judy*'s classes and it is also a concern of the National Standards as the following example shows: "Food provides energy and nutrients for growth and development. Nutrition requirements vary with body weight, age, sex, and body functioning (Personal Health Standards for 4-8 level, p. 168). This standard is only a sample of a set of recommendations related to health issues. For *Judy*, for example, this is a basic criteria in selecting knowledge. In this case, the relevant knowledge seems to come from biology and related fields such as biotechnology.

The case of Project 2061 is somewhat similar. The Project dedicates some sections to health (chapter 6 of SFAA) and also a specific section to health technology (Chapter 8). It is clear that Project 2061 has less to say regarding Science in Personal and Social Perspectives. In other words, the *Standards* seem to do a better job in this direction. However, Project 2061 did take into account this important aspect of teaching science.

Personal Relevance, as it is presented in the National Standards and Project 2061, is connected to social aspects of science. Some of these aspects were conceptualized in my framework of technology with the notion of technology as social practice. They also have been the core of the so-called STS movement (Yager, 1996). Although advocates of the STS movement complain for the lack of attention that the NSES show on the STS topics (R. Yager, personal communication September 1996), my reading of this document indicates that one would connect several standards with STS themes.

The connection between personal relevance and social aspects of science is only insinuated by the *Standards* and Project 2061. For example, the case of HIV is explicitly suggested in SFAA. This topic can be connected to discussion on DNA (as the case of *Judy* shows) and a discussion on sex. In this context, technology would play a role.

However, the notion of technology that the NSES and Project 2061 portray regarding this connection is technology as artifact (e.g., instruments). The explicit technological knowledge that allows researchers to connect biology with applications is not presented in both reforms.

Concluding Comments.

Project 2061 and the National Science Education Standards provide elements for a discussion about the introduction of technology in general education. I think that both reforms share several features regarding the position that technology should have in the K-12 curriculum. There are basic points that one can stress: 1) technology is seen as important, 2) there is a conception of technology that goes beyond artifact (particularly Project 2061 shows the epistemological value of technology, yet the Project was not explicit with the technological content knowledge that students should learn); and 3) the National Science Education Standards (NSES) seem to stress more the social aspects of science in which technology would find a place.

One could think that, in fact, the two leading reforms make room for technology into the science curriculum. Therefore, the only thing that one should do is...do it! However, one should remember that the introduction of technology as part of the science curriculum is nothing new. There have been several efforts which have not had real impact. One of the reasons is that usually these propositions are not explicit with the kind of knowledge that students can learn with this approach. This seems to be part of the problem in Project 2061 and the NSES, yet there is clear progress in the conception of technology presented at least in Project 2061 (a progress that can be evaluated by looking at Table 4.1 on the evolution of the relationship science/technology). However, it is still important to know what the connections between scientific and technological knowledge are in order to be aware of the potential that technology has for teaching science. This is a missing point of the intents made to introduce technology as part of the science curriculum.

A second problem the introduction of technology faces is its academic status. Technology is identified with vocational studies. In contrast, science is identified with high academic status. This is implicit in the National Science Education Standards. This assumption does not have support given the intrinsic epistemological richness of technological knowledge. However, the perception that teachers and reformers can have of technology is shaped by these problems of academic status. The introduction of technology into the curriculum forces us to rethink these potential problems. In the following chapter, I study why it is difficult to be explicit with the specific technological knowledge translated into the curriculum and how the problems of status of knowledge can or would be basic obstacles for introducing technology into the curriculum. In developing my argument I re-study some sections of the National Science Education Standards and mainly Project 2061. However, the chapter attempts to explain the process of translating scientific, and mainly technological, knowledge from expert knowledge into school knowledge.

CHAPTER 7

TRANSLATION OF SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE INTO SCHOOL KNOWLEDGE

My aim in this chapter is to study the translation of scientific and mainly technological knowledge into the curriculum. I am particularly interested on contrasting the translation of scientific knowledge in relation to the translation of technological knowledge into school knowledge. My thesis is that the difficulties that technology has had in finding a place into the science curriculum are hidden by a complex process of translation of knowledge which I explain in social and epistemological terms.

Translation of knowledge

There are several meanings of the term translation. In Physics for example, translation is related to the motion of a body, particularly its changes of position in relation to a given reference system.[1] The assumption in Classic Mechanics is that some basic proprieties of this given body (e.g. mass) do not change because of the translation. This assumption is only valid for low velocities in relation to the speed of light. In this context, translation and movement are synonymous, i.e., both refer to changes. The same holds for mechanics of fluids in which physicists and engineers use the term "flow" for referring to the translation of a special kind of physical object. In contrast to translation of bodies, flux has the connotation of continuity which at the end is nothing more than another methodological strategy in the treatment of movement of fluids (e.g., gases). This is the case in processes of transfer of mass, such as diffusion (i.e. the transfer of a fluid within

[1]Given a body, its position P_1 at the time t_1 can be represented by a point in a Cartesian system as $P_1 = (X_1, Y_1, Z_1)$ and its position P_2 at the time t_2 ($t_2 > t_1$) is represented as $P_2 = (X_2, Y_2, Z_2)$. The translation of the body is represented by the change of position ΔP ($\Delta P = P_2 - P_1$). The translation ΔP can also be interpreted from a vectorial point of view. Note that the representation of the body and its translation is based on a process of idealization, i.e. the possibility of representing real bodies by ideal points. This process of idealization of real objects and its correspondence representation by abstract constructs has been a powerful methodological strategy in physics and other sciences.

another fluid because of change of concentration.

As one can see, the term translation seems to refer to material objects. In contrast, when physicists or engineers talk about energy (which is a propriety rather than an object) they do not use the word translation. They use the word "transfer". It is illustrated by areas of disciplinary knowledge such as "transfer of energy" or "transfer of heat". The term "transfer of energy" is a misleading name because it produces the sense that "something" called energy is transferred. In fact, one could think that energy is an object that moves from one place to another rather than a propriety. As it is accepted now, energy is a propriety rather than an object. However, it is useful to talk about "transfer of energy", yet we know that energy is not a material object.[2]

A second meaning of the term translation is its linguistic connotation -the act of translating from one language (e.g., Spanish) to another language (e.g., English). From a formal linguistic point of view, a translation is a function that preserves some characteristics of a given language when this language is translated to another. P. Churchland (1979), for instance, suggests that "An optimal translation is a mapping [function] that preserves semantical importance" (p.67). From this point of view, the best translation will produce maximum agreement. I do not adopt this conception of translation. Given the multiple factors that affect the translation of scientific knowledge into school knowledge, it is not possible to guarantee that the goal of translating scientific knowledge

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[2]There are two potential analogies between transfer of energy and translation of knowledge. The first is an analogy that comes from the idea that energy is an object. In fact, from a historical point of view, the theory of caloric has the assumption that heat (now accepted as energy) is an object rather than a propriety. This theory assumes that heat is formed by little particles . In this context, transfer of energy means the translation of these particles. By the same token, one would argue that translation of knowledge mean translation of material knowledge. I do not endorse this mechanist conception of translation of knowledge. A second potential analogy comes from the idea that knowledge is an explanatory concept like energy. Although this analogy seems to be potentially fruitful, it should be analyzed further. I think that knowledge is more than an explanatory concept. It is a propiety of conceptual systems and outcomes of mental processes. I support a neuropsychological base of knowledge (Neisser, 1976; Bindra, 1976) in which social factors play critical roles - as the experiments of Alexander Luria, developed in the 30's- showed (Luria, 1976).

into the curriculum is to produce maximum agreement.

The term translation is used beyond physical sciences or linguistics. Mathematics and even philosophy make a wide use of the term. Translation from a geometrical point of view is related to specific kinds of changes of geometrical figures. Isometric translations are those which keep the structure, for example, the isomorphism, of translating a triangle onto a triangle with the same dimensions, yet in a different position. [3] From a philosophical point of view, Quine challenged the possibility of "translating" logical into empirical meaning. According to him, the distinction between analytic (logical) and synthetic (factual) truths is ill-founded; therefore, logical meaning does not have translation into real life (Quine, 1953).

One could go on looking for different meanings of the term translation. However, in general, it refers to changes. Sometimes it is about changes of material objects and another is changes of properties of these objects, but in general it is about changes. In the context of my work, I define translation of knowledge in the following terms:

The translation of knowledge from one community to another is a general socio-epistemological process which is referred to as the interpretation and/or reinterpretation of knowledge in a community other than the community where it was originally produced.

The word translation does not mean that the knowledge translated remains fixed. Usually the translation includes a reconstruction and production of new knowledge. In this sense, the term translation does not only mean the use of the same knowledge in different

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[3]The mathematician Felix Klein developed a program of unification of Geometry (the Erlanger Program) based on proprieties of figures which remain invariant under transformations. In his taxonomy, the Euclidean plane geometry is only a particular case of geometries which studies the proprieties of figures that remain invariant under translations and rotations. Here "translation" has the meaning of a change of position in the plane (see Boyer, 1986).

contexts (e.g. scientific knowledge in school settings); it also means reinterpretation and creation of new knowledge (e.g., school knowledge for purposes of everyday life).

Using the word translation in talking about knowledge has potential problems. The first potential problem is its common connotation with the translation of material objects. Such connotation would produce the false impression that knowledge itself is moving from one place to another, i.e. from one community to another or even from one brain to another. Based on this, one could conclude that there is knowledge independent of the human being who is producing or reproducing this knowledge, a position already suggested by Plato. I do not endorse this assumption. First of all, the meaning of translation of knowledge in the context of my research goes beyond its mechanical analogy with translation of bodies. Second, the expression "translation of knowledge" reflects a methodological strategy in my treatment of knowledge. In other words, I argue that from a methodological point of view it is convenient to think or pretend that there is translation of knowledge, i.e., that knowledge goes from one point to another or from one community to another. However, from an ontological point of view, knowledge is the product of the brain of a given human being who is embedded in a community.

The methodological treatment of "translation" of knowledge that I offer has some advantages. It particularly permits the study of the content rather than other proprieties related with knowledge (e.g., the cognitive processes which produces knowledge - thinking, learning, knowing, etc.). We use this methodological separation daily in our lives when we read one's idea on paper. For example, now you are not analyzing Fernando's cognitive processes. What you are doing is analyzing the final product, oversimplified, of several cognitive processes of Fernando's brain. These mental processes have been influenced for several factors. Some of them are social (the community in which Fernando is embedded now or was embedded 10 years ago). Others are personal factors (intrinsic psychological characteristics of Fernando's way of thinking...he likes "abstract" concepts). Several of these factors are unknown and many of

them are not relevant for the purposes of the argument that Fernando wants to make in this paragraph. You can escape from these complexities of Fernando's thinking by focusing on the final product of this process, i.e., the content that this paper represents (knowledge). You can separate, methodologically, my thinking from the paper that you are reading and also from the cognitive process which produced that. This methodological strategy would produce the false impression that Fernando's knowledge exists independently of Fernando (the person with his brain and his social history which produced this paper). However, this is not the case.

The general assumption that I endorse about knowledge is that there is not knowledge independent of the human being who produces that (by thinking). I also assume that there is not knowledge independent of the interactions of this human with other humans (by acting). In other words, the ontological position that I have about knowledge is that knowledge is the product of a cognitive process which occurs in the brain of a human being who is acting in a particular social context.

Translation of scientific knowledge into schools: A sociological perspective

The translation of scientific knowledge into school knowledge became socially important only when scientific communities appeared as institutions[4] (e.g., 300 hundred years ago in England) and when schools became public. (e.g., 150 hundred year ago in the USA). What is important is that the process of translation became a process of public interest. Although for centuries there have been processes of translations such as the case of the translation of geometrical knowledge into school knowledge following *the Elements* of Euclid, these cases were not socially important for the general public. The percentage of people who had access to this kind of education was minimal. The translation of scientific

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[4]In 1600 and early 1700 "...no professional mathematical organization yet existed, but in Italy, France, and England there were loosely organized scientific groups: the Academia dei Lincei (to which Galileo belonged) and the Academia del Cimentoi in Italy, the Cabinet Du Puy in France, and the Invisible College in England" (Boyer, 1968, p.367).

knowledge into school knowledge did not represent a social problem. The picture is different when one sees that now, in industrialized societies (and even in other countries) a wide spectrum of the population is expected to become scientifically literate (e.g., Science for all Americans of Project 2061). This is the intrinsic social character of the translation of knowledge which only appeared with the emergence of scientific communities and mainly with the emergence of public education as an institution. Therefore, without scientific communities, there would be no translation of scientific knowledge. Without universal education, there would not be public interest in studying translation of knowledge as a social phenomena. This is an oversimplified picture of the relationship between science and school science as institutions, but it is a preliminary image of how both communities, scientific and school communities, are connected by a flow and production of knowledge that I call "translation."

From my point of view, the process of translation of scientific knowledge into school knowledge is a socio-epistemological process. For methodological reasons, I will study first some epistemological characteristics of the translation of scientific and technological knowledge. This epistemological analysis will provide a basis to discuss some of the social factors which are behind the translation of specific scientific and technological knowledge.

Translation of scientific knowledge: A general introduction

The translation of knowledge on which I focus is a process of transfer of scientific knowledge from scientific communities to school communities resulting in science school knowledge. I argue that this process produces changes in the knowledge which is translated. In other words, because of this process, some aspects of the expert scientific knowledge (ESK) changes when it is used in school communities. Early in my work, I suggested that the change of scientific knowledge when it is translated to school subjects

would be explained for the following reasons among others:

> a) the users [of scientific knowledge] are different, in this case teachers have different goals than scientists; b) the reinterpretation of the theory introduces changes; c) the level of schooling of students and teachers introduces limitations; d) the rules and conventions in both communities, scientific and school communities, are different; e) the educational system is also a site of knowledge production. (Cajas, 1995a, p. 179)

It is possible that the reader would find problematic my interpretation that scientists and teachers have different goals. My point here is that both institutions, scientific and school communities, have different goals. I do not mean that schools do not have some overlapping goals with scientific communities. However, schools are being asked to do many more things than teaching science.

The second point is the changes to a given scientific theory when it is re-interpreted. Let us think of the notion of *force* and the different scientific theories about *forces.* Traditionally, the concept of force that has been translated from scientific communities to school communities is the Newtonian Mechanics. Usually, school science has the goal of teaching versions of the Newtonian Mechanics. The school goal seems to be the reproduction of Newton's laws. The reinterpretation of these laws introduces intrinsic problems. For example, what students and several teachers have is a phenomenological conception of force, i.e., force as perceptual or even visible actions (push or pull). For some people, these interpretations are only the perceptual roots of more abstract concepts of forces (diSessa, 1993). Although the goal of scientists and science teachers with their students is to use these conceptual tools for understanding natural phenomena, the level of schooling introduces limitations. It seems that only some elementary and secondary science teachers develop Newtonian conceptions of forces. Research in naive conceptions has shown the status of such notions in students, i.e., they are no developed conceptions of forces (Viennot, 1973). Therefore, the translation of the Newtonian Mechanics has been problematic, yet not impossible.

It is important to note that the translation of knowledge of which I am talking about

is the translation from expert scientific knowledge (ESK) to school science knowledge (SSK). My assumption is that SSK is the outcome of a complex process of selection, debate and reinterpretation of a small part of ESK. As I discussed in chapter 3, from a methodological point of view I separate the translation of expert knowledge (ESK) to school knowledge (SSK) in several different stages. For example, in my framework, the first generic translation from ESK to SSK includes a transformation of expert knowledge into subject-matter knowledge (SK). Remember that SK is the knowledge of science teachers (see chapter 3 and 4). Expert knowledge is related to subject-matter knowledge in different forms, some of which are epistemological relations (e.g., key ideas in the discipline versus key ideas in teaching, Deng, 1997; Cajas, 1995a) while other are social (Cajas, 1995a, Chevallard, 1990; Verrert, 1975).

The traditional picture of the translation of scientific knowledge into school knowledge is usually seen as a monolithic, passive and atemporal process. Even contemporary and progressive science education reform proposals such as Project 2061 present or assume such a static picture. However, a critical view of the history of science education and also a revision of the research on the evolution of scientific ideas show that the case is much more complex than that. Here, one should note that the way in which one sees the translation of ESK to SSK is shaped by one's conception on how scientific knowledge is produced, developed and communicated.

First of all, in developing scientific explanations within scientific communities, there is usually a set of competing ideas (Kuhn, 1962/1972). Only some of these ideas survive in a given era and few of them are translated into the school curriculum. For example, the concepts of force suggested by Aristotle, Leibinz and Descartes, among others, were not translated to the school knowledge. All of them have interesting approaches to the notion of force and its potential application for explaining and predicting the movement of objects (see an example in Silva, & Bastos, 1995, an historical analysis of the Leibiniz and Descarte' conception of forces). However, none of them is even

mentioned in traditional science classes. The Newtonian paradigm was the only one which was translated. What is interesting is that it was not the work of Newton the one that was actually translated to the school knowledge. Although the work of Newton is important, traditional histories of science have overvalued it. The school knowledge about forces comes from the re-creation of the Newtonian Mechanics suggested by Euler who "...put most of mechanics into its modern form..." (Trusdell, 1968, p.106). In fact, Leonard Euler (1707-1783) was the person who suggested several contributions to mechanics, including: 1) the use the concept of the *mass-point* for referring to bodies; 2) the definition of *acceleration* in an explicit way and its graphical identification; and 3) the introduction of the notion of *vector* (geometrical quantity). What we have in school is a kind of Euler-Newtonian Mechanics.

What is important for my account is that there were several competing ideas about forces and the way in which they could represent natural laws. Usually, school science does not show this history. One of the reasons, I argue, is that what is translated is not the original work, which is only understood by a few people. Given an original, potentially powerful framework, it is necessary to reconstruct the theory for other people to understand it. This process includes the cleaning up of the original context together with a codification process: "Reconstruction is needed to produce an account ordered enough to enable action to communicate what is going on" (Gooding, 1992, p.76). In approaching the same problem, Holton explains this process in terms of his "private" and "public" science constructs.

According to Holton, there are two different kinds of processes in the "natural" selection of scientific ideas. Private science (S_1) accounts for the complexities and uncertainties of the construction of scientific concepts. This process describes part of the implicit knowledge of "doing" science which is usually not reported (see the notion of procedural subject-matter knowledge defined in chapter 3 which is related to this knowledge). From the perspective of S_1, private science, creativity and ambiguity play

important roles in the development of scientific theories. However, the knowledge developed in S_1 (science-in-the-making), is not all translated to the public science (S_2), which is the science published in research journals, for example. This latter process, S_2, stresses translation as a body of knowledge (substantive expert knowledge) which does not account for the struggles of knowledge production.

S_1 and S_2 are components of the process of translation of knowledge within communities of experts. I do not theorize this process (there are already important contributions since the pioneer contributions of Fleck, the works of Merton, the contemporary contributions of Kuhn, Holton, Gooding, and all the contemporary work on philosophy of science of the last thirty years. There is also much work to be done). My study is not on the evolution of scientific concepts and theories nor a history and philosophy of science. I use some of these studies in order to make sense of another kind of phenomena: translation of knowledge from expert scientific knowledge to school knowledge, that is, its pedagogical transformation. Philosophy and history of science become here tools for analyzing what aspects of the expert scientific knowledge are translated into school knowledge, how and why.

T. Kuhn, for example, has made important contributions to the history and evolution of science. According to him, what is translated is what he calls normal science:

> In this essay 'normal science' means research firmly based upon one or more past scientific achievements that some particular scientific community acknowledge a time as supplying the foundation for its further practice. Today such achievements are recounted, though seldom in their original form, by science textbooks, elementary and advanced. These textbooks expound the body of accepted theory, illustrate many or all of its successful applications, and compare these applications with exemplary observations and experiments (1970, p.10).

It seems to me that Kuhn's framework accounts for what Holton has called public science (S_2) and private science (S_1) in quite different ways. However, in either model, Holton's or Kuhn's, the process of re-interpreting and decontextualizing scientific knowledge seems to be necessary for the advancement of science. Using both Holton's and Kuhn's references, one can distinguish, in principle, two kinds of reinterpretations: cognitive and

pedagogical. From a Kuhnian perspective, such a translation process takes place within scientific communities in order to consolidate "normal science". The account is epistemological and it is based on à kind of variation-selection model borrowed from the Darwinian theory of selection.

In either model, Holton's or Kuhn's, the process of re-interpreting and decontextualizing scientific knowledge seems to be necessary for the advancement (variation-selection) of science,

> The lesson to be drawn from history is that science as a structure grows by a struggle for survival among ideas; there is a marvelous mechanism at work in science which in time purifies the meaning even of initially confused concepts, and eventually absorbs into what we may label S_2 (public science, science-as-an-institution) anything important that may be developed, no matter by what means or methods, in S_1 (private science, science-in-the-making) (1985 p.189).

The case of the Newtonian Mechanics and the role of Euler in its reinterpretation is an example of a cognitive translation. There are so many more examples. Robert Millikan, a second example, designed an experiment for determining the charge of the electron. The experiment, its ontological assumptions, its methodological difficulties, its competing paradigms (in this case his rival Ehrenhaft) and even the skills developed in the experiment itself were not translated in school knowledge (pedagogical translation). What is translated is the final fact: "The charge of the electron is -1.6×10^{-19} Coulomb).[5] The implications of these reinterpretations on school settings are enormous. The reason is simple, the reconstruction of such an experiment is complex, if not impossible, in addition to the fact that we have few historical accounts, i.e., case-studies, which can help us to reconstruct realistic pedagogical versions. What we usually have in school science is a clean history in which science is a body of knowledge developed for heroes or gods.

So far I have presented a general description on how the process of translation of knowledge may be related to the evolution of science. I have mentioned that these descriptions tend to be cognitive, that is, epistemological. I have briefly mentioned other

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[5]Actually Millikan reported his results in other unites, $e=4.917 \times 10^{-10}$ esu (Shamos, 1959, p.246).

kinds of factors that affect the translation, such as methodological assumptions, ontological commitments, etc. In fact, researchers have identified different kinds of "reconstruction" of science. From my point of view, these "reconstructions" are "translations" only when the community in which the knowledge was originated changes. Here, the framework of David Gooding is a useful one. In fact, Gooding talks about other kinds of reconstruction of science, such as demonstrative (reconstruction that generates evidence of particular experiments), methodological (reconstruction which stresses agreement according to canons), rhetorical (reconstruction that attempt to convince), and normative (reconstruction that attempt to formalize). Table 7.1 is a re-interpretation of Gooding's reconstruction of science.

Table 7.1. Different types of reconstruction of scientific knowledge (reinterpreted from Gooding 1992, p. 78).

Kind of reconstruction	**Activity**	**Narrative**	**Enables**
Cognitive	Constructive	Notebook, sketches, letters	Representations, communication, argument
Demonstrative	Reasoning	Draft of papers letters	Ordering, descriptions demonstrations
Methodological	Demonstration	Research papers, monographs	Communication, criticism persuasion, reconstruction
Rhetorical	Demonstration	Paper, treatise	Persuasion, dissemination
Pedagogical (called didactic by Gooding)	Exposition	Textbooks treatise	Dissemination of exemplars
Normative	Reconstruction	Treatises of philosophy	Logical idealization

The reader should note that there are several different types of reconstruction of scientific knowledge. Each of them has quite different goals. From these sorts of transformations, the one that is more important for my account is the pedagogical transformation. In the case of Gooding's framework, the pedagogical transformation takes place within scientific communities. That is, this is an internal process of communication of science which is partially responsible for the evolution of science. When this transformation takes place outside of scientific communities, that is, when scientific knowledge is transformed (re-interpreted or re-created) in other communities (e.g. school communities), there is a *translation* of knowledge according to my framework. This translation accounts for the uses of scientific knowledge by non-professional scientists (e.g., high school students).

The translation of technological knowledge: An exploration

The first question that comes to mind is if the above explanation of the evolution of scientific knowledge also holds for technological knowledge. In order to clarify this point, it is important to note that my epistemological account on the translation of scientific knowledge has been illuminated by works of Kuhn, Holton and Gooding. In general, these authors share the idea that the history of science can be explained in terms of variation and selection of knowledge. From this perspective, the evolution of science is analogous to the evolution of biological species. There is a set of competing ideas (e.g., Aritotelian notion of force, Leibinz's notion of *Force Viva*, Newtonian idea of momentum, Euler's conception of acceleration), but only few of them survive (Euler's notion of force and acceleration for a point mass). From this generic perspective, one could make the case that the evolution of technological knowledge can also be explained in terms of variation and selection.

It is important to realize that there have been several attempts to explain the evolution of technology (reference: any book on history of technology). However, most of these

attempts have focused on the evolution of artifacts. As I showed in chapter 5, only in the last twenty years or so has there been an interest in studying the epistemological nature of technology (Layton, 1974; Bunge, 1976). During these two decades, philosophers of technology have also suggested the application of Kuhn's framework to technology (Laudan, 1984). The basic idea of these attempts is that the evolution of technology follows a variation-selection model.

When one sees the evolution of technology in terms of variation-selection models, one needs to be careful in clarifying the criteria of selection. Although a generic model of evolution may work for science and technology, the evolution of technology has different criteria given its extreme dependence upon procedural and practical knowledge.[6] In fact, in *What Engineers Know and How They Know It*, Walter Vicenti presents five specific historical cases on the evolution of modern aeronautics which he incorporated in a variation-selection model of engineering knowledge. A full account of this model and cases can be found in Vicenti's book (see also chapter 5 of this dissertation for a revision on Vicenti's taxonomy of engineering knowledge). Here, I will clarify the criteria of variation-selection rather than explaining the details of the model.

Given a specific body of technological knowledge, for example engineering knowledge, the criteria of selection seems to be based on utilitarian reasons. For example, according to Vicenti:

> ...the criterion for selection of a variation for retention is, Does it work? or more precisely, Does it help in design of something that works? This question, perhaps unexpressed, exists in the mind of anyone laboring to add to engineering knowledge, even in the most abstract reaches of engineering research (1990, p.248).

The evolution of science seems to have a different criterion of selection. In principle, knowledge is selected according to the kind of explanation. For example, Newtonian mechanics helps to understand "better" the universe than Aritotelian mechanics. Here,

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[6]Remember that this section focuses on epistemological factors of technology. When one sees technology in the context of social factors (i.e., economic, political, cultural) its complexity is even greater than science, yet both enterprises are related.

understanding means to describe, explain and predict. Although research on history and philosophy of science have shown a more complex picture of the evolution of science (e.g., Kuhn, 1962; Gooding, 1990), we know that scientific communities have been successful institutions in accumulating knowledge that explains and predicts natural phenomena in accurate ways. Technological communities, in contrast, have been successful in accumulating knowledge to create useful things.

When one sees scientific and technological communities as an outsider, one could conclude that the propagation of knowledge follows similar patterns. One first option would be to adopt a variation-selection model. In doing so, one may take a look at journals, conferences, textbooks, teaching traditions, etc., and then conclude that the basic elements of the propagation of scientific knowledge are similar to technological knowledge. This holds only from a very generic perspective. In order to see what is really going on with the evolution of technological knowledge, it is important to focus on a specific theory or a specific topic. Given the frequent uses I have made of the concepts of energy, heat and temperature, I will explore their scientific and technological roots. I heavily based my exploration on the examples presented in chapter 1 (pragmatic models of transfer of heat, pp. 27-31), chapter 5 (epistemology of engineering, how energy is seen from a scientific and technological perspective) and chapter 6 (specific knowledge to design a solar collector). The reader may need to re-read some of these sections while she/he is reading the following account.

The historical development of heat theory has its roots on the works of Newton and Fourier (Bergles, 1985).[7] There are abundant historical accounts regarding the contributions of Newton who developed an expression to explain the transfer of heat from a surface of area A to the surroundings. The expression is $q=Ah\ (T_{sur}-T_{surr})$, in which q is the rate of heat flow, A the area of transfer, h the heat transfer coefficient, T_{sur} is the

[7]Of course, I am making a huge simplification of this history. The origins of these concepts can be traced back to Galileo's gas thermometer or even to the Aristotelian notion of hot (Sanchez, 1997).

temperature of the surface of area A, and T_{surr} is the temperature of the surroundings, is attributed to Newton.

Based on the works of Newton, the French scientist, Joseph Fourier, developed *La Theorie Analytique de la Chaleur* (1822). For example, historians have reported that Fourier used the so called Newton's Law of Cooling, that is, $dq/dA=dT/dt=T-T_{air}$, to clarify the meaning of conduction in solids (Bergles, 1988). In fact, Fourier extended the works of Newton to the process of conduction of heat inspired mainly on problems related to temperature of the earth. Fourier was able to suggest the instantaneous flux of heat in solids (Trusdell, 1980).[8] By the time in which Fourier developed the theory of heat, the Newtonian paradigm was already solid. Therefore, his explanation on how conduction and convection take place was incorporated to the Newtonian world-view. What is important is that the theory of heat had its roots in an intrinsic conception of understanding the world, that is, describing, explaining, predicting.

The works of Newton and Fourier were the basis of posterior development of concepts of heat and temperature. Fourier particularly invented the mathematics of "heat flux" (Fourier's series, partial differential equations). At this point in history, the accounts on heat and temperature were scientific in the sense that they attempted to describe, explain and predict natural phenomena (e.g., the problem of cooling the earth; see Holton, 1985, pp. 285-287; see Fourier 1890, i.e., his *Oeuvres*, for a beautiful original account, see Grattan-Guinness, 1972 for a translation into English). However, at the same time, there were practical problems such as those related to increasing the efficiency of commercial stream engines (Carnot). This latter practical problem set the basis of the principle of conservation of energy (first law of thermodynamics) and the degradation of energy

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[8]According to Trusdell: "Fourier's great contribution is the concept of flux of heat" (1980, p.76). In order to define flux it is neccesary to use vectorial analysis, that is, the flux of heat q is defined in the following terms: q=-KgradT in which q is the flux of heat, K the specific conductivity, T temperature and grad the operator ($\partial/\partial x$, $\partial/\partial y$, $\partial/\partial z$). "Flow" of heat does not requires vectorial analysis and it is an expression less formal to represent the "movement" of heat.

(second law). Here, I see a separation in the history of science in relation to history of technology. This separation has important implications for my account.

In principle, physicists followed a "scientific" route, particularly they used the Newtonian paradigm to approach problems of heat and temperature by moving their explanations toward atomic models. The case of the kinetic theory of gases to explain processes of heat transfer is a classic example. In contrast, engineers approached problems of heat and temperature from more utilitarian perspectives. This separation is reflected in the way in which physicists have pursued problems of heat, temperature and energy in relation to engineers.

The history of thermodynamics is tied to the evolution of the concepts of heat, temperature and energy. This paradigm has been enriched by using the atomic theory. For example, notions of heat and temperature have been reinterpreted as atomic and molecular phenomena. Thermodynamics followed the ideal of the Newtonian paradigm of describing, explaining and predicting using causal and deep models. In fact, at the end of the 19th century, physicists had a common vision on the topic of heat transfer. The specific case of gases may be used as an example. According to Brush, this consensus includes the following *synthesis:*

> (1) Conduction is the process described in the kinetic theory, whereby fast molecules drift randomly from hotter to cooler regions of the gas where they collide with slower molecules and transfer to them some kinetic energy...
> (2) Radiation is the process of heat transfer by emission and absorption of electromagnetic waves, at a rate that depends on the temperature of the emitter. The total emission rate, integrated over all frequencies, is proportional to the 4th power of the absolute temperature...
> (3) Convection is described as transfer of heat by bulk motion of the fluid....(Brush, 1985, p. 44).

Although from a contemporary perspective one may introduce several corrections to this "synthesis," what is important is that *heat transfer* was framed as a way of seeing the world. This is reinforced by the very history of thermodynamics in which processes of conservation of energy were developed from universalistic and formal orientations (e.g.,

the basic laws of thermodynamics). However, there is another history of heat transfer. This history has to do with how engineers have used some basic conceptual tools of heat transfer to design things. In principle, rather than being interested in universal phenomena and explanations, engineers were looking for more effective ways of transferring heat in specific artifacts. Joule, for example, reported in 1861 how to increase the heat transfer in a condenser tube in which there is flow of water (Bergles, 1988, p. 56). The performance of a condenser tube with specific geometrical configurations is a local problem. The same holds for the design of a specific solar collector or any technological artifact. The knowledge gained from this research tends to be local rather than universal. The connection between the universal laws of thermodynamics or even the notion of heat transfer and the specific artifact is an open problem that philosophers of technology are just starting to approach.

The design of specific artifacts has forced engineers to create knowledge for very situated conditions. For example, the performance of a condenser, or the efficiency of a water heater (such as the solar collector I studied in earlier chapters), requires particular specifications. From an epistemological point of view, the process is not linear, that is, this is not the simple application of general and universal law to specific cases. Rather, there is an intrinsic generation of specific knowledge that is completely related to the specific artifact. The connection between the universal and the local can be mediated by standards (Shapiro, 1997) or by specific conditions (see chapters 1 and 2 of this dissertation, as well chapter 5 for examples). Even the general knowledge which is behind the analysis of heat processes from the perspective of engineering tends to be macroscopic rather than microscopic (see chapter 5 for a more detailed taxonomy of engineering knowledge and chapter 6 for a detailed analysis of the knowledge needed for designing a solar collector). In fact, engineers use atomic theories only when this is a necessary and unavoidable step in the creation of their artifacts (e.g., designing micro-electronic components of a computer); otherwise they hold macroscopic theories.

The separation that I report between thermodynamics and the heat transfer of specific artifacts reflects a delimitation of epistemological territories. This separation could be seen as the traditional vision that technology is the application of science. However, my point is different. The history of the development of the concepts of energy, heat and temperature depends on the community in which these concepts have been created, re-created, used, and re-used. Within scientific communities, the tendency has been the creation of universal knowledge, formal structures and deeper explanations (e.g., atomic and molecular explanation of heat transfer). These explanations attempt to be valid; that is, they explain, to some degree of confidence, what is going on in nature. In contrast, when one sees engineering models of heat transfer, they are not even valid from the scientific point of view. This reflects a basic epistemological difference between technology and science.

When Carnot developed his work on the efficiency that an engine could perform, he based his work on the caloric theory. This theory had been rejected by scientific communities because scientists have accepted that heat is not a material object, but rather a property (energy). What is interesting is that despite the use of an "invalid" theory, his practical outcomes are still important (useful from an utilitarian perspective). Physicists know that, but they do not explain why:

> Carnot used the caloric theory of heat in his analysis of steam engines; he assumed that heat is not actually converted into work, but that the flow of heat from a hot body to a cold body can be used to do work, just as the fall of water from a high level to a low level can be used to do work. Although the caloric theory upon which his results were based was later rejected by other scientists (and even by Carnot himself in notes that remained unpublished until 1878), his conclusions are still valid (Holton, 1985, p.288).

The reason is that in order to be efficient, you do not need a "true" description of the system (Bunge, 1983 and chapter 5 of this dissertation). Efficiency is not validity. Truth is not a concern of technological communities. However, one should not rush to the conclusion that all technological models are *lies*. What they are, I argue, is that they are

valid enough to the specific conditions of the design. This point requires a second explanation.

Currently, *heat transfer* within technological communities is still based on macroscopic models of heat. Moreover, several of these models still remain connected to theories of heat in which heat "flows" from one point to another. Heat flow is seen as the movement of an object from high temperature to low temperature. These models are invalid judged from a scientific perspective. However, they are still useful to do calculations, determine "areas of transfer", rates of transfer, coefficients of conduction, etc. In fact, one characteristic of *heat transfer* as a disciplinary territory in relation to thermodynamics is that it is based on "old" conceptions of heat rather than "scientific", "accurate", and "deeper" explanations (e.g. atomic).

The separation between *thermodynamics* for physicists and *heat transfer* for engineers reflects the approach of a generic topic from two different perspectives. Although both epistemological territories share several roots and borders, their epistemological commitments are quite different. It is reflected by the existence of journal of thermodynamics and journal of heat transfer. The latter refers mainly to the analysis of specific artifacts and particular process of heat transfer (for example the *Journal of Heat Transfer* of the American Association of Mechanical Engineering, textbooks dealing with heat transfer from the engineering point of view, and the specific "handbook" of heat exchanger, which are full of empirical tables, local laws, graphical trends, tables of efficiency of different artifacts). However, this is not only in the arena of heat transfer. Even the generic thermodynamics when it is seen from the perspective of a physicist looks different in the hands of an engineer (see chapter 5 regarding the same discussion in the case of Newton's laws). Engineers have invented conceptual tools that are not used by scientists, such as the case reported by Vicenti (1990) of the control-volume analysis.

Control volume analysis is a general framework in engineering thermodynamics that allows you to analyze a given volume. Focusing on a specific volume helps to do the

bookkeeping of physical proprieties such as energy balance, momentum balance, etc. The use of control volume analysis avoids the study of the underlying physics of complex systems. Although a physicist would prefer a detailed analysis (e.g., to study the movement of a fluid point by point), the complexity of the systems with which technologists usually work and the demands of practical outcomes have forced engineers to create tools that scientists do not use (they do not need them anyway!).

The idea that engineers think about their problems differently than scientists has been recognized long ago. However, this statement is usually made in abstract. The specific espitemological implications of these different ways of thinking are still unknown (Vicenti's clarification on the control volume analysis is an exception). My dissertation is another exception, but it is a study on the implication of technological knowledge in science education rather than a specific treatise on epistemology of engineering). Such implications are in the core of what I call translation of scientific and technological knowledge into the curriculum.

What is important from this epistemological exploration is the idea that the evolution of scientific knowledge is related in complex ways to the evolution of technological knowledge. Given the specific goals of technological communities, scientific knowledge is re-interpreted in contextual ways. Therefore, we can add to Table 7.1 another kind of translation of scientific knowledge: *technological translation.*

Table 7.2 Reconstruction of scientific knowledge to design artifacts.

Kind of reconstruction	**Activity**	**Narrative**	**Enables**
Technological	Design of artifacts	Plans sketches	Create new useful things

Note that Table 7.2 only reflects part of the discussion I have presented. The translation of scientific knowledge into technological communities also needs to be informed by the very

creation of new knowledge, technological knowledge, completely situated to the community, such as specific knowledge about specific artifacts (substantive and procedural) or specific frameworks that are invented by technologists and not necessarily used by scientists (e.g., control-volume analysis) .

The lesson I learn from this discussion is that the evolution of technological knowledge is related to the evolution of science. However, the specificity of the goals of technological communities shape the scientific knowledge used by technological communities. Moreover, such goals also determine epistemological characteristics of technological territories. The following table summarizes this contrast. The reader should be aware that this table reflects a crude separation between science and technology. However, the interface between both, that is, the common ground, is the interesting part of science education.

Table 7.3 Epistemological assumptions of science and technology drawn from the example on thermodynamics and heat transfer.

Science	Technology
The world is understandable	The world is manipulable
Knowledge is universal	Knowledge is local
Knowledge is to describe, explain and predict	Knowledge is to transform, design, improve

The translation of technological knowledge into the science curriculum.

The translation of scientific knowledge into the curriculum of general education already has a long history (e.g. DeBoer, 1991). In contrast, the translation of technological knowledge into K-12 curriculum has been more problematic. In fact, I argue that there has practically been no translation of technological knowledge into school knowledge in the sense in which I use the term technology. There have been practical applications of science such as the case of the science curriculum in the United States before the 50's. However, I do not see such applications as part of the introduction of technological knowledge. In

principle, because this curriculum did not recognize the very existence of technological knowledge that could connect science with students' everyday lives.

From an historical point of view we know of some cases that have attempted to introduce technology as part of the K-12 education. For example, the case of Central High School, last century, is interesting: "Perhaps the most vivid symbol of the utilitarian character of the practical curriculum was the inclusion within it of few courses that were strictly vocational ...stenography, bookkeeping, mechanical drawing and *civil engineering*..." (1988, p.22 italics added). The temporal context and the magnitude of these kinds of courses is explained later by Labaree: "Vocational courses did not appear in the curriculum until the mid-1840s, and they never constituted more than 15 percent of the students' time in class" (ibid., p.22). In this context, technology is identified with vocational studies. In fact, technology has been mostly identified with vocational studies (Lewis, 1994). This option, vocational studies, does not recognize the epistemological value of technology either.

Calvin Woodward, late last century, designed a version of high school engineering education "...to replace the traditional vocationally irrelevant education" (Collins, 1979, p.113). Woodward's attempt is interesting given its specific goal of introducing engineering into general education. However, his high school did not survive (Collins, 1977). Other attempts to introduce technology in general education are: *A Study of Technical Institutes* (the society for the promotion of Engineering Education (1931), *A curriculum to Reflect Technology* (William Warner, 1947), Engineering Concepts curriculum Project: The Man-made World (the Bell Telephone Laboratories, 1964), and the Jackson's Mill Industrial Art curriculum in 1990 (see Gradwell, 1996 for an extensive analysis of several cases). What is important to note is that the common pattern of all these attempts is that they have had almost no impact in science education.

Currently, there is a big concern for including technology into the science curriculum. This is the first time in the history of science education in which technology is

being included as part of curricular content. For example, Project 2061 and the National Science Education Standards are two current reforms that have suggested how to introduce technology into the science curriculum. Although both have quite different conceptions of technology, both reflect explicit attempts of translating technology into the science curriculum. To some degree, the assumption of both proposals is that science education will improve with the introduction of technological tasks. However, as I showed in chapter 6, despite these attempts and the rich generic conception of technology endorsed by Project 2061, the translation of technology into the science curriculum is going to be difficult if not impossible. The reason I have to support this is related to the lack of clarity that both proposals have regarding the specific technological knowledge that students should learn and its specific connection with science education. I explain this lack of clarity in terms of the complexity of technological knowledge and also in terms of the social position that this knowledge has in a given social structure.

There have also been alternative attempts to introduce technological knowledge. Researchers have been studying the potential technology has in science education. Some examples are the case of Raizen and her colleagues at the National Center for Improving Science Education (NCISE) in Washington (1995). Raizen's book (1995) is an extensive report of the status of technology education in the context of science education. A second example is the curriculum materials developed at Northwestern University (Hsu, Walhof & Turner, 1998; Bumgartner, 1998). Another example is the work of Martia Linn at Berkeley regarding the introduction of pragmatic models to learn notions of heat and temperature (thermodynamics). In fact, I opened my dissertation with an analysis of the work of Linn at Berkeley (Linn 1997).

In light of my discussion on the nature of technology, one can conclude that Linn is suggesting the introduction of technological knowledge. The goodness of her proposal is that these models seem to be more relevant to students' everyday lives than abstract school science. The same holds for the other reports (Raizen, et al., 1995; Bumgartner, 1998).

They all assume that with these activities, students will connect science to their everyday lives. However, the problem with these reports is basically the same as Project 2061 and the National Standards problem; that is, there is a lack of clarity on the specific knowledge students will learn. This lack of clarity, together with other characteristics of the translation of technological knowledge into the science curriculum, needs to be studied.

After this short review of the attempts of introducing technology in general education, one should ask why technology has not found a place in general education and mainly in the science curriculum. What factors have affected the translation of technological knowledge into the K-12 curriculum? The explanation I offer takes into consideration two dimensions: 1) the kind of knowledge which is translated, and 2) the social position of the knowledge in a given social structure. The former is related to the intrinsic nature of the translation of technological knowledge as opposed to the translation of scientific knowledge. This dimension also addresses philosophical status and pedagogical implications of technology. The latter dimension has more social connotations such as, the role of professional battles in the construction of K-12 curriculum. Both are basic arguments to understand the potential translation of technology in science education.

The translation of scientific or technological knowledge into school knowledge includes the translation of the view of the nature of knowledge, i.e., the assumption on what is valid knowledge. Traditionally, science education reforms tend to translate, explicitly, only the content, i.e., the knowledge. The philosophies behind such content, the criteria of validity for example, are only implicitly translated. The case of current science education reforms is a mix because to some extent they are explicit with the nature of science that they propose, e.g. Project 2061 and the National Science Education Standards. In fact, both educational reforms partially present explicit views of the nature of science. Project 2061, for example, suggests a set of ontological, methodological, epistemological and ethical principles of science that should be translated into school knowledge (Cajas, 1995a). With the exception of its section on technology, the conception of "valid" knowledge in

Project 2061 tends to be general, universal, and abstract knowledge. From this perspective, science is a body of objective knowledge which is close to the truth.

The case of technology is quite different. As I discussed in an earlier section of this chapter, technological knowledge is not tested for its validity. What is important is whether or not it works. The criterion is more utilitarian. The test is for usefulness rather than for truth. This locates technological knowledge in a more mundane position than scientific knowledge (Lewis, 1991, 1994). From an epistemological point of view, this utilitarian perspective is different. Scientists assume that *the world is understandable* while technologists assumes that *the world is manipulable*. The motivation behind science and technology is rather different. In this sense, whereas for scientists knowledge is an end, for technologists it is a means for dealing with practical goals. This situation re-introduces an old tension between abstract and practical knowledge. Abstract knowledge tends to have higher status than practical knowledge. Moreover, what is translated into school knowledge is a kind of abstract and decontextualized knowledge. What is valid is a *platonic* view of knowledge (Lewis, 1994). Practical knowledge is not valid from this platonic perspective.

The conception of what is considered valid knowledge and who is deciding such validity are important elements in the determination of what knowledge at the end is translated into public education. A classical position tends to value platonic conceptions of knowledge. Furthermore, canonical scientific knowledge can be easily re-interpreted from this idealistic position. The tendency of educational systems is to focus on esoteric knowledge rather than mundane knowledge,. This is the essence of the academia. This phenomena is implicit in the account that the sociologist Durkheim presents about the history of the educational systems in Europe, mainly France, together with the formation of the Universities (Durkeheim, 1938). Because of their historical and philosophical roots universities tend to value abstract orientations rather than empirical ones, and then universities impose the knowledge that should be taught.

The implications of having a conception of knowledge which overvalues abstract

and authoritative discourses are important for education. From a pedagogical point of view, it is easier to develop didactic (teacher-centered) approaches to communicate knowledge already developed. From this perspective, codified knowledge has more advantages over contextual, local, tacit, and procedural knowledge, that is, practical knowledge on which technology is based.

The tension between abstract and practical knowledge which is a reflection of the tension between esoteric and mundane knowledge and also universal and local knowledge is only a part of a potential explanation on the difficulties of translating technological knowledge. A second important point is the social position of the knowledge. Some societies tend to value different kinds of knowledge than others. Therefore, it is not only the nature of knowledge the important factor, but it is also important the social position of this knowledge in a given social structure.

The social position of the knowledge depends on the kind of community that shares such knowledge and the social position that this community has in a given time and society. Engineering knowledge, for example, presents interesting characteristics for being included as a part of general education. Engineering knowledge, in the sense in which I have presented here, can play a connecting role between science and students' everyday lives. Moreover,

> Given the clear-cut importance of engineers above all of the professions in industrial society, we might expect that engineering training would dominate the educational system. Indeed, it is plausible that an industrial society could operate with an educational system devoted almost entirely to engineering (1979, p.159).

However, the process of translating knowledge into schools is not only shaped by epistemological factors. There are intrinsic and basic social problems that affect such process. The case of American engineering studied by Randall Collins illustrates this point:

> Throughout the nineteenth century, then, American engineering failed to achieve either a united profession or a widely accepted system of education...the more popularly oriented forms of engineering education-the mechanical institute and the

training schools-failed from their fatal trait of low status connotations (ibid. pp. 168-169).

The roots of this low status of American engineering is related to the problems of the formation of professions. Engineering as profession comes from humble positions such as skilled laborers and entrepreneur administrators "The skilled laborer side of engineering proved an even more serious embarrassment" (ibid., p.174). In addition, the referent of the engineers are not embedded with esoteric connotations: "Engineers, however, deal with relatively uncontroversial and unemotional tasks...Even more ironically, engineers and technicians suffer from the very success of their techniques. The outcomes of their work are quite reliable..." (ibid. 174). These characteristics of engineering knowledge make it very useful to be included in connecting school science with students' everyday lives. However, the same characteristics make engineering knowledge very low on our traditional scales of valuable knowledge.

In attempting to introduce technology as part of the curriculum of science education, one should be aware of the complexities already reported. As I showed in earlier chapters, technology has the potential of connecting science to students' everyday lives. In this way, technology can be used to satisfy basic goals of current science education particularly by connecting science with students' everyday lives. However, this connection cannot take place without affecting the basic goals of science education. This is the last part of my argument.

A generic case of translation: The goals of science education

In general, it has been suggested that there are three goals for science education. These goals are economic, political, and cultural. In clarifying these goals, I use the idea that any human society can be analyzed at least in these three basic systems (economic, political and cultural). These three systems are interconnected and the kind of connection depends on the type of society. What follows is a general characterization, rather than precise definitions, of each system. The economic system has the purpose of material

production, for example manufacturing. The political system is referred to the state or government, i.e. the control and administration of the social power and also the political interconnection among citizens. The cultural system is formed by intellectual workers who are engaged in artistic, humanistic, religious or scientific knowledge production.

This simple way, rather than simplistic way, for analyzing a human society has methodological advantages. In principle, it provides a general framework for making sense of the way in which people have justified the introduction of science into the curriculum. I argue that there have been three general arguments for introducing science into the curriculum: economic, political, and cultural reasons.

The economic justification has stressed the educational needs that the economic system requires in order to produce goods and services. Contemporary industry, for example, needs (according to the followers of this view) some understanding of mathematics, science and technology in order to produce with high levels of efficiency. David Labaree has called this educational goal social efficiency: "The *social efficiency* approach to schooling argues that our economic well-being depends on our ability to prepare the young to carry out useful economic roles with competence"(1997a, p.42). Although during the last two decades there has been a renewed call for improving education in order to improve productivity, the argument has been used consistently across the history of public education as Labaree and other authors have shown.

The second generic goal of schooling that I analyze is its political goal. Although this argument has been used for understanding problems of democracy, equity, participation, assimilation, etc., this goal is also important for understanding the role of science in school curriculum. The political purpose of American education has its roots in the necessity of forming republic citizens. It was one of the more used justifications of Horace Mann. Labaree defines this goal as the *democratic equality* goal of schooling "From the democratic equality approach to schooling, one argues that a democratic society cannot persist unless it prepares all of its young with equal care to take on the full

responsibilities of citizenship in a competent manner" (1997a, p.42). Within the contemporary context of science education, the argument has been that citizens need scientific and technological knowledge in order to make democratic decisions (e.g. demanding environmental laws).

The third general reason that people have used for justifying teaching science is the cultural reason. From this perspective, we teach science because it is part of our culture, like music. From this view science enriches our lives and science also provides important ways of thinking (habits of mind) which include curiosity, creativity, etc. As humans, we are interested in antique civilizations, in the movement of galaxies, etc. This is the favorite justification of teaching science from the "pure" disciplines.

From my perspective, these three general goals of science education, and schooling in general, also set the basis for further explanations of why we teach science in general education. In principle, these three goals are related to the production of three different kinds of capital: economic capital (extensively studied for classic economic theories) political capital (or social capital in the sense of Coleman 1990, or Bourdieu, 1988, i.e., resources provided by human relations, an area of research which has not received much attention from sociologists), and cultural capital (the less developed area of research. P. Bourdieu,1988, presents an important argument, but it is still a general argument. J.S. Coleman goes beyond and suggest ways for the concrete uses of the social and cultural capital constructs). In addition, these three goals of education are interconnected and they only represent a first approximation to the question of why we teach science. The interconnection that these goals have depends on specific contextual and temporal situation. Despite this contextual and temporal limitation, I argue that these three general goals are basic for understanding more complex goals.

When one sees the three goals of science education described here, one sees different conceptions of why we should teach science. The general reasons seem to be explained by economic, political and mainly cultural arguments. Project 2061 is an

example of this kind of argument. One can explain the translation of scientific knowledge into school knowledge using this generic case and within the notion of translation earlier defined.

This simplistic picture of the translation of knowledge that I present looks clean and rational. However, this is not the case. In fact, I argue that the process is neither rational nor clean. It is not rational because the translation of knowledge is affected by assumptions that are ill-founded. Some of these assumptions are contradictory goals. Think of the economic goal of learning science in relation to the cultural goal. Learning science for economic reasons is not necessarily in line with learning it for intrinsic reasons. Curiosity is not utility. In addition, the process of translation hides incredible complex ideological positions. In fact, it is difficult to determine whether or not there are/were genuine reasons for improving science education. Usually, the proposals are embedded within political rhetoric such as economic productivity or democratic participation which cannot be realistically satisfied for the kind of knowledge suggested. At the same time, the battle for professional status is shaping the translation together with personal agendas.

An important aspect of the process of translation is the assumption that people make about it. It is usually accepted that teaching science will improve productivity, increase democratic participation and solve the problem of scientific literacy. In other words, it is assumed that the three generic goals of science education, economic E, political, P and cultural C, will be satisfied. If one thinks of these three goals in terms of three social forces <E, P, C>, the assumption is that these three goals will push the progress of a given society. However, these three factors are the intended goals of any science education reform. Their efficacy should be analyzed looking at the history of science education in a given society. From this history, one can determine a set of different goals that appears again and again. In particular, I think of two kinds of goals that have embodied the goals of education in general and the purposes of science education: learning science understanding and learning science for applications.

Translation of technological knowledge: Potential problems

The selection of knowledge that should be taught in public education has been a constant social concern particularly during the last years in which national calls for reforming education have focused on science and mathematics. I have used the construct *translation of knowledge* as a theoretical tool for understanding this selection of knowledge. Bernstein, for example, has advanced the idea that "how a society selects, classifies, distributes, transmits and evaluates the educational knowledge it considers to be public, reflects both the distribution of power and the principles of social control (1975, p.85). This general assumption is important, but it does not illuminate the internal mechanics by which society "selects," "classifies," or "transmits" knowledge. In fact, one could assume that there is a logical selection, i.e., a rational process of selecting educational knowledge. My argument is that there is not a such rational process. The translation of scientific knowledge, and the potential translation of technological knowledge, is not a rational process. It is a socio-epistemological process shaped by competing and sometimes contradictory goals of science education. In addition, factors of status and internal battles of the formation of professions tend to affect the translation of a given body of knowledge.

If the process of translation were a rational one, could expect a clearer relation between what is the knowledge that a society needs and what is the knowledge that is taught in public education. From an economic point of view, one could argue again that in a technological society, the educational knowledge should be technological. This is not the case. Although the process of translation is partially shaped by these changes in society, there is not a clear relation between real needs and potential real solutions. The same holds for the political and even the cultural goals of education. These goals are reconstructed and transformed for other educational goals that emerge from the interpretations that people have about schools. One fundamental goal for understanding contemporary American education is the emergence of social mobility as dominant goal (Labaree, 1997a). From this perspective, education is a means for jumping in the social scale. This utilitarian position of

education affects what actually is taught in schools and how this knowledge is perceived by students and parents.

Throughout this dissertation, I have argued that technological knowledge has important epistemological richness that allows it to be used in science education. Technology provides opportunities for learning science in more authentic ways. An emphasis on the cultural nature of technology as knowledge and a way of thinking, with its potential connection to science, seems to be an optimal solution to the problems of teaching science for understanding and applications. However, this introduction will face important problems.

The first problem that the introduction of technology will suffer is a problem of status. The tension between high academic status of science and low academic status of technology will play an important role. Another potential problem is the commitment that science teachers have unconsciously made with disciplinary knowledge. To complicate matters, we need to take into consideration what the opinions of the parents are. How do they see the introduction of technology into the science classes of their children? The connotations of vocational studies will play an important role in their acceptance. Actually, what parents are looking for is not a meaningful curriculum rather than a curriculum that can differentiate their children from others (Labaree, 1997b). Given the fact that technology tends to be more mundane than science, science is more adaptable to produce differentiation and stratification. Particularly one would argue that science will be more connected to college-bounded students and technology more to low status vocational careers. These are some of the problems that the introduction of technology in general education will face.

EPILOGUE

HOW TECHNOLOGICAL KNOWLEDGE WOULD CLOSE THE GAP BETWEEN UNDERSTANDING AND APPLICATION

The tension between understanding and applications I have studied in this dissertation can be seen as a distance between different communities. When a given person does not belong to the community in which the knowledge was originated, I propose that there is the emergence of an epistemological distance (between his/her knowledge and the community's). Some examples of such distance are: a) the distinction I made between external and internal relevance of science; and b) the difference between scientific and everyday problems.

The basic point of my dissertation is that it is possible to reduce the distance between understanding and applications for some types of outsiders, particularly for science teachers and their students in general education in relation to scientific communities. The general epistemological mechanism that I suggest for reducing such distance is to introduce technological knowledge into the science curriculum. The argument is that technology can play a connecting role between academic knowledge and students' everyday problems. Technological knowledge can be located in the interface between several kinds of knowledge that I have re-identified, such as: abstract versus practical; universal/local; academic/everyday-life knowledge, etc. If the epistemological distance between understanding and application is reduced, there would be more chances to learn science and mainly there will be more options for students to reconstruct a kind of science more relevant to their lives.

A basic connection between science and technology is the notion of design. As I reported in chapter 6, design is related to the creation of artifacts, particularly the specifications of how a system should be organized or how a process should be executed (Bunge, 1985). The design of artifacts is one of the meanings of applications of science

and it is perhaps the most important connection among science, technology and science education.

Traditional engineering design has been described as the process of 1) facing a problem, 2) proposing solutions, 3) building artifacts to solve the problem, 4) testing the design, etc. From this methodological position, science and technology are very similar. In fact, they both solve problems in an organized way. Moreover, design can be seen as the process of making hypotheses of how the world should work:

> Engineering design shares certain characteristics with the pointing of scientific theories, but instead of hypothesizing about the behavior of a given universe, whether atoms, honeybees, or planets, engineers hypothesize about assemblages of concrete and shell that they arrange into a world of their own making (Petroski, 1992, p. 43).

This methodological connection between science and technology is part of the concern of the National Science Education Standards (see chapter 6 of this dissertation for an extensive analysis of this and other reforms which include technology), as well as the reports of contemporary researchers (Raizen, et al. 1995; Schauble, et. al 1991; Roth, 1996). In general, the thesis is that science education will improve through design projects. This argument needs to take into consideration the socio-epistemological explanation I have developed on the process of translating technological knowledge into scientific tasks. A typical example is the design of a bridge that supports as much weight as possible while the bridge remains as light as possible. This task was carefully studied in chapter 2. Here I only review some of its implications to science education in light of my overall argument.

From a methodological point of view, the design of a given bridge shares several characteristics of scientific tasks. In this line of thinking, one may assume that engineering design and scientific investigation complement each other. However, what one is doing here is translating technological knowledge (e.g., specific knowledge for designing a bridge) into scientific tasks (i.e., ***why*** a given design works). According to my description on the epistemological nature of technological knowledge, this translation is asking for the connection of two quite different world-views.

Specific research on the role of design in science education has assumed some connections between scientific understanding and technological tasks. Roth for example, believes that "...children who designed towers, strong arms, bridges, or domes would learn (a) about properties of materials and forces operating in structures and (b) how to modify material properties, structural strength, and stability" (1996, p. 131). My dissertation suggests that this translation is possible, but it is problematic.

In principle, I have illustrated that science teachers need to be exposed to a different kind of knowledge. The framework on teacher knowledge developed in chapter 3 and enriched in chapter 4 shows that the introduction of applications also requires a different kind of pedagogical content knowledge as well as different philosophical assumptions about knowledge (knowledge of knowledge).

In the case of the introduction of technology the framework on teacher knowledge suggests the integration of technological knowledge, pedagogical content knowledge for technological tasks and knowledge about technology. Think of the case of designing a bridge. In addition to traditional school classic mechanics, teachers will have to explore notions of strength, stiffness, stability, tension, compression, etc. (see Table 6, chapter 2 for a detailed analysis of the knowledge needed for this task). There are curricula for science education which refer to the introduction of this design (e.g., the Canadian Association for the Promotion and Advancement of Science, 1991; Hsu, Walhof, & Turner, 1998). These curriculum materials attempt to reduce the epistemological distance between understanding and applications in science education. My dissertation suggests that this is possible, but it should be more than an addition of scientific plus technological knowledge. Rather, science teachers will need to integrate scientific with technological knowledge in contextual, that is, situated ways. Such integration requires a better description of the technological knowledge to be included in the science curriculum and its process of translation.

The introduction of technological designs into science education should be

illuminated by the recent works on epistemology of engineering. Based on this kind of research, I have shown how this community, the engineering community, has a particular world-view that transforms scientific knowledge into situated applications. Particularly, I illustrated how there is the emergence of specific knowledge to deal with specific artifacts. In fact, notions of understanding and applications depend on the community in which one is embedded. These communities not only provide knowledge, they basically impose ways of thinking about the world.

Of course, introducing technology into the science curriculum is not a new idea. Technology and engineering are old activities. Therefore, the history of science education is full of attempts to introduce practical applications and even technology into the curriculum. However, research on epistemology of technology, particularly on engineering knowledge, is new. In many ways, research on engineering design is almost a new branch of the human knowledge as the references of my earlier exploration show (chapter 5 and 7): *The International Conference on Engineering Design* in Copenhagen, 1983; the Journals *Research in Engineering Design* (USA, since 1989) and Journal of *Engineering Design* (UK, since 1990), the pioneers works of D. Schön (1983; 1987), and the anthropological studies of engineering (Buciarelli, 1988; 1994); specific research on engineering knowledge (Vicenti, 1990; Faulker, 1994), not to mention an incredible amount on work on sociology of technology (e.g., Latour, 1987; the journal *Science, Technology and Human Values*). I could go on presenting more references; however, the point is that the introduction of technology into the science curriculum needs to take into consideration this new research. This dissertation suggests one way to do that.

I frequently used the topic of energy to frame several of my examples. I chose to do that given the fundamental role that energy should play in science education. I showed that the goal of teaching energy from the perspective of traditional curriculum is to describe, explain and predict natural phenomena (chapter 5). Think of the case of solar energy. School experiments on solar energy (if they are done) are used to "understand" sources of

energy, rates of energy flow and transformation of energy. The goal behind that is the construction of knowledge to describe, explain, and predict. The same holds with the uses of these tools in other areas such as movement of objects. Energy-related concepts are used to analyze phenomena. Concepts such as force, work and power, are developed around the analyses of the movement of objects of thermodynamics processes to be understood from analytical perspectives

When you see energy from the perspective of technology the goals change somewhat as well as the concepts themselves (chapter 6 and 7). In principle from the perspective of technology, the goal is the use of energy for utilitarian reasons. A technological task can be the design and construction of a solar collector to transform energy. This task changes the way in which we usually "see" energy and even the way in which we "see" the Sun. In a society in which traditional sources of energy have became dangerous (pollution) and where energy is no longer inexpensive (e.g., oil) , solar energy will be, perhaps, our only source of life. Therefore, we have to deal with the Sun from several perspectives. A technological school task relating to this problem can be the construction of a solar collector to heat water. Of course few people heat water for its own sake. Heating water should be an activity around the solution of a specific kind of problem. It is difficult to predict the specific activity in which students can find that heating water is an authentic activity. I am assuming that it is possible to construct these settings with a certain level of authenticity within classroom situations. This will depend on the teachers' knowledge and material resources and mainly on the goals we have to teach science to the general public.

What is important for my example on the solar collector is that what I call a technological task is constructed around: a) the solution of a specific relevant problem (negotiated by students and the teacher and restricted by real-world conditions), and b) the design and construction of artifacts to face such problem(s). This changes the traditional relationship between the learner and the knowledge established in science education. In

principle, learners will need to interact strongly with artifacts (by designing and transforming materials for the construction of the solar collector). In doing so, teachers and students will need to develop specific knowledge situated to the design of the artifact.

The knowledge created in the design and actual construction of the artifact (solar collector) is not universal. I mean it is not valid for all solar collectors. This is specific knowledge useful for the design of the specific artifact and it is restricted for the specific conditions of this problem (heating water for some reasons that are constructed and negotiated between teachers and students). In contrast to the traditional goal of science education which tends to teach universal knowledge (thermodynamics in this case), the design and construction of a solar collector establishes a different relation between learner, knowledge and artifacts.

The relationship between the learner and knowledge is changed by technological tasks. This is because technology forces one to design and actually construct artifacts. It is in the construction of the artifact that students can construct their own practical knowledge (from the design until the final product). This is not an anarchical process. As far as I see, teachers should have an important role in developing contexts to do these kinds of activities. Teachers, of course, need to learn a different kind of knowledge which includes technological knowledge, as an important part of their preparation. What kind of technological knowledge teachers need to know is a question that can be illuminated by this dissertation.

The introduction of technology into the science curriculum in many ways is the introduction of a specific world-view different than traditional science education's view. By integrating technology into the science curriculum, we are asking science teachers and their students to see the world in different ways, to be in the world in different forms, and mainly, to act and interact differently. This challenges basic assumptions of science education.

The first assumption to be challenged is the notion of rationality. The world-view that

has dominated science education seems to identify rationality with deductive, universal, deterministic arguments. The assumption is that one can reason using some general rules of logic or general scientific laws to approach the world. This platonic (pythagorean) conception has made us believe that rationality is the essence of understanding; in other words, **rationality <--> understanding**. This is the Principle of Sufficient Reason defended for centuries by Western philosophies (Goldman, 1984). Technology assumes a different notion of rationality. Design can be understood as a complex interaction between understanding and creation, that is understanding and action. Therefore, the kind of understanding in the context of technology is different than the analytical understanding defended by science. Although technological design may be related to analytical thinking, rationality is not the touchstone of design (Schön, 1987; 1983). Design needs an epistemology of actions rather than an epistemology of reason, yet they are interconnected.

The same problem can be seen from a psychological perspective. Robert Sternberg (1996) has suggested three fundamental aspects of intelligence-analytic, creative and practical. Following works of Neisser (1976), Sternberg has clarified these three components of intelligence. We know that traditional science education has privileged analytic intelligence. Practical intelligence has been under-valued and it does not have a place in the science curriculum. However, when we ask science teachers to connect science to everyday problems, we are moving to more realistic problems. In these contexts, analytic intelligence is not enough. In fact, cognitive researchers have shown that people reason about realistic situations using neither analytic thinking nor specific rules (Kirsh, & Maglio, 1984). Rather, they need pragmatic reasoning schema (Cheng, & Holyoak, 1985) which, in the context of teaching science for understanding and applications, I interpret as a mix between analytic and practical intelligence.

Sternberg's theory also includes the notion of creative intelligence. Design can be seen as the creation of novel realities (artifacts) which in engineering design must be useful artifacts (practical intelligence). Using Sternberg's theory, one can suggest that one

direction to improve science education is to promote more than analytic intelligence (Sternberg, 1996). My research moves in this general direction too. However, in contrast to psychological research, which tends to see the problem of education in terms of individual characteristics, I see the problem from a socio-epistemological perspective. From this perspective, any movement of the science curriculum from being analytic to being more practical will challenge basic goals of science education. Certainly, the tension between understanding and applications can be seen as a reaction to different and sometimes competing goals of science education. These goals need to be studied from a wider perspective. My framework on the translation of scientific and technological knowledge into school knowledge is one option.

As I showed, from the perspective of the economic and political goal of education (Labaree, 1997a), science has extrinsic values, that is, science is to do something useful (e.g., political participation, job training). In contrast, from a cultural perspective, science tends to have more intrinsic values. From this view, one learns science for curiosity or enjoyment or even for more basic reasons such as the basic meaning of life. These three goals, economic, political, and cultural only represent part of a complex set of goals that seem to compete among them.[1] This is not only a problem of science education. Rather, this is a basic problem of contemporary education in which education can be seen from the perspective of several competing goals (Labaree, 1997a). My dissertation suggests that these basic problems of science education ought to be seen from a wider perspective such as socio-epistemological frameworks.

From a rich picture of different goals of science education, I selected two generic ideas: teaching science for understanding and teaching science for applications. It was

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[1]There are several goals of science education that I do not analyze. Most of them are related to general goals of education. Within industrialized and post-capitalist societies, education has become a way to change social status (the social-mobility goal). Credentials are an intrinsic part of such process (Collins, 1979; Labaree, 1997b). I do not analyze here such basic goals. However, I think that the goals of science education should be seen from the perspective of these sociological frameworks.

partially because of the current concerns of educational reforms on connecting science to students' everyday lives. This dissertation suggests that in order to connect science with students' everyday lives, it is important to open traditional science curriculum to alternative territories and construct a situated science to everyday life. This requires flexibility to move ourselves from one world-view to another in order to reduce their epistemological distances. Technological territories are one option. However, in doing so, there are several problems one needs to face.

A first problem with the introduction of technological knowledge in the sense in which I have suggested is a common problem with teaching science. I am assuming, for example, that students are interested in building a solar collector. It is difficult to support this assumption. In fact, educational researchers frequently report the lack of motivation in science education classes. However, one of the reasons, I argue, is that traditional school scientific knowledge does not provide flexibility for its use in students' everyday lives. I explain this with the concern of traditional science education in solving academic problems. With this knowledge, it is difficult for teachers and students to face more real problems. A different alternative is to think of a scenario in which students and teachers negotiate real-world problems to be solved. This opens a new set of pedagogical possibilities in which we do not have much experience. I think that in these settings, the distinction and connection between scientific and technological knowledge are important.

Another problem the introduction of technology faces is its academic status. Technology is identified with vocational studies which have had low academic status (a tension between analytic and practical). In contrast, science is identified with high academic status. The difference in status does not have support given the intrinsic epistemological richness of technological knowledge. This is more related to problems of evolution of professions reflected on school curriculum in which notions of knowledge and rationality are competing. However, the perception that teachers and reformers can have of technology is shaped by these problems of academic status. The introduction of technology into the

curriculum forces us to rethink these potential problems. This is one important outcome of introducing technology into the science curriculum. In other words, introducing technology into the science curriculum will enable us to think about why we teach science in general education. Approaches to this basic question require us to open our minds to alternative ways of thinking as well as alternative epistemological territories.

The contemporary call of science education reforms of connecting science to students' everyday lives hides incredible complexities. In fact, from a socio-epistemological perspective, I illustrated how these goals compete. However, one may still ask for the social conditions which are moving traditional science curriculum toward everyday life applications. In others words, why the current concern on connecting school science to students' everyday lives? One potential answer is the ideal of constructing a democratic society via education. Other answer may be the evolution of society itself toward a technological social structure. At any rate, I see the problem of connecting school science to everyday life as a basic opportunity to discuss our current concern of translating science for the general public, particularly K-12 education. In this situation, I see that the most important question we should ask is: What is the kind of science that society needs?

This dissertation suggests that connecting science with students' everyday lives requires the reconstruction of a specific kind of science, that is, a science re-interpreted in specific and local conditions. Engineering is a good example of this process. Engineers usually use science for their specific needs. Their "use" of science is not the simple application of general and universal knowledge to particular problems. Rather, they invent knowledge for specific situations illuminated by practical and mundane information. Science plays an important role in their designs. However, they integrate in a very utilitarian way several kinds of knowledge. A similar situation is needed in facing everyday life problems. In fact, I suggest that science teachers need to be exposed to this technological way of thinking if they are going to help their students to connect science with students' everyday lives problems.

When we ask science teachers to connect science with students' everyday lives, we are asking them to bridge two generic communities which are represented by scientific and everyday knowledge. Here, I have suggested the use of technological communities to find epistemological conditions to use science in relevant ways to students' everyday lives. I presented evidence on the potential connection between science and technology in the context of general education. I have shown that there is a complex, but potentially fruitful, epistemological connection between science and technology. Although we will deal with different world-views (science and technology), I assume that the epistemological distance between scientific and technological communities is smaller than the distance between science and everyday life.

Note that I am not advocating for the introduction of the generic ideology of engineering into science education. This is a different problem. Engineering communities share ways of seeing the world. Some of them seem to be useful in connecting science to everyday life. It does not mean that the science that society needs should be "engineering science". No! Although I think that we still do not know what kind of science society needs, we know enough about the generic ideology of engineering connected to problems of power and control and mainly tied to a business conception of life (Layton, 1971). I am not asking for introducing this ideology into the science curriculum. I am asking for opening traditional scientific knowledge to alternative epistemological territories. Technological knowledge is an important element that can help us to connect school science with students' everyday life problems. Technology can reduce the distance between scientific communities and the general public. However, technology is not the magic solution to the lack of scientific understanding in society. Scientific understanding as a goal of science education needs to be re-evaluated. Scientific understanding as a social phenomena needs to be re-studied. The introduction of technology in the sense I have suggested in this dissertation can help us to do this re-evaluation, particularly because of the connection that technology provides between understanding and applications.

Finally, it is important to say that from my perspective, science for the general public is going to be useful in everyday life only when people are able to construct such importance. That is, we cannot assume that the importance of science is the same for a scientist as for the general public. When science transcends its disciplinary boundaries, its importance should be evaluated beyond disciplinary perspectives. The evaluation and construction of the kind of science society needs requires conceptual frameworks to understand the process of translation of scientific and technological knowledge into school knowledge. These frameworks should help us to understand how knowledge is dependent on communities and how it "moves" from one community (e.g., scientific and technological communities) to another (e.g., schools). Each community has different world-view that shapes the kind of knowledge that is generated and translated. The nature of technological knowledge is a good example of how its local and situated characteristics make its process of translation difficult. However, this process is necessary on behalf of students' uses of science in more realistic scenarios. This dissertation suggests that technology, as curricular content, is an important medium to teach, learn, use and reconstruct science. A re-evaluation of technology and its epistemological richness can help us to reduce the distance between the general public and scientific communities. In others words, technology can close the gap between understanding and applications of school science.

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