RENEGOTIATING THE PEDAGOGIC CONTRACT: TEACHING IN DIGITALLY ENHANCED SECONDARY SCIENCE CLASSROOMS

By

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ABSTRACT

This qualitative case study explores the effects of emerging digital technology as a teaching and learning tool in secondary school science classrooms. The study examines three teachers' perspectives on how the use of technology affects the teacher-student pedagogic relationship. The "pedagogic contract" is used as a construct to analyze the changes that took place in these teachers' classrooms amid the use of this new technology. The overarching question for this research is: How was the pedagogic contract renegotiated in three secondary science teachers' classrooms through the use of digitally enhanced science instruction. To answer this question, data was collected via semi-structured teacher interviews, classroom observations, and analysis of classroom documents such as student assignments, tests and Study Guides.

This study reveals that the everyday use of digital technologies in these classrooms resulted in a re-negotiated pedagogic contract across three major dimensions: content of learning, method and management of learning activities, and assessment of learning. The extent to which the pedagogic contract was renegotiated varied with each of the teachers studied. Yet in each case, the content of learning was extended to include new topics, and greater depth of learning within the mandated curriculum. The management of learning was reshaped around metacognitive strategies, personal goal-setting, individual pacing, and small-group learning activities. With the assessment of learning, there was increased emphasis on self-directed interactive testing as a formative assessment tool. This study highlights the aspects of science classrooms that are most directly affected by the introduction of digital technologies and demonstrates how those changes are best understood as a renegotiation of the teacher-student pedagogic contract.

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DEDICATION

I would not have started nor would I have finished this program without the support of two very special people. First, my mother and angel of mercy, Mrs Bernice Kujore has unselfishly given of herself to my family and I, we, will forever be indebted to her. Second, my dear husband Debo has been consistent in his support of my academic endeavours. It is to these two that I dedicate this thesis.

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CHAPTER ONE

INTRODUCTION AND BACKGROUND OF THE STUDY

Introduction

The imperative to do 'something' with digital technology has a particular impetus for teaching and learning at all levels of education.[1, 2] This imperative stems from mandates from school boards, pressures from parents and the business community. Due to this impetus, schools in North America have been well equipped with technology with an increasingly higher expectation on teachers to integrate digital technology into their teaching and learning practices. For example, in the province of British Columbia, Canada, there is strong government support for the use of digital technology in schools. From 1980 to 1985, the number of computers in B.C. schools increased from 100 to 8,000, and in 1985, public schools in British Columbia had one computer for every sixty students (The British Columbia Teachers Federation Task Force on Microtechnology in The Schools, 1986). The most recent report on information and communications technologies in schools by The Canadian Education Statistics Council (2003) show that, in 2000 the student-to-computer ratio was six-to-one in British Columbia schools. The Canadian average was seven-to-one while in the United States the ratio was six-to-one.

Despite the widespread increase in the availability of digital technologies in North America, the transformative teaching practices anticipated as part of the promised technology revolution have failed to materialize (Buck, 2001). While recognizing that there are pockets of effective technology integration that have led to improved student learning, increased engagement with the subject matter, and increased student-centred learning, the percentage

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[1] In the last decade, there has been an increase in the sophistication of computer technology. With this increase and the increasing number of peripheral accessories for the technology, computer technology is now commonly referred to as digital technology. In this thesis, the terms digital technology, technology and computer technology are used interchangeably. This usage is common practice in the literature.

[2] Digital technology, in the context of this dissertation, refers to computer-based applications used for synchronous or asynchronous teaching and learning, network infrastructures, peripherals and the hardware on which these applications run.

remains disappointedly low relative to the availability of computers in schools (Bork, 2003; Cuban, 2001; Hodas, 1993; Zhao, Pugh, Sheldon, & Byers, 2002). In secondary schools, the effective use of the technology is still the exception (Becker, 2000; Means, Penuel & Padilla, 2001), and when computer technology is used in schools it is typically used in ways that conform to the regular classroom practices (Bork, 2003; Hodas, 1993); the result is a situation where "computers meet classroom; classroom wins" (Cuban, 1993, p. 187). Thus, from two decades of research, it is now clear that achieving improved learning through digital technology integration is much more difficult than was first anticipated. However, some researchers have shown that when computers are successfully integrated into classrooms, such classrooms become more student-centred, with the result that teaching and learning are significantly enhanced (Becker, 2000; Dede, 2000; Mergendoller, 1996; Sandholtz, Ringstaff & Dwyer, 1997; Zhao, 1998).

Larry Cuban, (1993, 1999) has long argued that the reason for the pattern of "limited and unimaginative" instructional use of computers in today's classrooms "even when teachers swim in a hospitable sea of technology" (Cuban, 1999, p. 53) is that the problem with technology integration is not necessarily one of resources but of values. Cuban (1993) went on to explain why digital technology has not changed schools as much as other organisations: "Certain cultural beliefs about what teaching is, how learning occurs, what knowledge is proper in schools, and the teacher-student (not student-machine) relationship dominate popular views of proper schooling" (p. 186). Cuban's point here is that the cultural beliefs integral to schooling do not necessarily support technology integration. These beliefs are absent in other organisations. In his article titled "High-tech Schools, Low-tech Teaching," Cuban's stance was still the same in 1999 when he noted:

> Introducing a half-dozen machines into classrooms changes social relationships. Teachers' beliefs about their authority, control of their students -- their very role -- come into sharp focus when they are asked to use software that would seem to replace

what the teacher has traditionally done. While some teachers find this exhilarating and rush to accommodate the *change in classroom relationships*, [Italics added] many pause to consider the gains and losses to them and their students. (Cuban, 1999, p. 53)

These remarks by Cuban provide a rationale for my research about the teacher-student pedagogic relationship in a technology enhanced learning environment. The need for a different means of inquiry, one that looks beyond problems associated with resources in technology integration, to problems associated with the lack of congruence between technology integration and educational values, provides both justification and motivation for the research undertaken in this dissertation.

Salomon (1992) recommends that to fully understand the effect of technology integration on teaching and learning, researchers need to examine the learning environment, including how individuals interact and change. Responding to this recommendation, researchers have examined how introducing technology into classrooms changes classroom practices (Linn & Hsi, 2000; Mumtaz, 2000; Provenzo, Brett & McCloskey, 1999; Woodrow, Mayer-Smith & Pedretti, 1996). As practices change in digitally enhanced classrooms, so do roles and responsibilities, and ultimately teacher-student and student-student relationships (Charp, 1998; McGrath, 1998; Swan & Mitrani, 1993). Could the change in teacher-student relationships be one of the most fundamental and possibly missing pieces of the technology integration puzzle? How important are teacher-student relationships in the digital classroom? Do changes in practice associated with technology use serve as a stumbling block to innovative computer-based pedagogy? To understand the importance of the teacher-student dimension in technology innovation, this study closely investigates how such teacher-student relationships change in digital classrooms and how teachers perceive and enact these changes. In this dissertation, I present a study of three teachers' efforts to integrate and sustain digitally enhanced practices in their classrooms.

Research Question

The framing of the overarching research focus for this study is informed by emerging literature around the concept of pedagogic contract, an offshoot of the social contract theory. A brief discussion of the literature on the theoretical concepts that informed the framing of the research questions is essential in helping the reader to appreciate the importance of asking these questions in a digitally enhanced classroom environment. Hence, the presentation of the research question is followed by a discussion on teacher-student relationships, then an introduction to the literature on pedagogic contract and finally the social contract theory.

The research question that guides this study has two parts:

> **How have digitally enhanced classrooms enabled three teachers to renegotiate the teacher-student pedagogic contract, and how do the teachers enact the changes?**

The focus of this study, then, is to document some of the salient features associated with the effect of the introduction of digital technology as a teaching and learning tool in secondary science classrooms on the teacher-student pedagogic relationship from the teachers' perspectives.

Teacher-Student Relationship

Teaching is a complex, multifaceted set of activities involving cognitive and emotional understanding (Featherstone, 1993; Hargreaves, 1998). Teachers make instantaneous decisions, interact constantly with the students, and develop and use various forms of knowledge in order to engage students and facilitate their learning (Buchmann, 1990). In doing so, teachers establish relationships with the students they teach (van Manen, 1991, 1994). Van Manen suggests that in order to truly understand teaching and learning, researchers must move beyond a merely rational, technical view of effective teaching to a view that includes recognition and understanding of the relationship between teachers and students (van Manen, 1994). To van Manen, pedagogy is more than the mastery and effective delivery of curriculum content. Effective pedagogy also involves understanding and caring for students through day-to-day interactions between the teacher and students in the classroom.

Van Manen's concern is with the affective aspects of teaching. His position provides valuable background and insights and helps describe some aspects of my study, but also neglects some key features of the student-teacher relationship. Without a doubt, a teacher may be *in loco parentis,* but this is not the only responsibility of the teacher. There also exists a curriculum, above and beyond the familial, moral education provided by parents, one that is contractual, as it must meet provincial and national standards associated with this aspect of a teachers' practice. However, there is another type of contractual space associated with teaching and learning practices in school that is being called a "pedagogic contract" (Hildebrand, 1999), and it is in this latter contractual space that I locate my study. In this dissertation, I delimit the definition of a pedagogic relationship to the school relationships that exist between the teachers and their students that is centred on curriculum content and the issues of teaching and learning.

The Pedagogic Contract

Central to the concept of school and teaching is the relationship between teachers and students (Brophy & Good, 1974; Pianta, 1999). Students and teachers spend many of their waking hours in the social arrangement called a classroom, and as in all social settings, they interact with one another and develop relationships specific to that setting. The social and pedagogic practices that teachers develop in their classrooms influence how a class develops and the norms that are established for learning. While certain norms are evident in explicit classroom talk between teachers and students, there also exists an unspoken social agreement about expected classroom behaviour and how teaching and learning should transpire in the classroom.

In his book, *This is School! : Sit Down and Listen!* Aspy (1986) illustrates the unspoken contractual arrangement that exists in classrooms by enumerating five important lessons children learn during their early years of schooling:

1. Don't feel: In learning situations, people do not respond to one another's feelings.
2. Don't think: Learning consists mostly of memorization. The corollary being that thinking and memory relate to pseudo-problems rather than real-life situations.
3. Don't talk: In order to teach, teachers must talk most of the time. The reverse of this lesson is that students must listen. In short, teaching is telling and learning is listening.
4. Line up: In order to learn we sit in rows.
5. Don't get involved: In learning situations, people do not get excited about learning.

The book is based on data accumulated from about 200,000 hours of classroom instruction from 42 states in the United States and seven foreign countries over a period of twenty-two years. According to Aspy, children glean unspoken lessons based on the manner in which they are taught. These lessons determine how children behave in classrooms. By the time students enter their senior years in school these silent lessons have become deeply engrained, difficult to change, and constitute an expectation of normal classroom behaviour. While Aspy expressed his ideas using extreme language, not much has changed in the manner of classroom instruction and interaction since Aspy's book, as I will argue later in this chapter and also in the chapters on the literature review.

All I Really Need to Know, I Learned in Kindergarten (Fulghum, 1989), is a phrase that has sometimes been used to describe the essence of kindergarten and sometimes, elementary education. Yet what do children learn in kindergarten that is all they need to know? According to the Aspy study, it is the unspoken norms and expectations of schooling. I first heard this phrase at a teacher-parent meeting when my youngest son's kindergarten teacher was addressing the parents at the beginning of the year. The teacher concluded her talk by jokingly saying that she and the other kindergarten teacher at the school do all the work while the remainder of the teachers fill in the gaps. When my oldest son started kindergarten he was very excited because he said that he would finally learn to read the 'big' books that I did not read for him at bedtime. When I picked him up after his first day of school on a September afternoon, I asked "Segun, what did you learn in school today?" He answered, rather unenthusiastically "Rules!" After some prodding, he elaborated: the teacher instructed them that they had to put their hands up before talking, not talk unless asked, line up in a straight line when leaving the class, not leave their seats without permission, not yell in class, to name only a few of the rules expected to be followed. The second day of kindergarten, I asked the same question, and he replied, "More rules." I thought this incident was merely amusing until I started analyzing the data for this study. Certainly according to the Aspy study, one may assume that students learn to expect certain things and behavioural patterns from teachers and likewise the teachers have certain expectations of students. If children learn all they ever need to learn in kindergarten, and quickly learn that school is all about rules, then Aspy's (1986) five lessons seem fitting. Hildebrand (1999) refers to such lessons and expectations as the "pedagogic contract" (p. 1).

The "*contrat didatique theorie*" translates into English as the "theory of didactical situations" is developed by Guy Brousseau (1984, 1997). Brousseau, (as cited in Mercier, Sensevy and Schubauer-Leoni, 1999, p. 342), defines the didactical contract as "a system of reciprocal expectancies between the teacher and the students concerning knowledge." Hildebrand (1999) explains that she re-labelled the term didactic to pedagogic because she felt that English-speaking teachers/researchers were more comfortable with the term pedagogic since the term didactic is associated with transmissive teaching. In relabelling the term, she extends Brousseau's work outside the field of mathematics education and expands Brousseau's notion of the didactic contract. I discuss this more fully in chapter two.

Hildebrand (1999) defines the pedagogic contract as the prevailing classroom norms and practices. She explains that these norms have been generated by the collective approaches used by teachers in the past and have led to a particular set of established pedagogic practices in the context of particular classrooms. For example, when students walk into a science or math classroom, they have certain expectations of the practices appropriate to that classroom. These day-to-day classroom practices set the tone of the teaching-learning relationship and include clear expectations of what constitutes a 'normal' pedagogic relationship with the teacher. Hildebrand argues that the pedagogic contract is a relationship that requires a level of trust on the part of the students that the teachers will indeed use their competencies, knowledge, and skills to facilitate learning. This trust is reciprocal in nature because the teachers also trust that the students will behave and engage in learning in a manner that is required by the teachers.

The pedagogic contract encompasses the general pedagogic atmosphere of the class. According to Hildebrand:

> It includes pragmatic factors such as whether students are mostly expected to talk and /or to listen; whether students are expected to answer questions and/or ask them; whether a climate of problem posing and/or problem solving exists; whether students are expected to produce and/or reproduce knowledge. (1999, p. 2)

The pedagogic contract also includes whether negotiation occurs in both what and how particular subject matters are taught, and what particular learning activities and forms of writing are acceptable in the classroom (Hildebrand, 1999). In any situation where a teacher chooses to step outside the conventions of a particular classroom practice through innovative teaching, these teachers ask students to think in unfamiliar ways, thereby disrupting the pedagogic contract. These disruptions can sometimes lead to the re-establishment of new practices and norms through both implicit and explicit renegotiations with the students.

Hildebrand (1999) conducted a study on the introduction of creative writing practices in science classrooms. The study illustrates what happens when teachers intentionally set out to "break" the existing pedagogic contract and establish new norms for acceptable classroom practices. She found that the introduction of creative and imaginative writing in the science classroom constituted a breaking of the pedagogic contract.[3] The previous collective practices of science classroom teaching did not include imaginative writing in science classrooms; hence students did not enter the science classroom expecting to write poetry. Not surprisingly, the students resisted the teachers' efforts to change the practices of the science classrooms. The teachers responded with perseverance and a willingness to scaffold the students through the process because they believed in the value of the writing innovation, and thus succeeded in changing the teaching and learning practices. In this dissertation I use Hildebrand's concept of the pedagogic contract as a means of understanding teacher-student relationships in three digitally enhanced secondary science classrooms in British Columbia, Canada. The renegotiation of the pedagogic contract from the teachers' perspectives is the focal point of this study.

The investigation of a pedagogic contract highlights relationships and foregrounds negotiation. Hence, it is a form of social contract. I acknowledge that using the construct of a pedagogic contract carries the danger of linking it to the popular definition of a legal contract, which suggests a fixed state. I caution that the pedagogic contract is only used as a rhetorical and conceptual device, and I do acknowledge that the teacher-student relationship is complex, continually evolving and being re-negotiated. Consequently, my usage of the term

[3] I have chosen to use the term "renegotiation" of the pedagogic contract rather than "breaking" the contract as used by Hildebrand. The term break suggests a sense of finality while the term renegotiation has a sense of fluidity associated with it.

does not suggest a static contractual relationship. Rather, I have drawn upon the writings of the social contract theory that have been based largely on Rousseau's work.

The Social Contract Theory

The social contract theory dates back to ancient Greece, has a long tradition in Western Philosophy, and it forms the underlying principles of democracy (Black, 1993). Philosophers such as Hobbes, Locke, J.J. Rousseau, and Kant elaborated the theory in the 17th and 18th centuries. These philosophers differ in their views on the proper relationship between individuals and the political institutions that govern them, but they agree on two major points. First, they all assert that the social contract between citizens and political institutions provides the ethical justification for the existence of the institution. Second, they all believe that an action in violation of the social contract by any of the parties constitutes forfeiture of a claim to legitimacy for that action (Watson, Shepard & Stephens, 1999). For example, in late sixteenth century France and Netherlands, a contract became a characteristic way of justifying political actions, in particular, resistance to superior authority. From the seventeenth century onwards it played an important part in the way political authorities were defined and justified, and how their powers in many ways were delimited (Black, 1993).

Dobuzinkis (2000) defines social contract as an implicit arrangement between individuals who also revise it occasionally. The social contract is an implicit arrangement because there is no explicit agreement signed, as in a legal contract. Quite often one is not aware of a social contract until the contract is challenged and individuals react to the disruption, followed by the realisation that an implicit contract did exist. Dobuzinkis (2000) argues that for more than two centuries, the social contract theory has been a symbol of a political order founded on agreement among rational individuals who are equal participants in the political process. Dobuzinkis' ideas on political order are at best theoretical and break down easily when one observes political practice. The ideas of equality and consent are problematic. Political systems are based on differences in levels of authority. The differential level of authority is an important distinction in examining the relationship between teacher and students since teachers are in a differential power relationship with their students.

The social contract tradition deems an institution legitimate if consenting citizens either implicitly or explicitly agree to its conditions. In this sense, the social contract is not a description of how institutions are built but a metaphorical normative benchmark against which the justness of actual institutional conduct and policy may be measured (Watson, Shepard & Stephens, 1999). D'Agostino (1996) contends that "in its modern guises, contract approaches are not intended as accounts of the historical origins of current social arrangements, but, instead, as answers to, or frameworks for answering questions about legitimacy and political obligation" (p. 1). Kolm (1996) maintains that the social contract must be the outcome of interactions occurring in real life and not derived from a hypothetical perspective.

A contract is a conditional type of oath or promise. The nature of the social contract is such that it is difficult to determine whether unanimous agreement has been achieved. Agreement in the context of the social contract is usually theoretical. Accordingly, the social contract lacks the actual bargaining and the ensuing agreement that constitute a legal contract (Rosenfeld, 1998). Different circumstances call for different norms, and different types of social contracts account for different aspects of social and economic justice. Social contracts operate within the broader context of a public philosophy that gives meaning to such arrangements but is not itself contractually negotiated (Dobuzinkis, 2000). From a purely formal standpoint, a social contract is essentially similar to a legal contract, with the obvious difference that the latter is typically bilateral and has legislative consequences while the former is multilateral and always evolving (Rosenfeld, 1998).

Using the above construct of the social contract theory, the pedagogic contract can be characterized as a form of social contract that exists between each teacher and the students. This contract is centred on those teaching-learning relationships that operate in a classroom environment. Because both teachers and students have well-defined expectations makes this a contract with all the attendant social implications that such a relationship involves and invokes. I develop the link between pedagogic contract and social contract more fully in chapter two.

Against this brief background, the main focus of my study is to examine and document what happens when teachers try to change this "pedagogic contract" – the underlying prevailing classroom norms that govern the teacher-student relationship. In this study, introducing digital technology into the classroom constitutes a disturbance of the pedagogic contract, which necessitates a redefinition of the contract and renegotiations of teachers' and students' roles and expectations within that contract. The notion of a pedagogic contract provides a useful construct through which the changes in norms, practices, roles and relationships can be investigated. Teachers' perception of the ways in which the pedagogic contract is renegotiated is the focal point of the analysis.

Pilot Study

From January to March 2000, I conducted a pilot study with three teachers who were engaged in exploring the use of technology-enhanced instruction in their science classrooms. They are part of a project called Technology Enhanced Secondary Science Instruction (TESSI). I provide more details about this project in Chapters Four and Five. I was interested in their perceptions of teaching and learning issues related to their uses of digital technology in their science classrooms. The pilot study consisted of a few classroom observations in each class followed by one-hour interviews with each teacher. The preliminary analysis of the pilot study demonstrated that the use of computer technology in the classroom does indeed affect the teacher-student relationship. There are some similarities between the pilot study parameters and this final study:

1. The setting was similar because it was within the TESSI group of teachers, and one of the teachers in this study also participated in the pilot study.

2. The teachers involved in the pilot study were all grade 12 science teachers, as they are in my study.
3. The teachers were all experienced and competent computer technology users.

The major difference between the dissertation study and the pilot study is that the focus of the pilot study was broader. Undertaking the pilot study proved useful in four major ways. First, I was able to confirm that examining the teacher-student relationship was indeed a legitimate and significant question to ask in the TESSI setting. Second, I was able to determine that the issues of teacher-student relationships were accessible through interviews and classroom observation. Third, the extent to which individual TESSI teachers integrated technology varied, so through the pilot study, I identified the teachers with varying levels of technology integration that provided some contrast for my study. Fourth, the observation and interviewing process during the pilot study gave me the opportunity to improve my observation and interviewing skills in these respects: refining questions during the course of an interview, developing more focussed questions between one interview and the next, and using questions or comments to manage the overall tone and character of the conversations.

Limitations of the Study

There are four limitations to this study: First, teacher interviews and participant observations cannot capture the entirety of the classroom experience that describes teacher-student relationships. However, by observing the classes at different times during the semester, and juxtaposing the observation data with the interviews, I was able to identify many key aspects of the manifestations of the teacher-student relationship.

The second limitation is related to my presence as a researcher in the classroom. With the presence of an observer, the classrooms were no longer the "usual". To address this classroom disruption, I made several visits to the classrooms prior to data collection in order that the teachers and students could become accustomed to my presence.

The third limitation concerns the interventionist quality of the observation and interview process. The fact that the teachers knew that they were being observed and would be interviewed ultimately may have influenced their practices and their choices of certain practices and actions. Thus, they may have paid closer attention to the issues that they knew would interest me. To ameliorate this situation as much as possible, the interviews were conducted as conversations, where I emphasized my desire to learn from the teachers. All of these teachers are more experienced than me, and because I was working at the time as a substitute teacher,[4] it was easy for both them and me to realise that I have a lot to learn about classroom dynamics. Furthermore, all of the teachers were familiar with the presence of researchers in their classrooms as members of the TESSI team, hence they were used to being observed and interviewed.

The fourth limitation concerns the effects of the research process on the teachers and their classroom pedagogy. My presence and questions may have caused the teachers to reflect more on their relationship with the students, but my impression is that my study had little, if any, effect on how the relationships were enacted in the classroom. In addition, I believe my presence had little effect on the significant classroom incidents that were either observed by me or reported to me by the teachers because the data was based primarily on interviews, and the classroom dynamics that I observed were part of the classroom practices. The study was conducted from January to June thus many of the regular classroom practices were already established the previous autumn, before the commencement of my study.

Significance of the Study

This study has many features that make it a significant contribution to the understanding of the effects of using digital technology in education. First, most of the studies investigating the effects of digital technologies in education have been explored in

[4] In some countries this is referred to as supply teacher or teacher on call. This is where a teacher gets called in to work if the regular teacher has to be away.

relatively small-scale, short-term test projects. These test projects tend to be well funded with personnel and technical resources that are atypical of school settings. The results from such studies would be extremely difficult to generalize (e.g., on a case-to-case basis) to regular classrooms (Mergendoller, 1996; Saye, 1997). My study involves teachers within a long-term technology integration study. Project TESSI is in its twelfth year. The student to computer ratio of three-to-one or four-to-one in TESSI classrooms is close to the six-to-one average in North American classrooms. Commercially available software are used in TESSI classes, as opposed to in-house, dedicated and specifically designed software that tends to be used in test-bed projects. [5] Any classroom in the lower mainland area of British Columbia, Canada could, with relatively modest support, acquire the resources and support possessed by teachers found in the TESSI project. I expect that the results of this study will be an example from which educators in *typical* classrooms can learn.

Second, the classroom context is a dynamic interaction of personal, social and technological dimensions that affect teaching and learning. This study explores one aspect of the classroom dynamics: the teacher-student pedagogic relationship. In an era of the proliferation of digital technologies, a deeper understanding of this important aspect of classroom dynamics is needed to guide the development of effective and comprehensive support for teachers within the context of teaching and learning relationships in digital technology enhanced classrooms.

Finally, this dissertation draws upon the social contract theory, in beginning to develop a richer and more complete notion of a pedagogic contract construct as a conceptual device for making sense of classroom practices.

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[5] Software are programs that add functionality to a computer and perform a variety of functions. The programs can be used to simulate, analyze, measure, research, manage, publish and present concepts.

Synopsis of the Chapters

This thesis is presented in seven chapters. Chapter One presents the introduction, rationale, research questions, and the significance of the study. The pedagogic contract construct and the social contract theory are introduced. Chapter Two is a review of literature on perspectives about teacher-student relationships. There is also a discussion on the usefulness of the pedagogic contract as a conceptual device in examining the teacher-student relationship. In Chapter Three, themes about the effect of digital technology on teaching and learning situate the study within the growing field of research conducted on teaching and learning in digital technology - enhanced learning environments. A review of the literature on the use of digital technology in science education is also presented.

Chapter Four is a discussion of the methodological framework and includes a description of the participants, research design, methods of data collection and analysis. I also discuss the rationale for using a qualitative research design in general and briefly review the methodological underpinnings of case study methods and their relevance to the purpose and process of my research in particular. Issues of validity and reliability of the study are also discussed. Chapter Five is a detailed description of the research context. A discussion of the implicit and explicit norms and practices in TESSI classrooms as a foreshadowing of the analysis in the next chapter are also presented. I have devoted the chapter to the context based on my assumption that the effect of digital technology is best understood within its context of use. In Chapter Six, I present the findings and the analysis of the study in the form of a detailed discussion of the major dimensions and themes derived from the research data. Chapter Seven presents a cumulative discussion of the results of the study in relation to the research questions that framed the study, in addition to the broader perspectives found in the literature. I also discuss the conclusions of the study and the knowledge claims that I make. The implications of the study for teaching practice, professional development, technology integration, and further research are also presented.

CHAPTER TWO

REVIEW OF RELATED LITERATURE: TEACHER-STUDENT PEDAGOGIC RELATIONSHIPS

Introduction

One of the important characteristics of the school as an organization is the nature of the relationship between teacher and students. This relationship is most manifested in the classroom. The classroom is a socially and culturally organized environment for teaching and learning. Teachers and students cannot help but exist in relation to one another in the classroom context. Teachers observe and react to their students in their everyday interactions. By so doing, teachers become familiar with the general personalities of their students and their more specific characteristics as learners. Teaching, as such, is simultaneously a personal and a social activity during which knowledge is refined and reconstructed through teachers' actions and interactions in the classroom (Clandinin & Conelly, 1996).

The teacher-student relationship affects mutual growth and development through the processes of interaction and communication (Goode, 2000). Studies such as Muller, Katz and Dance (1999), have also shown that when teachers foster a good teacher-student relationship in the classroom, the result is an increase in student achievement and an improvement of students' attitudes. Increased student attendance, fewer discipline problems, and higher aspirations have also been correlated with a good teacher-student relationship (Pigford, 2001; Skinner, Bryant, Coffman & Campbell, 1998). In underscoring the importance of the teacher-student relationship, Noddings (1992) suggests that the teacher-student relationship is crucial to teaching and learning, perhaps more crucial than teachers' philosophies about or knowledge of pedagogic methods because these relationships contextualize the interactions and decisions of students and teachers. Because this relationship is a vital part of the context of teaching, the teacher-student pedagogic relationship continues to be a topic of interest among researchers.

My review of literature is divided into two chapters representing the two distinct bodies of literature that inform this study. Chapter Two begins with a review of significant contributions to major perspectives on teacher-student relationships. This is followed by a discussion of the social contract theory and the emerging pedagogic contract literature. This chapter also provides a comprehensive and compelling argument for the relevance of the pedagogic contract, -- an offshoot of the social contract theory -- as a conceptual device in investigating teacher-student relationships.

Chapter Three is a discussion of varying perspectives on the effects of technology use on the classroom context. The review then focuses on innovative attempts made in secondary school science with computer technology as a teaching and learning tool. Finally, I note the different ways in which computers are used and the peculiarities of each method used in the science classroom. While the two bodies of literature discussed in Chapters Two and Three are two distinct areas of study, I argue that there are points of overlap between them that have enabled me to define a research focus. Summaries of the common findings in the literature are also intertwined in the review with a discussion of the gaps and limitations that provide the significance for this study.

Perspectives on Teacher-Student Relationships

Studies on the teacher-student relationship can be classified into two broad categories: the caring and parental relations aspect of the teacher-student relationship and the formal contractual aspect of the relationship. The former emphasizes the tone and tact of teaching, while the latter is concerned mostly with the institutional and contractual relationship, one that tends to be more formal than personal. Because of the intensely personal nature of teaching, studies within the last two decades on teacher student relationships have understandably focused on the caring aspect of the teacher-student relationship. This focus is understandable, because the discussion concerns relationships and children. The focus has also been a reaction against the strictly mechanistic and legalistic aspect of teacher-student relationship that has dominated much of the earlier educational psychology literature. Even though every child is in school by virtue of a formal contractual relationship, some researchers who have focused on the affective tone and tact aspect of teaching may have underestimated the significance of the contractual aspect of the teacher-student relationship.

One of the notable contributors to the tone and tact aspect of teaching is Max van Manen. To van Manen (1986, 1991, 2002), pedagogy is best seen not as a technical, rational skill focused on teaching content knowledge, but as a positive relationship between adult and children. He advocates a move from the rationalistic view of teaching toward an emphasis on the understanding of the relational aspects of pedagogy, pointing out that a teacher may possess strong technical skills but still be a bad teacher (van Manen, 1994). He further asserts that this relationship is inherently positive in nature and underlies both the ability of teachers to teach in a positive manner and the ability of students to learn. Van Manen opines that this relationship may occur between parents and children, teachers and children, or other adults and children (van Manen, 1991, 1994). He calls for pedagogic thoughtfulness in dealing with children, explaining that pedagogic thoughtfulness is sustained by a certain kind of seeing, of listening, of responding, through which tact grows in the adult-child relationship.

Van Manen is a strong advocate of tact in teaching. He acknowledges that teachers and other adults also benefit from establishing pedagogic relationships with children but he focuses his theory primarily on how such relationships benefit the children themselves. His theory of a positive pedagogic relationship between adults and children brings into focus the importance of relationships concerning student learning, but fails to address the effect of such relationships on the adults involved. Hence, his theoretical description of the pedagogic relationship tends to be unidirectional in terms of growth and benefits, seeing knowledge growth and other benefits in children as a result of the relationship (Goode, 2000). He does not pay as much attention to the effect of this pedagogic relationship on the development of the adult, on the learning content or on how pedagogy is enacted in the classroom.

Furthermore, all his studies were conducted with elementary school children, suggesting that his theory focuses on children in the early years of schooling.

Another significant contributor to the importance of the affective aspect of teaching and relationships is Andy Hargreaves (1994, 1998). Hargreaves' position is that the classroom as a place of learning for students is also a workplace for teachers and as in all work places, relationships are cultivated which are important for its smooth running. But unlike some other dispassionate jobs, Hargreaves notes: "good teachers are not just well-oiled machines, but rather they are emotional, passionate beings who connect with their students and fill their work and their classes with pleasure, creativity, challenge and joy" (Hargreaves, 1998, p. 835). Like van Manen, Hargreaves' concern is that research on teaching in North America has tended to focus on the technical aspects of teaching and pedagogy, to the neglect of the relational and emotional aspects. This neglect, he argues, has led to an incomplete understanding of teaching and of teachers. He argues that teaching involves emotional labour, emotional practice, and emotional understanding. As an emotional practice, teaching involves the forming of relationships with others in the school context, particularly between teachers and students. This relationship is affected by educational change practices as Hargreaves, Earl, Moore and Manning (2001) argue:

> Educational change efforts affect teachers' relationships with their students, the parents of those students, and one another. Teachers make heavy emotional investments in these relationships. Their sense of success and satisfaction depends on them. (p. 136)

Their finding is based on a study of twenty-seven 7^{th} and 8^{th} grade teachers who were involved in implementing curriculum change in Ontario, Canada. One of their conclusions that educational change affects the teacher-student relationship is important for my study, but they only studied this effect from the affective aspect of the teacher student relationship. My study examines the effect of educational change on the contractual aspect of the relationship.

Although I do not want to undermine the significant contributions made by these authors' position on the relevance of emotions in teaching, there is a risk of an overemphasis that suggests that the practice of teaching is driven by emotions. For example, Chapter Six of the Hargreaves et al. (2001) book *Learning to Change*, has the following subtitles: Emotional Practice, Emotional Understanding, Emotional Labour, Emotional Goals and Bonds, Emotions and School Structure, Emotions and Pedagogy, and Emotions and Planning. In concluding that chapter, they assert: "teacher's emotional commitments and connections to students energized and articulated everything these teachers did: how they taught, what they taught, how they planned, and the structures in which they preferred to teach" (Hargreaves et al., 2001, p. 156). I would argue that this could be an overstatement because there is still a contractual aspect of teaching that stipulates what and how teaching should occur, which is not based on teachers' or students' feelings. There is the curriculum to consider and course content to cover. Emotions are a part of the context of a job. But if teaching is mostly about emotions, then the notion of teaching standards will be undermined. In addition, the danger of this stance is that teaching can then be overly tipped toward being a work of the heart, undermining the professionalism of teaching and the place of the contractual aspect of the teaching profession. This view may then lend credibility to the infamous saying, among non-educators, that "teachers are born not made."

In a phenomenological study on how a teacher sought to create an atmosphere of home in her classroom, Sinclaire (1994), provides a classic example of the in loco parentis perspective on teacher-student relationship. In her book, *Looking for home: A phenomenological study of home in the classroom*, Sinclaire describes home as "a place which provides us with the sense of communion with others that helps the individual self emerge" (1994, p. xix). Sinclaire sought to foster this kind of feeling in her classroom. Through the recounting of her own experiences at home as a child, and her students' experiences, Sinclaire documents her students' responses to her efforts to build a positive relationship with each student, and with the class as a whole. For example, she writes of one of her students:

> He tells me his family history while I am silent and patient in listening. I stay with what he is revealing so that we can achieve a certain intimacy. In listening, I hear his pain and uprootedness and, as a result, I see him differently. John too is changed in the telling and in being heard. (Sinclaire, 1994, p. 37)

Sinclaire worked with children and adults who are mostly second language learners. She found that the relationship between the teacher and students is a critical element of a positive learning environment and that it affects the teacher's development and growth. Her study concludes that her relationship as the teacher with students and her focus on building a sense of *home* in her classroom improved her ability to establish a trusting environment in which children could grow, learn to relate to others, and develop a sense of belonging and an understanding of who they are as individuals. While this affective aspect is vital, the contractual aspect of teacher-student relationship also deserves attention.

Robert Pianta's (1992, 1999), body of work on teacher-student relationship is another example of the in loco parentis aspect of the teacher-student relationship. His studies including Pianta and Kraft-Sayre, (2003); Pianta, Cox and National Center for early Development & Learning U.S (1999), focus on the psychological aspect of the teacher-student relationship arguing that, "in many ways, children's relationships with adults in school may mirror the relationships that they have with parents in the family context and may provide many of the same functions such as play, mastery, affiliation and attachment" (Pianta & Steinberg 1992, p. 5). Pianta and Steinberg (1992) examined the effects of the teacher-student relationship on student success. Viewing this relationship through the frame of attachment theory, they stressed the importance of a positive teacher-student relationship, noting that the teacher-student relationship influences student growth, achievement, and knowledge. Pianta has also explored issues such as: how the mother-child relationship affects the adjustment of the child to school (Pianta & Steinberg, 1992), how teacher-child relationships affect concepts of risk in children and adults (Pianta & Walsh, 1996), and how the teacher-child relationship, in particular the teacher's conception of that relationship, affects students learning and achievement (Pianta, 1999). Pianta acknowledges that a teacher's perception of students affects how the teacher interacts with, and teaches individuals and groups of students but did not address the effect of how and what a teacher teaches affects the teacher-student relationship. As is typical of studies on the teacher-student relationship this study was conducted with elementary school students.

Brophy (1996), and Brophy and Good (1974) also contribute to research on teacher-student relationship. They considered the contractual in addition to the affective aspect of the teacher-student relationship. In a comprehensive meta-analysis of various quantitative and naturalistic studies, Brophy and Good (1974) examined the causes and consequences of teacher-student relationships at the elementary and middle school levels. They found that individual differences in students make differential impressions on teachers, and that such impressions lead teachers to form differential attitudes and expectations about different students. What I found noteworthy about their research is that they studied teacher-student interaction patterns as an indicator of the teacher-student relationship. In collecting their data, they counted how many times student A talked with student B and how many times the teachers talked with students A, B or C. They also categorized each conversation in terms of who initiated the talking and whether the exchange was a question, clarification or general instruction in say one lesson period. I would argue that counting the number of interactions is an inadequate way of studying relationships. A relationship transcends discrete interactions as the symbolic interactionism theory proposes, because there are meanings associated with interactions or exchanges that may not be clear to an observer and certainly not captured in terms of a narrow category system of behavioural responses. Having any relationship ultimately presupposes a commitment that is meaningful beyond the current interaction. In this study, I use the term teacher-student relationship because I believe that teacher-student relationship should be studied holistically or organically and that it includes but is not limited to discrete interactions. Nevertheless, some of the studies I cite, in particular the earlier ones, use the term *interactions* but very often they refer to the same idea.

In a different approach from studies that tend to focus on the effects of the teacher-student relationship on different aspects of students' learning, Goode (2000) investigated the effect of the teacher-student relationship on the teacher. His phenomenological study examines the influence of the pedagogic relationship between a female beginning teacher and her kindergarten students on the teacher's development of practical teaching knowledge. His analysis was built mostly on three of Shulman's (1987) categories of professional knowledge: general pedagogic knowledge, pedagogic content knowledge, and knowledge of learners and their characteristics. Goode found that:

- by emphasizing the tone and tact of teaching, the teacher was able to have a closer relationship with the students;
- the teacher - student relationship helped the teacher to develop an understanding of what she knew and who she was as a teacher;
- the ways in which the students responded to various aspects of classroom teaching affect the kinds of strategies employed and those sustained by the teacher.

Goode's study provides an understanding of the world of a teacher's construction of pedagogic knowledge and makes a direct claim that the teacher-student relationship does indeed affect the teacher's development of this knowledge. The main similarity between Goode's study and mine is the correlation between the teacher-student relationship and the classroom teaching and learning strategies.

There are two major commonalities between the studies reviewed thus far in this chapter. First, is the emphasis they all put on caring as the centrepiece of the teacher-student relationship and their view of school as a second home and teachers as surrogate parents. My study provides a necessary balance by presenting the view from the other side of the *relationship coin,* that of the contractual aspect of the teacher-student relationship.

Second, virtually all the studies have been conducted at the elementary and a few at the middle school level. How though, does the teacher-student relationship operate at the secondary school level? Does the teacher-student relationship still play a key role in the teachers' and students' development? Lynch and Cicchetti (1997) have noted that the nature of the teacher-student relationship moves from a care-giving focus in the earlier years to a mentoring, monitoring and problem-solving focus during the adolescent years. Wilson (1976) also argues that: "secondary students do not seem to want the diffuse 'liking' or 'love' relationships with teachers that characterize relationships with elementary teachers" (p. 99). How then does the nature of the teacher-student relationship affect different aspects of classroom practices in secondary school classrooms? In the next section I discuss some notable studies on teacher-student relationship in secondary school settings.

Teacher-Student Relationships in Secondary School Classrooms

In a two-year ethnographic study of teacher-student relationships as contexts for secondary literacy, Moje (1996) investigated how and why a veteran content teacher and her students focussed on the use of literacy practices and events in a first year high school basic Chemistry class. Of her four research questions, the last one is of interest to my study. She asks: "How are decisions about literacy events and practices shaped by classroom interactions and how do the decisions shape interactions?" (p.172). She found that the participants' experiences and beliefs about teaching and learning affected the meanings they derived from their classroom interactions. These interactions led to the development of relationships that contextualized their literacy practices. The literacy practices were also encouraged and supported by the relationship that had been built in the classroom culture. The teacher in the study contends that her primary goal was to help students use literacy strategies to learn how to learn Chemistry. Because of the relationship that the teacher fostered with the students, the teacher moved from a subject-centred teaching orientation to a student-centred one. A quote from the teacher's interview cited in the paper, cogently captured the teacher's belief about teaching and learning. She said: "I've learned over the years that I don't teach subjects, I teach students, and so I've geared my teaching toward helping them learn how to learn" (p.186). Her focus on students rather than on content is a clear indication of a student-centred classroom.

Moje's study was conducted in a secondary school content area like my study but differs in the sense that her focus weighed primarily on the influence of the life histories such as biographical details, and memorable school and family experiences on classroom decisions. Her findings regarding the influence of the teacher-student relationship on the literacy practices were relatively thin. Even though she made some generalization to other content areas, her primary concern and focus of analysis were literacy practices. Two of her findings have particular relevance to my study.

First, Moje contends that previous life and classroom experiences are past interactions that have given rise to the meanings that teachers and students bring to their current classroom interactions. When their previous knowledge and beliefs support certain notions of learning, students find it easier to accept the practice the teacher is trying to promote in the classroom. For example, in Moje's study, the students' beliefs and practices supported notions of the role of organization in Chemistry teaching and learning. In the Chemistry classroom, literacy was practiced as a tool for organizing thinking and learning. Hence, the students were able to accept the practice of literacy when the teacher presented it to them as an organizational tool.

Secondly, she found that students' beliefs about teaching and learning were also shaped by their interactions with the teacher. Because of the teacher's confidence and commitment to building the students' self esteem, the students viewed the teacher's specific literacy strategy as unique and effective. Furthermore, because the students were interested in academic success, and in many cases had to work hard to achieve success, they viewed with favour the teacher's teaching and the literacy strategies that she taught.

The teacher's knowledge about learners enabled her to build relationships with her students that encouraged connections and established rapport. In turn, these relationships created an atmosphere of respect and trust that encouraged students to participate in the literacy activities as the teacher structured them, thus shaping the practice of literacy in the classroom. Her study concluded that the Chemistry classroom context was shaped by the teacher-student relationship. This relationship was dependent on the knowledge and belief systems that students brought to the classrooms. The students interpreted classroom strategies and practices based on their beliefs.

A shared work ethic, pending college attendance and career goals also supported the teacher's goal of helping the students learn how to learn. Students knew that they would be expected to take more responsibility for their own learning in college, so they appreciated the kind of strategies for independent and organized learning that the teacher taught. Thus, their common beliefs about science, teaching and learning supported literacy practices as an organizational tool. But what happens when there is a dissonance between the teachers' and students' beliefs about teaching and learning when unfamiliar strategies are introduced? Moje's study did not answer this question. Moje's study provides a contrast to Hildebrand's 1999 study in which the students resisted the introduction of literacy practices in their secondary school science classroom.

In a case study of teacher change, Briscoe (1991) examined the dynamic interactions among beliefs, role metaphors and teaching practices in a secondary school Chemistry class from a social psychological perspective. In the study, the teacher shifted the focus of his teaching away from teacher-centred practices and emphasis on content, to student-centred practices. The teacher also decided to emphasize problem solving relevant to the use of

Chemistry in daily life. The discussion of the teacher's conceptualization of his roles and the beliefs that support them are of interest to my study.

Firstly, Briscoe found that the teacher's beliefs about management constrained his change of practices. He was trying to fit new practices into an old management structure. The teacher felt it was important to have a good relationship with his students in addition to obtaining a positive feedback from them. This led to the adoption of management techniques that were designed to minimize what he considered conflict between himself and his students. For example, the teacher had difficulty managing small group activities, since neither he nor his students were familiar with the increased teacher-student and student-student interaction that is fostered by small group activities. This created some friction in his relationship with students, so he lessened the amount of personal contact required between himself and his students by assuming a more traditional role of whole class lecturing. According to the teacher, he could not operationalize pedagogic knowledge regarding teacher-student interactions during small group activities.

Secondly, Briscoe found that the teacher found it difficult to change his practices because his belief about his role as the source of knowledge was supported by a set of beliefs about the expectations that students, other teachers and administrators had regarding classroom practices. Even though, for example, the teacher believed in allowing students to be more in control of their own learning, the students were unfamiliar with such roles. These changing roles created friction between the teacher and his students. When students complained about certain curricular requirements or activities, the teacher reduced the cognitive demands of the tasks to accommodate the students. To a certain extent, then, what he taught, and certainly how he taught, was influenced by his relationship with his students. According to Briscoe (1991), one of the reasons the teacher felt comfortable in maintaining traditional practices was that "to implement innovative techniques to his satisfaction meant coming into conflict with students' beliefs and other's beliefs about school" (p.192). That thought contributed to the feeling of being constrained: the teacher felt inhibited to effect the kind of change he felt he needed to effect. Briscoe asserts that the beliefs and expectations guiding practice are often nested in a belief system that has developed over a lifetime of experiences, both in and out of the classroom. This belief system is manifested through norms and practices that have also developed over time. I posit that these norms and practices constitute the pedagogic contract as I noted in chapter one and will discuss fully later in this chapter. Although the teacher believed he was relatively successful in changing his practices by maintaining a cognitive awareness of what he does not want to be, he was still in the process of constructing the role that matched his vision. Briscoe (1991) concluded that her study indicates that individual commitment to change on the part of a teacher is not sufficient to bring about the desired changes. Because of the conflict between the teacher's and others beliefs about the teacher's role, the teacher felt disempowered to change. I would argue that such a conflict occurs because of the teacher-student pedagogic contract.

Hildebrand's (1999) study on using the pedagogic contract as a construct in investigating teacher-student relationship has been very useful for the conceptualisation of my research questions and analysis. She introduced the idea of a pedagogic contract to analyse changes in classroom norms and practices when teachers choose to teach in unfamiliar ways. By choosing to teach in unfamiliar ways, such as through the use of creative writing in science classrooms, Hildebrand argues that the teacher is choosing to break the norms and practices that constitute the pedagogic contract. As explained in chapter one, the result was that students resisted the changes and the teacher had to devise strategies to minimise students' resistance.

Feedback from the students also revealed that when the teacher had managed the transition into a new pedagogic contract, most of the students accepted. This acceptance became possible once students adjusted their expectations to the new set of prevailing norms. Hildebrand concluded that changes in pedagogy could occur only within the space of a reciprocal relationship. Students will accept an adjustment if they see a reward for themselves in terms of learning or enjoyment of learning. Changes in teaching practices can be seen as purposeful and worthwhile if teachers employ strategies to alleviate students' resistance to changed expectations. In order to alleviate students' resistance to changed expectations, Hildebrand advocates the use of clear purposes, structured classroom processes that include choices and explicit assessment criteria. As mentioned in chapter one, like Hildebrand, I used the construct of a pedagogic contract for understanding the significance of changes that occurred in teacher-student relationships in three digitally enhanced secondary science classrooms in British Columbia, Canada. In my study, teaching with digital technology constitutes the change in practice. The concept of a pedagogic contract is an emerging body of literature that is based on the social contract theory. In the next section, I provide a more comprehensive description of this construct and explain its relevancy to my study.

The Pedagogic Contract

Brousseau (1984, 1997) utilized the theory of didactical situations to identify the main features of didactical systems as they are set up to teach mathematics. He contends that the didactic contract is both used to set up and explain the teachers and students' didactic behaviour in the learning of mathematics. Mercier, Sensevy and Schubauer-Leoni, (1999); and Rouchier, (1999) are examples of researchers belonging to The European Research in Mathematics Education Group that have published some studies using the construct of didactical situations in the learning of mathematics. These studies were translated into English from the French language. Da Silva, Manrique, Bianchini, Dubus and De Souza (2002), applied the construct of didactical situations in their study of first-year level calculus students in a college in Brazil. They investigated whether exploring functions in a computer environment would improve students' performance. In order to create a learning environment that allows the students to be more active, critical, investigative and independent of teachers the teachers felt they had to break the conventions of the didactic contract. They contend that one such didactic contract of mathematical knowledge is that every mathematical problem has only one solution, and that there are particular steps to arriving at this solution, known by the teacher. Furthermore, the students must find and arrive at this solution by way of such particular steps. The authors found that even when students were aware of identical or competing models of solving problems, they ignored them to focus on the one similar to what they think the teacher expected them to use or had previously used. Their study found that it was important to help the students to think independently of the didactic contract so that the students may identify and apply identical concepts that were suggested. The researchers concluded that computer technology proved to be an excellent environment that allowed students to show an independent attitude to their learning thereby breaking the conventions of the didactic contract.

Sierpinska (1999) distinguishes between the didactic contract and the pedagogic contract. She contends that the notion of didactic situations developed by Brousseau in 1978 (as cited in Sierpinska, 1999) examined only the rules of teaching and learning of particular knowledge such as mathematical knowledge and not teaching in general. She argues that Brousseau introduced the concept of didactic contract to explain why some students were succeeding reasonably well in other school subjects but were failing only in school mathematics. Brousseau attributed the failure to the didactic contract in which the students were concentrating on finding out what actions the teacher expected them to perform, or uncovering the implicit contract rather than concentrating on solving the problems. Hence Sierpinska argues that if one were to examine the rules that are relevant for more general teaching strategies such as classroom management, lesson planning, and assessment then we may speak of the pedagogic contract. Following the reasoning of Sierpinska then, the didactic contract resides at the micro level and focusses more on general teaching and learning strategies employed by the teachers and students. In this scheme, the social contract will be the macro unit of contractual analytic theories focused more at the level of regulating practices in a particular culture or sub-culture. The question that remains pertinent to my study asks, which of these contracts becomes the unit of analysis? I argue that the rules of classroom management must necessarily encompass at least a part of the rules associated with teaching knowledge. The pedagogic contract, using Sierpinska's arguments, involves the expectations of differential classroom management strategies in different classes. For example, the expectations in the Woodworking classroom are different from those in a Language Arts classroom and from those in a Science classroom. The difference encompasses but is not limited to the particulars of the subject matter that affects classroom management. For example in a social studies classroom, the teacher can expect varying answers to certain questions, but this does not usually transpire in a science classroom. Therefore I have chosen to use the pedagogic contract in the expanded sense used by Hildebrand (1999).

In a recent book titled *The pedagogical contract*, Too (2000) explains that the pedagogic contract denotes historically the moment when two individuals, the professional teacher of Greek antiquity and his young pupil, mutually consent to engage in the activities of teaching and learning. The pedagogic contract, according to Too regards the pedagogic community as comprising only the teacher and the students. The give-and-take interaction between the teacher and the student is such that "the teacher gives something of value - a body of knowledge, a set of skills, a way of thinking, of living, and so on - *in return* for which the student renders some form of payment, perhaps a salary, a gift or gratitude" (Too, 2000, p. 7). Too contends that teaching and learning differ from conventional material and social contracts in ways that defy rigid categories. That is, the contract facilitates individuals to move in and out of roles at different points in their intellectual lives because there are times when these roles are fluid and negotiable. For example, Rouchier (1999) argues that the dynamics of teaching and learning are managed by changes of contract during this process. It seems to me then that the basic difference between a pedagogic contract and a social contract is that the pedagogic contract applies to the teaching/learning situation while the social contract is a more encompassing tool for analyzing cultural practices.

The pedagogic contract could be a site of possible disappointment and destabilization. As it is open to the violation or mismanagement of exchange that occurs when at least one of the parties does not fulfil his or her side of the agreement. The case I make in this thesis is that introducing digital technology as a teaching and learning tool offers the potential to create a violation of the contract and hence it is a useful construct to use in examining basic aspects of the teacher-student relationship. While there are many similarities between Too's and Brousseau's work, curiously Too did not make any reference to Brousseau's earlier work on the pedagogic contract. Although the notion of a pedagogic contract is not yet widely used as a construct, at least in the North American research literature, there are a few studies that allude to the notion of an implicit classroom contract without specifically calling it the pedagogic contract. I discuss such studies in the next section.

Teacher-Student Relationships and the Pedagogic Contract

In their study on authority and convergence in a computer-supported collaborative learning environment, Hubscher-Younger and Narayanan (2003) found that effective computer-supported collaborative learning requires students and teachers to change how they understand and assign authority. They argued that an authority structure exists in communities of students and teachers and that this authority structure had a large impact on subsequent learning and collaborative learning activities. They claimed that college students "are not novices at assuming the role of student; but are skilled students experienced in social roles, norms and conventions that effect social interaction and communication" (Hubscher-Younger & Narayanan, 2003, p. 314). They posit that there is a classroom contract in place in which students appear to believe, and that this implicit contract was violated when the students were asked questions that required them to do their own investigating rather than relying on instructors' lectures. Even though the term pedagogic contract or social contract was not used in the study, it is quite clear that such a contract is what they are referring to. The authors also found that adherence to the previous classroom contract led to learning problems: students were not able to break free from traditional notions of authority in order to venture into locating other available materials of which they were aware.

The researchers recommend, then, that the classroom contract be explicitly rewritten, with authority reassigned based on the input and agreement of both teacher and students. They also stress that each party must understand their intended roles and the corresponding benefits. It is curious that the authors would advocate an explicitly rewritten statement of contract despite the fact that a written pre-existing contract did not exist. This confirms that the pedagogic contract exists because each individual involved has a clear understanding of this implicit contract. The idea of the pedagogic contract depends on a set of shared, if often tacit and unspoken, behavioural norms about the acceptable forms and purposes of communications and actions. As is often the case with such norms, they are often invisible in the ordinary course of events and become salient only when breached or when one or another participant questions them. This was the case in the study by Hubscher-Younger and Narayanan (2003).

In a study on social rules and communicative contexts in kindergarten, Wallat and Green (1979), studied how kindergarten children learn about the expectations or rules for social action during classroom lessons and activities. They found that social rules such as when to talk and when to ask questions are the products of teacher-child interactions for instructional purposes. They explain that teachers use verbal and non-verbal cues to establish classroom norms. They call for research that moves beyond the interactionist perspective of studying the teacher-student relationship, arguing that, if a classroom observer were attending to only verbal statements of rule, a wrong judgement could be made. They argue that spoken discourse does not carry social meaning by itself; classroom members construe the meaning from the combination of verbal, non-verbal, paralinguistic and ecological cues.

Their study concludes that kindergarten children were aware of the implicit and explicit rules of classroom interactions in and across various classroom contexts. Different cues served to establish these rules. They further explain that when breaks occur in social rules, teachers use the opportunity to restate and re-establish and/or modify behavioural expectations and check the children's knowledge of such expectations and of social rules. Breaks in behaviour, therefore, highlight the behavioural expectations of a situation.

In a similar study, Blumenfeld and Meece (2001) conducted a large-scale investigation into the nature of teachers' socialization communication and its relationship to children's understanding of various aspects of the student role. They found that about 57% of teacher communication was concerned with procedures, routines and adherence to rules, while the communication concerning academic performance was significantly less. Hence they concluded that teachers in the early grades spend a relatively large portion of their communicative efforts instilling procedural norms, and have expectations according to rewards for conformity to basic role expectations. In the higher grades, teachers expect older students to know more about and be better able to meet role requirements. As a result, teachers communicate less about procedural matters as they expect students to have an established awareness of the requirements. Both students and teachers are very clear about these expectations. Both studies by Wallat and Green (1979) and Blumenfeld and Meece (2001) lend credence to Aspy's (1986) assertions of five lessons children learn in the early years of schooling as discussed in chapter one. The assumption for my research perspective is that the procedural norms taught in the early years of schooling help to establish the pedagogic contract.

The three studies reviewed above show that the teacher-student relationship involves well-defined roles and congruent goals. In fact, these expectations are incorporated into students' and teachers' very definition of "school". Norms of the teacher-student relationship are based primarily on the idea that both teachers and students are to behave so as to promote student learning. Any behaviour that is perceived to violate this norm is viewed as less than legitimate (Muller, et al. 1999), and in such a case constitutes a breaking of the pedagogic contract. The challenge, of course, is that actions that teachers perceive as promoting student learning may not necessarily be so recognized by the students. It is this incongruence of expectations that causes tension in the teacher-student relationship, and necessitates the renegotiation of the pedagogic contract.

The pedagogic contract is more difficult to change in secondary school classrooms because, the social context that shapes and is shaped by the type of content learning associated with that subject -- be it literacy, mathematics or science -- is unique. The structure of secondary schools where teaching and learning practices are more content-oriented promotes the development of a learning culture that revolves around individual content areas. Within each classroom though, teachers and students can define and negotiate rules, norms and values that create a unique classroom culture (Erickson, 1986; Mercer, 1992). There are also, albeit to a lesser extent, norms and practices that span different content areas.

The pedagogic contract can be viewed as representing old certainties and familiarities of teaching and learning whose classroom routines give a sense of order, control and comfort. Duffy (1995) suggests that the method of school and formal learning has been culturally inscribed long before the students attend school. She elaborates further that "etched deeply into this cultural inscription is how teachers should do their teaching and how learners should do their learning, in what contexts, and according to what rules of relationship between them" (Duffy, 1995, ¶ 4). Duffy's point suggests that the expectations of the pedagogic contract extend even beyond the classroom. While this position makes sense, it is beyond the scope of this study. Suffice to mention that renegotiating the pedagogic contract involves an open, more creatively generated thinking. It involves exploring possibilities and thinking beyond the traditional pedagogic model of a teacher lecturing in front of a classroom of students.

Becker (2000) contends that, traditionally, classroom teaching and learning has been characterized by an emphasis on a one-way skill and knowledge transmission from teacher to students. This transmissive pedagogy usually involves:

- The use of an externally prescribed curriculum of discrete skills and factual knowledge;
- Direct presentation and explanation to students of procedural and factual knowledge;
- Frequent assignment of written exercises to students aimed at teaching them to remember factual knowledge and to accurately perform skills;
- Evaluation of students' mastery of skills and knowledge using written tests that prompt students to recognize factual statements and to apply learned algorithms and other skills to produce correct answers (Becker, 2000, p. 9).

Becker further explains that one of the reasons this pedagogy has become so entrenched is that assessment of factual knowledge and specific skills can be accomplished with a fair degree of reliability and validity, both through teacher-constructed tests and by the use of large-scale external assessments. Using such tests as measures of academic achievement, transmission pedagogy has been principally supported by evidence from studies of math, reading, and language instruction particularly in the elementary grades. This legitimacy makes it difficult to accommodate other forms of classroom learning that incorporate a range of important competencies such as decision making about competing theories, presenting evidence that is most relevant to constructing a good argument about a controversial issue, collaboration with classmates about the best way of accomplishing a task in the midst of many correct ways, or using outside resources for analysis. Many of these innovative forms of classroom learning are facilitated by the use of digital technology as a classroom teaching and learning tool. Skinner, Bryant, Coffman, and Campbell, (1998) argue that students are shaped not only by "classroom structures and larger social processes" (p. 297) but also act as agents who actively co-produce with teachers notions of themselves and ways of acting especially in the classroom, all of which lends credibility to the notion of a pedagogic contract. The students' actions in the classroom can lead to the acceptance or non-acceptance of certain classroom practices, making the notion of a contract plausible.

There are limitations to the pedagogic contract as expressed in the literature for the conceptual purposes intended in this dissertation. Firstly, the construct neglects the definite differences in behaviour among teachers, (e.g. in the amount of student autonomy they allow and in the difficulty of the work they assign). Secondly, the construct neglects the differences in a single teacher's behaviour toward different students in the classroom, treating all the students essentially as one entity. Nevertheless, in examining the teacher-student relationship in digitally enhanced classrooms, the literature provides the basis from which such a study may be analysed. The basic building blocks of the teacher-student pedagogic contract are in the norms and practices that have been the implicitly accepted, and indeed expected form of behaviour.

Norms, Practices and the Pedagogic Contract

The classroom is a central site for teachers as they enter into reciprocal relationships with students through a variety of practices and interactions. Meaning and practice evolve in classroom and school settings through the daily social routines or practices that have been established which lead to the creation of understanding and action by students and teachers. Norms become reinforced through repeated practices. Norms are implicit and explicit rules of behaviour and are inevitable elements of group interaction. Most groups develop norms without ever discussing such. The relationship among classroom norms, practices and the pedagogic contract can be likened to the concept of an equilibrium reaction in Chemistry. A reaction is at equilibrium if is the concentration of the reactants is equal to the concentration of the products. A change in the concentration of any of the reactants affects the entire system, which then readjusts itself until equilibrium is re-established. The question which arose frequently during the study, however, was: which one of these three, i.e. norms, practices, and the pedagogic contract changes first in the technology enhanced classroom? The technology is the catalyst in the reaction. My conclusion is that there is no sequence in the causal relationship among these three. Any of the three attributes can change first, what follows is merely a re-organisation or renegotiation of the other two.

The basic premise of the analysis of my study is that the norms and practices that define the classroom constitute a pedagogic contract between the teacher and the students. These norms arise out of both verbal and non-verbal communicative actions. The teacher has the central role in initiating and guiding elaboration in the formation of these norms. The individual student plays an active role in this formation too, hence the pedagogic contract. For example Coburn (2003) refers to norms of social interactions as an established pattern of teacher and student talk. These norms reveal much about teachers' views of the location of classroom expertise, the power relationship and how knowledge is developed (Bransford, Brown, & Cocking, 2000). One critical aspect of the classroom norms and practices that affects the teacher-student relationship is the place of authority and power in the relationship. I discuss this in the next section.

Authority, Power and Teacher-Student relationship

Authority is the major force that affects classroom communication and social interaction. Authority is the power given to certain people, objects, representations or ideas to affect thought, opinions and behaviour. The teacher is the authority figure in the classroom. The representations that are provided by the teacher, the styles and conventions the teacher employs acquire importance and assume authority in the eyes of the students. This often leads to an implicit belief by the students that everything they are expected to know will be either explicitly provided by the teacher, or can be derived from his/her explanations and examples. In such a situation, students see themselves as passive absorbers of knowledge, rather than co-constructors in the knowledge building process. The authority structure that exists in communities of students and teachers affects subsequent classroom learning. Hubscher-Younger and Narayanan (2003) contend that effective computer-supported collaborative learning requires that students and teachers change how they understand and assign authority. The student-centred classroom best demonstrates this change.

One of the main features of a student-centred classroom is one in which the teacher shares power with the students in the production and transmission of knowledge. Munns, McFadden and Koletti (2002) found that, when students are allowed to be active participants in classrooms and are involved in interruptions to the discourses of power, there is a greater likelihood that they will develop ownership of their learning. Munns et al. (2002) also differentiate between what they call procedural and substantive student engagement. Procedural student engagement is when students are on-task while, substantive student engagement occurs when students are in-task. They argue that the aim of student engagement is to go beyond the idea of students being on-task by complying with teachers' wishes. Rather, the aim is for students to be in-task having a psychological investment in their work, particularly when the tasks are optional. This, they argue requires a sharing of power in the classroom. One of questions to be answered by my study is if and how the use of digital technology as a teaching and learning tool promote substantive student engagement.

The power structure of the teacher-student relationship is inherently asymmetrical. Brophy (1996) calls for teachers to be authoritative rather than being either authoritarian or laissez-faire. Teachers can choose to share or deny power. Relinquishing some of the power they have traditionally wielded is not easy for teachers or students, because teachers have been the traditional arbiters of knowledge in the classroom. To ease the transition involved in power sharing, Cazden (2001) suggests that teacher talk is critical for learner consciousness. This teacher talk in the form of scaffolding students through the process of learning helps regulate behaviour, confers decisions about learning, promotes thinking and provides opportunities for student interaction and feedback. This study contributes to the research on the understanding of the notions of power and authority in digital technology enhanced classrooms.

Summary

In discussing the theoretical underpinnings of this study, I have presented in this chapter significant contributions to the different perspectives on the teacher-student relationship. Most studies on teacher-student relationships have tended to focus on the emotional aspect of the relationship, mostly at lower grade levels. There is a gap, then, in study of the higher grades and also in examining the contractual aspect of the teacher-student relationship. My study will help fill this present void.

Central to the research focus is the use of the pedagogic contract as a conceptual device in understanding teacher-student relationship in technology-enhanced classrooms. Thus current thinking in social contract theory and its derivative, the pedagogic contract has been presented. Omissions in the research have been pinpointed, with particular attention paid to its value as a conceptual tool for the present study. I have argued that classroom norms and practices, which constitute the teacher-student pedagogic relationship exist in equilibrium, hence if any one of the factors is affected, a renegotiation of the existing contract occurs.

Although many studies on effective teaching acknowledge the importance of teacher-student relationships in establishing rapport and communication with students, few studies examine how teacher-student relationships and interactions shape the decisions teachers and students make about classroom practices and learning. This study focuses on how an innovation affects the classroom relationships and how the relationships also serve to contextualize and shape the innovative practice. The innovation in this study is teaching and learning with digital technology. The following chapter reviews the pertinent literature on digital technology as a teaching and learning tool.

CHAPTER THREE

REVIEW OF RELATED LITERATURE: DIGITAL TECHNOLOGY AND CLASSROOM PRACTICES

Introduction

In this chapter, I review research on the classroom changes associated with the integration of digital technology into classroom teaching and learning. Specifically, I review studies that consider the influence of digital technology on the different aspects of the classroom context in general, and on teacher-student relationships in particular. The major argument I develop in the first section of this chapter is that the introduction of digital technology into classroom practices affects teaching and learning in ways that are not necessarily *technological.* Rather the technology provides one vehicle for re-conceptualising classroom pedagogy by facilitating changes in pedagogic practices. Such practices include engaged student learning, student-centred learning and constructivist practices. Since there are very few studies that specifically address the effect of digital technology on the teacher-student relationship, I also review studies that address the effect of digital technology on the classroom context. While many educators consider digital technology as a positive innovation in the classroom, some educators consider the use of the technology threatening to the teacher-student roles and relationship. I examine this concern and discuss its implications for my study.

Since my context is science education, in the second section of this chapter, I review research that reports on innovative attempts made in secondary school science with computer technology as a teaching and learning tool. Finally, I note the different ways in which computers are used and the peculiarities of each method used in the science classroom.

At the time this study was conducted, digital technology designed to enhance understanding of scientific content consisted mostly of in-house or data-based commercial software. Broadband access to the web was still in its infancy. Thus in this chapter, I include only studies that focus on using scientific software and associated digital resources in either middle or secondary school to promote conceptual learning. While a body of literature examines the use of technology for problem-based learning and inquiry-based approaches in science classrooms, I do not include those studies in my review. I also exclude studies that focus on the use of the information and communicative aspects of digital technology, particularly those that have focused on the capabilities of the Web solely to access data. I acknowledge that Web-based learning appears to be the direction use of digital technology is headed, with many of conceptual learning software programs now shifting from CD-ROM to Web-based. Hence, I have included studies that report on an integrated approach to technology use that sometimes include but are not limited to Web-based learning. Many projects involving technology integration now rely primarily on the web as evidenced by an analysis of networked classrooms conducted by Laferriere, Bracewell, Breuleux, Erickson, Lamon and Owston, (2001). I include such studies in this review.

Effects of the Introduction of Digital Technology on the Classroom Context

Perhaps the most significant comprehensive large-scale longitudinal study on the processes and effects of technology implementation in schools is the pioneering Apple Classroom of Tomorrow (ACOT) project, documented between 1985 and 1998. This project was funded by Apple Computer Inc., and at the height of the project there were approximately 32 participating elementary and secondary school teachers located in at least five ACOT sites across the United States of America, (Fisher, Dwyer & Yocam, 1996; Sandholtz, Ringstaff & Dwyer, 1992). The project was characterized by a large infusion of technology combined with continual technical support provided, usually in the form of an onsite technical consultant.

The ACOT project and study was predicated on the assumption that if technology were made available to teachers, they would use it to transform their teaching practices. After three years of technology infusion, the dream of transformed classroom practices was not realized, prompting changes in the focus of the project toward a more deliberately student-centred, constructivist philosophy. Only then was there some evidence of a slow shift toward classroom transformation. Because of this shift in focus, the attention changed to teaching and learning rather than being solely on learning how to use the technology. While the goal of the technology use was to demonstrate the technology's power to effect change, the slow pace quickly proved that the realization of the anticipated changes were more difficult than was first imagined. Dwyer, Ringstaff and Sandholtz (1990) noticed: "even when innovative teachers alter their practices and beliefs, the cultural norms continue to support lecture-based instruction, subject-centred curriculum, and measurement-driven accountability" (p. 4). The researchers realised then that the target of innovations should include changes to cultural norms such as teacher beliefs about teaching and learning; hence they conducted workshops to address such issues.

Following the implementation of these workshops, subsequent ACOT studies on the changes in the classroom facilitated by digital technology found that classrooms changed from "knowledge instruction to knowledge construction learning environments" (Dwyer, 1996, p. 20). The changes they observed in classrooms are summarised in Table 3.1 on the next page, taken from Dwyer (1996, p. 20). Table 3.1 illustrates the changes in teaching practices that are possible with the use of digital technology. The ACOT researchers found that when technology was used in the classroom, the teacher-student relationship changed: the teacher's role evolved towards that of a collaborator and facilitator, and the classroom changed from a teacher-centred one to a learner-centred one.

Table 3.1: Attributes of Instruction and Construction Learning Environments

	Knowledge Instruction	**Knowledge Construction**
Classroom Activity	Teacher-centred (didactic)	Learner-centred (interactive)
Teacher Role	Fact teller (always expert)	Collaborator (sometimes learner)
Students Role	Listener (always learner)	Collaborator (sometimes expert)
Instructional Emphasis	Facts (memorization)	Relationships (inquiry and invention)
Concept of Knowledge	Accumulation of facts	Transformation of facts
Demonstration of Success	Quantity	Quality of understanding
Assessment	Norm-referenced (Multiple choice items)	Criterion-referenced (Portfolios and performances)
Technology Use	Drill and Practice	Communication (collaboration, information access, expression)

Other reports illustrate educational technology's potential to change teaching (Dwyer, 1994; Sandholtz, Ringstaff & Dwyer, 1997). The ACOT researchers also found that fundamental instructional changes have a more positive impact on student engagement than any technological tool by itself, leading many educators to refer to the technology as a catalyst in classroom teaching and learning. (For example see, Fisher, Dwyer & Yocam, 1996; Woodrow, Mayer-Smith & Pedretti, 1996). Sandholtz, Ringstaff and Dwyer (1997) argue that teachers must adapt their instructional strategies to accommodate the benefits afforded by the integration of technology. They contend that the critical factor in technology-enhanced learning is not the novelty of the technology, but rather how the technology is used. They claim that many of the dilemmas ACOT teachers were confronted with during the process of technology implementation related more to their beliefs about traditional teacher roles than to problems inherent in the use of the technology.

Subsequent research in smaller scale technology integration projects have confirmed that the use of digital technology fosters attributes of the knowledge construction environment described in the ACOT study. Researchers such as Barnea and Dori (1999), Dede (2000), Duhaney and Zemel (2000), Schofield (1995), Woodrow, Mayer-Smith and Pedretti (1996), have shown the potential of enhancing learning with digital technology. What is noteworthy about these studies on technology use is that they illustrate that the advantages of using the technology, such as those outlined by Dwyer (1996) relate to learning, and do not necessarily require the use of the technology. Technology is important however as a catalyst in fostering an enhanced learning environment.

The ACOT project was exemplary in many respects but left many questions unanswered. First, due to its exploratory nature, the ACOT study did not probe deeply into different aspects of the classroom changes experienced as a result of using the technology. For instance, changes to the teacher-student relationships were not explored. Second, the majority of the initial studies were conducted at the elementary and middle school levels, with minimal description of implementation in secondary science teaching. Third, the majority of applications described were general productivity tools such as word processors, databases, spreadsheets, graphic programs or desktop publishing applications. Lastly, the primary concern of the ACOT project was access to technology, rather than integration of the technology. This emphasis on access was based on the assumption that increased access to computer hardware and software will encourage teachers both to learn to use, and identify instructional uses for digital technology. Despite these limitations, the ACOT project is considered seminal and the descriptions of teachers' experiences encouraged other studies on the use of technology in the classroom.

In a more recent large scale study, Becker (2000) conducted a survey of 4,000 American teachers focusing on their educational philosophies, characteristic teaching practices, uses of computers in teaching, and various aspects of their school environments. Becker found that given certain conditions, the use of digital technology fostered transformative teaching and learning. These conditions include:

- Classroom availability of computers and suitable software;
- Teachers who are at least moderately skilled in using computers themselves;
- Teachers whose personal philosophies support a student-centred, constructivist pedagogy;
- Schools' daily schedule that allowed time for computer use as part of classroom assignments.

Becker argued that where these conditions are present, classroom pedagogy changed such that teachers and students "engaged in authentic efforts at increasing academic understanding rather than going through the more superficial traditional practice of schooling" (2000, p. 26). Becker also found that effective use of digital technology can lead to improved student learning, increased engagement with the subject matter and increased student-centred learning. These are deep-seated changes that significantly affect teaching and learning, but again with the technology acting as a catalyst.

Becker specifically refuted Cuban's (1999) assertion that most teachers use digital technology to support, rather than alter their existing teacher-centred practices, resulting in insignificant changes in classroom pedagogy. He also refuted Cuban's claim that the culture of the classroom always prevails, even over the evident pedagogic changes that the use of computer technology can afford. Becker contends that Cuban's assertion did not hold true for the teachers in his study who were implementing technology.

Becker's quantitative study is a useful overview for policy purposes, but for the reality of day-to-day classroom practices, a qualitative study that examines the complexity of how some of these specific classroom changes occur or fail to occur is needed. Such a study provides a deeper understanding and aid future attempts at technology integration. My study contributes to such a deeper understanding.

In a review of studies on the effectiveness of computer applications in core curricula, Cuban and Kirkpatrick (1998) note that there is a need for researchers to examine the social contexts within which technology is being used. My search of the literature reveals that very few studies are dedicated systematic inquiries into the relationships between the classroom context and the use of technology, especially in high school settings. There are even fewer studies that inspect the teacher-student relationship within such settings. The studies I discuss in the next section have attempted to understand the different kinds of classroom structures and relationships that occur when technology plays a major part in teaching and learning.

Digital Technology and Teacher-Student Relationships

Based on a meta-analysis of a two-year action research project reports of 40 teachers in the United Kingdom, Somekh and Davies (1991) suggest a model for a transformative pedagogy for technology. One of the primary objectives of the action research was to study the role of technology in developing pupil autonomy in primary and secondary school learning. Focusing on their own classrooms, the teachers attempted to implement a transformative pedagogy using microcomputers in their classrooms. The transformative pedagogic model that they propose involves a change in the roles of the teachers and students such that the students take more responsibility for their own learning. They also suggest that the teachers and students become co-learners in the classroom such that the students are able to control access to and use of information, and sometimes adopt the role of a teacher in a supported context. Somekh and Davies (1991) summarize the role of the teacher as "critical friend: a co-learner collaborating with students" (p. 161) and argue that this is a creative rather than a passive role. Their study highlights the possibilities of the changes in the teacher-student roles with meaningful technology integration, but they suggest that their conjectures and recommendations need further testing and refinement in other settings.

In a study that investigated the effect of digital technology on classroom dynamics Tiene and Luft (2001) researched ten K-12 public school teachers whose classes spent two months in a technology rich facility at the local university. Analysis of teacher surveys, classroom observations and interviews revealed that students' achievement was higher than that of previous classes, who had worked on the same curriculum without the use of the technology. Tiene and Luft also found that digital technology altered the classroom dynamics in two positive ways. First, technology served as a catalyst for productive student interaction, promoting team or individualized efforts as needed in the development of projects. Second, the researchers found that there was evidence that using the technology enabled some teachers to play a more facilitative role while for others it reinforced their traditional lecture-giving method of teaching. The study did not explore why this was so.

While there are useful lessons that can be learned from this type of *test-bed* study, the research by Tiene and Luft (2001) that was conducted in an atypical classroom setting makes replication and scalability difficult. The setting was a university state of the art technology room to which the researchers had access for two months. Because of the two-month duration of the project, the classroom context was only altered temporarily. This leaves questions about what happens when technology is used in a classroom all-year. Further, the focus of the Tiene and Luft study also leaves questions about the teacher-student relationship and how that relationship changed. It would also have been helpful to know why and how the technology enabled a role change for some teachers but did not make a difference for other teachers.

While the studies reviewed thus far have only reported on the teacher-student relationship as a minor player in digitally enhanced classrooms, the next two studies that I review specifically investigated the centrality of the teacher-student relationships in such classrooms.

McGrath (1998) conducted a qualitative study that explored the effect of technology integration on teacher-student interactions. McGrath's research is part of a technology integration project that was in its 10th year at the time of McGrath's study. The collaborative project involved researchers in an institute of technology working with K-12 teachers, administrators, schools and districts in the effective integration of digital technology in math and science classrooms. The teachers used various applications of technology to create classroom experiences and lessons that engage their students in real-world problem solving. Based on teacher interviews, McGrath found that the technology increased students' motivation, promoted student-student collaboration, and enabled opportunities for more depth of understanding. The use of the technology also encouraged varied methods of assessment of learning, promoted deeper teacher-student conversations, and enabled changes in role so that the teacher became more of a facilitator.

Although McGrath's study was based on teacher interviews, there was no mention of the number of teachers that were interviewed or how long the teachers had been using technology. Further, the range of grades K-12 is very wide. One study on the issues of teacher student relationship in a technology integrated learning environment, within such a range, underestimates the significant differences in pedagogic practices across these grade levels. Despite these limitations, McGrath's findings contribute to an understanding of the importance of teacher-student relationships in digitally enhanced classrooms.

As part of a large-scale reform project, Charp (1998) conducted a preliminary teacher survey on the effect of educational technology on students' learning, teachers' teaching and parental involvement. Charp's two-page preliminary analysis focused on the changing teacher student relationship in a reformed educational context that uses state-of-the-art technologies in the classroom. Data was analyzed from a survey of 125 middle and secondary school teachers who have regular classroom access to technology through the Internet, application software and content-specific software. The study found that the role of the teacher changed from the deliverer of instruction to that of the academic guide and coach. The classroom also became more student-centred and student-directed. Like the McGrath's study, Charp's report provides limited detail about the context. The content area was unspecified, and the findings were listed in point form with minimal explanations. Nevertheless, the McGrath and Charp studies are the only two that I have found in the literature that examine teacher-student relationships in digitally enhanced environments. Given that most of what teachers do in their daily work is predicated on there being some kind of relationship with the students, it is clear that more studies need to be conducted in this area. My study represents one effort in helping to fill this present gap in the literature.

One common finding among the studies by Somekh and Davies (1991), Tiene and Luft (2001), McGrath (1998), and Charp (1998) is that the benefits of technology use in the classroom have more to do with issues of learning in general than with learning about the use of technology. Rarely did these studies emphasize increased technological competence as the major advantage of implementing technology. Instead, they highlight the different issues of teaching and learning that have been made possible by the technology such as: student centred learning, collaborative learning, opportunities for thematic and interdisciplinary explorations, to name just a few. These researchers suggest that, as the use of digital technology becomes more developed as a teaching and learning tool, there will be far-reaching changes in classroom pedagogy and relationships.

While the studies discussed in this section present generally positive views of the changes brought about by using digital technology, there are a few studies that show that some educators are not as enthusiastic about the changes that occur in the roles of the teachers and students in technology-enhanced classrooms. These educators consider digital technology a threat to classroom structures, processes and relationships. In the next section, I discuss the view of some educators who believe that using digital technology in the classroom could pose a risk to the teacher-student relationship.

Technology Integration: Empowerment or Disempowerment?

Earlier in this chapter, I argued that the introduction of digital technology into the classroom has the potential of affecting classroom pedagogy and relationships. While some teachers eagerly anticipate this potential for change, others do not see any justifiable reason to fix something that does not appear to be broken. Hence, even as some educators view the technology as empowering, others consider the effects dis-empowering to teachers, as they fear that it erodes some of the authority of the teacher in the classroom. The literature I review in this section illustrates this perspective.

While early researchers on the use of computers in schools such as Papert (1980) were convinced of the transformative effects that computer technology would have on classroom teaching and learning, Cuban (1999, p. 53) suggests that such "techno-enthusiasts" underestimate the power of the context to influence how technology becomes used in schools. For example, teachers decide if, and how, computers are used in the classroom (Cuban, 1993). It follows then that if teachers view the technology as dis-empowering, then they either are not likely to use the technology at all, or they will use the technology in ways that conform to their classroom practices. This kind of use does not lead to a transformative classroom in which students are more in control of their own learning. Geiselhart (2001) contends that the real advantage of technology use has been in the enormous potential of the technology to educate, democratize and empower both students and teachers. Geiselhart's position leads one to ask: Do teachers view the potential of the technology to democratize and empower students positively or negatively? Does the use of technology undermine the role of the teacher as some educators suggest?

Nissenbaum and Walker (1998) addressed concerns expressed by various educators and administrators that classroom use of computers offers a threat to the classroom structure, processes and relationships. They conducted a meta analysis of studies that expressed these concerns and set out to analyze claims that computers will decrease the personal contact between teachers and students in the classroom and dehumanise schools by breaking down the teacher-student relationship. In examining these concerns, Nissenbaum and Walker note that studies on social interactions in classrooms where computers are used are rare. From their analysis of the few existing studies, they conclude that existing empirical research indicates that using computers in schools increases rather than decreases social interaction. They also noticed that in the studies they reviewed, most of the interactions and communications that occur in such classrooms dealt with the use of technology. Thus, while the use of computers increased the number of classroom interactions, it is their opinion that those interactions may be less socially meaningful. Hence they call for increased research into the kinds of interactions that occur around technology use.

Nissenbaum and Walker (1998) also consider whether the use of computers in schools undermines the student-teacher relationship and threatens to displace teachers. They admit that they did not find any empirical work that directly addressed the questions of how computerization affects the teacher's role, or how it affects the student-teacher relationship. Based on three older studies (Hess, 1970; Turkle, 1984; Reeves & Nass, 1996), Nissenbaum and Walker suggest two major scenarios that they believe point to a threatened teacher-student relationship. First they contend that if the power, status, and influence of teachers were greatly reduced in a technology integrated learning classroom, then student-teacher relationships would certainly suffer. This position supports my argument of the presence of a teacher-student pedagogic contract in which the power structure is clearly demarcated with the teacher in the authoritative position. Nissenbaum and Walker's second scenario, suggests that students' frequent use of computers can undermine the image of the teacher as the expert. This scenario according to the authors is even more likely in math or science classrooms or other subject area classes where computers play a central role. Nissenbaum and Walker's viewpoint is in direct conflict with many studies that show that in technology enhanced classrooms, teachers are becoming facilitators of the learning process and higher order students' thinking and not just attendants to mundane educational transactions (e.g. Becker, 2000; David, 1994; Jacobsen, 2001; Jonassen, 1995; and Linn & Hsi, 2000;) and thus teachers' expertise is not threatened.

Concerns such as those expressed by Nissenbaum and Walker about the effect of technology on the classroom relationship indicate some teachers' apprehension of the change in classroom practices fostered by the use of the technology. This apprehension may contribute to the tendency to limit the use of the technology to merely perform the work teachers already do, albeit more easily and efficiently. This limited use of technology does not transform classroom pedagogy.

Studies have shown that a transformed pedagogy is needed for effective technology integration to occur (Somekh & Davies, 1991). Attempting to integrate technology into existing structures of the educational context will not result in enhanced learning. Breuleux, Laferriere and Bracewell (1998) wonder if by relying on existing assumptions about teaching and learning, educators are missing opportunities to make creative use of emerging technologies. Breuleux, et al. (1998) contend that school and classroom organizations have been modelled to serve an industrial era in which students are prepared to be obedient, conformist and competitive individuals. Classroom interactions have also successfully been directed to these ends. But the use of computer technology has the potential to support schooling to foster students' intellectual capacities. This approach calls for teachers who are willing to relinquish their control and promote learners' acquisition of autonomy and capacity for collaboration (Scardamalia & Bereiter, 2000). But will this change in approach diminish the role of teachers? Nissenbaum and Walker's concerns are worthy of empirical investigation.

The lack of systematic significant research into the effect of technology on teacher-student relationship underscores the need for my study. It is imperative to ask: How does the integration of digital technology affect the traditional roles and relationships of teachers and students in the classroom? How do teachers and students perceive these changes in roles and relationship? My study contributes to this important dialogue by focusing on teachers' perceptions of the teacher-student relationship in three secondary teachers' science classrooms. Since the context of this study is science education, in the next section, I discuss pertinent issues about the integration of digital technology into teaching and learning science.

Digital Technology as a Powerful Tool for the Science Classroom

This section provides a concise review of recent advances in using digital technology as a tool for understanding secondary school science. As society becomes more dependent on digital technology, it is inevitable that science education will do the same. My concern in this section is to examine what is known about the ways in which digital technology has been contributing to extending secondary school science teaching and learning. In doing that, I discuss science reform efforts and discuss the contribution of technology to such efforts. I then conclude with a discussion of the implications of the use of the technology in the science classrooms on the teacher-student roles and relationships.

Many educational theorists and science education specialists have long expressed the need for reforms in science education. The calls for reform were fuelled by low student enrolments, the dissatisfaction of many teachers and students with science instruction, and accumulating evidence of how science is learned (Raizen, 1998). Goals specified for such reforms include:

- a shift in the emphasis of science from breadth and memorization to depth and understanding (Raizen, 1998; Spitulnik, Stratford, Krajcik & Soloway 1998);

- fostering science process skills rather than teaching merely the scientific knowledge (Lawson, 1995; Tobin, Kahle & Fraser 1990; Raizen, 1998; Wellington, 2000);
- promoting a constructivist approach to science learning (Maor & Taylor, 1995; Osborne & Wittrock, 1983; White, 1988);
- instruction through the presentation of real-world problems and applications, rather than abstract knowledge providing opportunities for students to investigate natural phenomena (Lederman & Zeidler, 1987; Tobin, Kahle & Fraser 1990);
- exploring inter-subject linkages across fields of science and other subject areas (Raizen, 1998).

Efforts and strategies aimed at implementing these reform goals over the years have been relatively unsatisfactory. One of the reasons is that teachers found the sheer management of the classroom activities that are necessary for successful implementation of these changes burdensome in the light of an already overloaded curriculum. For example Hodson (1993) found that there is a gap between science teachers' beliefs about science and the classroom activities they foster, because classroom management and organizational principles tend to be teachers' immediate concerns followed by considerations about concept acquisition and development. Consideration about the nature of science and scientific activity was the least of the teachers' immediate concerns in the classroom. Other researchers such as Lederman and Zeidler (1987) had earlier obtained similar results. Although research shows that science teachers are among the lowest rates of digital technology users in schools (Peck, Cuban & Kirkpatrick, 2002), technology has been touted as a promising 21st century science teaching and learning tool in the realization of many of the science reform efforts outlined above (Ardac & Sezen, 2002; Good & Berger, 1998).

Five major reasons have been suggested to explain why digital technology could play a central role in science education reform initiatives:

- Science education has always included, at least in principle, an obligation to the use of technology in one form or the other, given that many accomplishments in science are often accompanied by an application of technology (Flick & Bell, 2000);
- Scientists routinely use technology to model observations, visualize data, access and communicate information, and control experiments, and school science is a practical subject that involves observing, measuring, communicating and discussing, investigating, handling things, monitoring and recording results (Flick & Bell, 2000);
- School science is also theoretical, involving thinking, hypothesising, theorizing, simulating and modelling and inferring (Wellington, 2000);
- The processes of science such as measuring, recording, processing data and communicating scientific concepts are now seen as equally important as the content of science such as its laws, facts and theories (Wellington, 2000);
- Though there has been modest success in implementing constructivist strategies in science education, many researchers and science educators such as Jonassen, (1995), Jonassen, Howland, Moore and Marra (2003), and Jonassen, Peck and Wilson (1999), and Linn and Hsi (2000) are of the opinion that digital technology will further augment teachers' efforts in this area.

Science educators have taken advantage of the capabilities of digital technology for teaching and learning science (e.g. Linn & Hsi, 2000). Such capabilities include the ability of the technology to collect and store large amounts of data, perform rapidly complex calculations on stored data, process and display large amounts of data in a variety of formats. There are three broad categories of digital technology tools that are used to enhance teaching and learning in science classrooms: Microcomputer based laboratories / Data acquisition tools, Simulation programs, and, other recent technologies for science education. I discuss how these tools are used in science classrooms. I also discuss results of research about the use of these various technologies in science classrooms.

Data Acquisition Laboratories

Previously known as microcomputer-based laboratories (MBL), data acquisition laboratories involve the use of sensors to collect data and measure properties such as temperature, pressure, PH value and so on. The data points are then translated almost immediately into a spreadsheet or graphical format for analysis. Unlike simulations, the data acquisition laboratories are not meant to replace the real world with computer-generated imitations but rather are critical in facilitating the translation of the everyday sensible world of nature into the more abstract, quantified world of the scientist. Data acquisition labs are tied directly to the laboratory setting. The main advantage of the data acquisition labs lies in the ability to collect very large amounts of data and then quickly translate them into meaningful patterns that students can use to construct their understanding of the concepts under study. Data acquisition labs can also facilitate a more instinctive understanding of scientific representation of real-world phenomena, enabling students to learn science in ways that may otherwise be impossible.

Research on the use of data acquisition labs has tended to focus on the students' understanding of various graphs and how well students could interpret graphs and connect such information to the phenomena under study. The majority of studies find evidence that the students' understanding of some science concepts can be enhanced through data acquisition labs (for example, Nakhleh, 1994; Nakhleh & Krajcik, 1994; Rogers, 1997; Stratford & Finkel, 1996; Thorton & Sokoloff, 1990). Indeed Barton (1997) contends that MBL's makes teaching and learning in the science laboratory very powerful.

Simulation Programs

The potential of simulations to enhance learning is associated with the theoretical and real-world connection that is possible through the manipulation of complex variables within a microworld. Simulations offer the potential to help students explore abstract and complex systems. In a simulation, an interactive program allows the user to interact with either (1) a scientific model of the natural or physical world or (2) a theoretical system (Weller, 1996). Because of the steep learning curves associated with using simulation programs, they tend to be more commonly used in college level science courses. But with advances in technology, simulations are becoming more sophisticated, user-friendly and providing more options for user-control of the variables.

Closely related to simulation tools are image processing tools. Image processing tools like those used by research scientists in various fields such as Biology, Astronomy, Medicine and Earth Science are also used for investigative studies in mathematics and science classrooms (Greenberg, Raphael, Keller & Tobias, 1998). Image processing tools are based on real life data sets and allow the manipulation of digital pictures on the computer, allowing invisible features or properties to be made visible through the use of false-colouring, animation and contrast amplification on the computer. The images are numerically encoded which then allows different quantitative analysis to be applied to examine the images and deduce meanings and relationships.

Research on the effect of simulations in secondary school science classrooms emphasizes descriptive outcomes that have generally been positive. For example, simulation programs have been found to increase conceptual understanding by promoting the formation of dynamic mental models of the phenomena under study (Akpan & Andre, 1999; Fisher, 1997; Lewis, Stern & Linn 1993; Williamson & Abraham, 1995; Roth 1995). Good and Berger (1998) are of the opinion, and I agree, that well designed simulations will become a more significant and pervasive tool in the twenty-first century science classroom.

Recent Technologies for Science Education

Recent digital technologies used in science education include application programs, multimedia technology and the Internet. Their use is varied and generally not specific to science education. These technologies are used for information, instruction, communication, record keeping, analysis and management of test banks. Application programs such as word processors, presentation tools, graphical tools, databases, multimedia, and spreadsheet have generally had a low profile in science classrooms.

Digital technology is also used in the science classroom as an assessment tool. This is done in a variety of ways that goes beyond the conventional record keeping, analysis and management of test banks. For example, the technology is used for:

- open-ended response testing that allows students to present their answers within a set standard deviation for partial or full marks (Singley & Taft, 1995);
- figural responses where students draw the solution such as an organic compound (Martinez, 1993); and
- multimedia interactive testing (Woodrow, Mayer-Smith, & Pedretti, 1998).

In their analysis of trends in computer applications in science assessment, Kumar and Helgeson (1995) suggest a trend towards testing the students' process or performance of learning instead of the product. They suggest that *solution-pathway analysis testing*, where a student can take multiple pathways towards a solution, may become more prevalent in the future. This trend in assessment is consistent with the direction of science reform towards fostering science process skills rather than merely the scientific knowledge. There is need for research on the effectiveness of this emerging method of assessment.

The Internet is at the forefront of technological information revolution. It is the most common use of digital technology. The Internet is an unquestionable asset to students and teachers because it alters the limitations of time and place of learning. Perhaps the greatest benefit to the science community is the ability to interact with other teachers, students, and scientists synchronously and asynchronously. Closely linked to the Internet is hypermedia, which affords a non-linear construction of learning and/or expression of concepts (Beichner, 1994; Briano & Midoro, 1998; Wisnudel, 1994). The Internet has combined hypermedia and multimedia to take computer research and telecommunications to another level as seen in the development of CSILE (Computer-Supported Intentional Learning Environments) and WebCSILE (Scardamalia & Bereiter, 1996). The GLOBE environmental study (Finarelli, 1998) and the Collaborative Visualization (CoVis) project (Edelson, Pea & Gomez, 1996; Gordin, Polman, & Pea, 1994) are examples of using hypermedia technologies to create virtual scientific communities by promoting collaborative learning among students in different locations and also linking scientists who are often in remote locations with the students in the classrooms. Computer-based planning tools such as PIVit are used to create multiple representations of science project designs (Marx, Blumenfeld, Krajcik & Soloway, 1998).

Digital streamed video-on-demand is an emerging use of the Internet technology. Even though this technology is still in its infancy and hence fraught with technical problems, it offers the potential to enhance and enrich classroom teaching and learning (Owston, 2000). A Canadian public television broadcasting agency and a large school board in Ontario, Canada conducted a pilot test of streamed video delivery to one of its secondary schools. Segments of streamed video, keyed to secondary school science and mathematics curricular outcomes were delivered to classroom computers. Wideman and Owston (2000), (as cited in Owston, 2000), conducted an evaluation of the pilot test. They concluded that "despite a litany of technical difficulties, … streamed video can offer teachers an effective way of teaching about dynamic and/or multivariate systems" (Owston, 2000, p. 7). Owston also suggested that watching the video can aid in students' understanding of dynamic processes that are part of the complex systems studied in science and mathematics.

Finally, the World Wide Web (WWW) is a repository of a myriad of resources such as sample lesson plans and tests, teaching ideas, and learning tips for the science education community of teachers and students. The challenge sometimes is in sifting through all the information and finding ways to use the technology to enhance learning.

Within the three aforementioned major categories of technology use in science classrooms, the use of digital technologies in science education is diverse and eclectic. Using a combination of a variety of technologies in a science classroom can occasionally be challenging since they all have distinctive learning curves and pedagogic roles. This is probably one of the reasons why studies on the effect of a combination of these technologies are rare. Most of the research into the use of digital technology in science tend to be about the effectiveness of unique or prototypical technology in specialized situations or in discrete tasks and employed short-term interventions (Weller, 1996). Longitudinal studies, such as TESSI, involving teachers that are experienced users of a combination of a variety of digital technology tools are rare. This underscores the need for my study.

While indeed many of the studies on technology use in science classroom have been positive, a fundamental premise to these reform efforts in science education is nicely summarised by Linn, diSessa, Pea and Songer (1994), who conclude that: "Considerable evidence from investigations in science classrooms suggests that both the science curriculum and the role of the science teacher need reformulation" (p.7). Their argument is that it is indeed in the reformulation of roles that meaningful changes can be experienced with technology integration. This reformulation of roles takes on a special significance in science teaching because it is an area where traditionally the teacher has always acted as the gatekeeper of scientific knowledge. The teacher tends to control the pace and the sequence in which concepts are learned. Thus, one asks how does the role of the science teacher become reformulated in technology-enhanced classrooms? My study of teacher–student relationship in digitally enhanced classrooms sheds some light on this significant issue.

Summary

In this chapter, I have presented a review of the literature on digital technology integration and the classroom. Two major arguments were developed in the first section of the chapter. First, I have argued that successful technology integration appears to be less about the technology itself, but more about the fundamental changes to teaching and learning that are made possible, and facilitated by the technology. As Harrington (1993) puts it "the essence of technology is by no means anything technological" (p. 1). Haughey (2002) also echoes this view in her review of Canadian research on Information and Communications Technologies (ICT), when she said: "the integration of ICTs is not about technology but about change" (Haughey, 2002, p. 19). In this chapter, I have shown that one of those fundamental changes to the classroom context and practices in technology enhanced learning environments include changes in the roles and relationship between teachers and students.

The second argument in this chapter is that while some educators perceive the changing teacher-student relationship as empowering some educators disagree and view it as dis-empowering the authority of the teacher as the expert in the classroom. Hence one of the aims of my study is to examine whether the use of digital technology as a teaching and learning tool poses any credible threat to the teacher-student relationship.

In the second section of this chapter, I discussed the different ways in which digital technologies are being used in science education, and the implications of this use for reform efforts in science education. Finally, I have argued that the introduction of digital technologies often leads to changes in the classroom relationships among many things, but studies examining these changes in relationships are sparse. Hence my study is imperative. In the next chapter I present the methodology of my study.

CHAPTER FOUR

METHODOLOGY

Introduction

The question that has guided this research is: How have digitally enhanced classrooms enabled three teachers to renegotiate the teacher-student pedagogic contract, and how do the teachers enact the changes? The context-specific nature of using digital technology, and the need to understand such integration within its context, necessitates the use of an in-depth case study methodology. In this chapter, I discuss the rationale for using a qualitative research design in general, and briefly review the methodological underpinnings of case study methods and their relevance to the purpose and process of my research in particular. This chapter is divided into four major sections. The first section is the rationale for the adopted methodology. The second section describes the research context and participants, as well as the roles and relationships of the participants and myself within the study. The third section provides a detailed overview of the data sources, collection procedures and methods used to analyze and present the data. The final part of the chapter discusses the criteria of soundness of the study.

Rationale

A case study is an examination of a particular situation, event, context, or practice. The case study has a long history of use in the fields of anthropology, psychology and law, and permits levels of understanding and explanation not possible through conventional experimental or survey designs. Educational researchers have found the case study to be helpful in providing deep understanding of the complexities and nuances of many educational contexts (Stake, 2000). The case study approach also provides a suitable vehicle for generating enough description essential to an understanding of the context of the situation under investigation. Case study as a social research method can also be used to develop and test theory (Denzin, 1989; Glasser & Strauss, 1967). This methodology has been found to be well suited to research and development concerned with educational uses of technology, an emerging area in which theories about teaching and learning with technology are still developing, and many studies have adopted this procedure.

In an article on the need to embrace diverse methods of research in computing studies, (Selwyn, 2000) contends that the addition of a qualitative dimension to education computing research allows a focus on what actually happens (as opposed to what has apparently happened or what could happen) when computers are used in education settings. In this way, qualitative findings can be used to illuminate quantitative data. He further states:

> There is a need to broaden methodological horizons with educational computing. By considering alternative theoretical perspectives, we can begin to form a multi-dimensional view of what is a very complex area of education. Given the increasing salience of educational technology, research cannot afford to spare educational computing the analyses that technology has been subjected to in other areas of the social sciences. (Selwyn, 2000 p. 96)

Selwyn's view echoes prior views of researchers such as Wiesemmayer and Koul, (1998), who have studied the effectiveness of computer technology using quantitative analysis. These researchers recommend the use of case studies to further understand and illuminate the complexity of the effects of using digital technology in various educational contexts. This study contributes to the broadening of such a methodological horizon. Large-scale quantitative studies are useful in providing overall pictures, but they also sometimes provide statistics that become meaningless without an understanding of the context in which the study is embedded. Personal engagement with case studies and longitudinal studies, however, offers rich opportunities for exploring, understanding and responding to larger questions. Hence the use of a qualitative case study research methodology in this study. In this research project, the case study is used as a method of arriving at a comprehensive understanding of a particular phenomenon, namely the teacher-student pedagogic relationship, and to articulate some propositions that support the definitions of the features of a pedagogic contract.

In all classroom research projects there are many decisions to be made regarding where to focus, how to look and listen, and what to include. There is much to notice in all classrooms, and this complexity is exacerbated in computer technology-enhanced classrooms, especially in TESSI classrooms where students are often engaged in multiple activities. At the onset of the study, I had decided to investigate teachers' perceptions of their development as teachers while attempting to integrate technology into their classroom practices. Shortly after I started my classroom observations, after documenting and observing various routine activities in the different classrooms, I decided to focus on specific routines and classroom activities that describe the teacher-student relationship. Although issues of pedagogic contract could certainly be explored in any instructional event, only those aspects of classroom activities that were affected by technology-enhanced instruction are significant to this study. Therefore, this study is neither an ethnographic account of life in the different classrooms, nor a phenomenological study of participants' perspectives. Rather, I have chosen to analyze and theorize on a particular topic, the pedagogic contract, using interview data and classroom observations.

This study is about the achievements and struggles that three teachers confronted to turn their ideas about teaching and learning with technology into working pragmatic reality in their classrooms. Specifically, this study illustrates some of the complexities of teacher-student relationships in technology enhanced learning environments as the teachers understood and experienced it. Recognizing what this complex process of using digital technology means for teachers permits an understanding of some of the realities, not just the possibilities, of teaching and learning with digital technology.

Significance of Teachers' Perspectives

The literature on educational change is replete with the acknowledgement of the pivotal role that teachers play as change agents (Darling-Hammond & Berry, 1998; Fullan & Hargreaves, 1992; Hargreaves, 1994). Like any educational change, the teachers' role in technology integration is vital to its success. They provide the essential interface among the learner, the curriculum, and the technologies; structuring, interpreting, coordinating, and integrating the educational experiences.

In understanding teachers' desires for change, it is imperative to understand the factors that affect their decisions about which aspects of classroom activities they change and which ones of their tried and true practices they conserve. The teacher-student relationship is one factor that may affect such decisions. This research analyses the insights provided by teachers to provide clearer pictures of the realities of their efforts at providing engaging pedagogies while integrating digital technology into teaching practices and the effects of this integration on their relationship with the students. Hargreaves (1994) advises researchers that in working closely with the teachers in understanding their perspectives, the researcher has a responsibility of not necessarily endorsing and celebrating everything that teachers say and do, but to allow the teachers' voices and perspectives to be heard. Allowing the teachers' perspectives to be heard is of paramount importance to this thesis.

Research Context and Participants

The TESSI Context

The context for this study is a technology integration initiative project (TESSI). One of the main goals of the TESSI project was to serve as an exemplar for future initiatives of technology integration. The TESSI project is a case in and of itself. In the next chapter, I elaborate on the TESSI research project and some of its explicit and implicit assumptions, especially as they relate to teacher-student relationships. In this thesis however, I have chosen to concentrate on three teachers within the project and examine their pedagogic relationships with their students.

The Participants

The three participating teachers in this study were originally invited to participate in the TESSI project by the TESSI Director, Dr. Janice Woodrow. My decision to work with these three teachers was influenced by ease of access and by the teachers' willingness to participate in my study knowing that their classroom practices would be subject to the scrutiny of a research inquiry. The pedagogic practices in each classroom developed as part of ongoing research within the TESSI project, which meant that there had been considerable advance work in the previous years that facilitated the teachers' level of familiarity with teaching science in technology enhanced classrooms.

This participant group is not intended as representative of all science teachers. Rather, participants were chosen specifically, based on the need to work with teachers who were willing to enter into the processes and time commitments involved with the research work. I perceived these qualities, as well as a genuine interest and engagement in reflecting on and gaining an understanding of their own classroom practices with technology use, as essential for participants in this study. The teachers' names, though they are not opposed to being identified, are disguised with pseudonyms in order to respect the anonymity agreement with the school and the School Board. I would have loved to name the teachers because I think they deserve a lot of credit for what they have done. The teachers were chosen as representative of expert users of this pedagogical approach: each had been using computer technology for at least five years and has been implementing TESSI for at least three years. I knew each of these teachers through our shared interest in computer-enhanced learning. They are not novices, nor were they coerced into using technology in their classroom.

Each of the teachers has an undergraduate degree in Science and a Master of Arts degree in Education. None of the teachers have had any significant formal training in computer studies beyond one or two courses taken during their graduate program. They all, however, expressed initial interest in using technology mainly for administrative classroom tasks prior to joining the TESSI project, and were eager to expand their uses of computer technology. Even though all the teachers have limited formal training in digital technology, they are self-taught and soon assumed leading roles in digital technology and related reform initiatives in their schools and districts (Mayer-Smith, 2003). Two of the three focus teachers have presented papers and workshops at various local and international conferences on the use of computer technology. In the next section, I present a brief background of each teacher.

Alex

Alex is one of the two initial developers of the TESSI model and its instructional resources. He has been with the project since its inception in 1992. He has collaborated with and trained educators at each of the expansion sites in British Columbia and Mexico. He has been successfully integrating technology in his classroom at the junior science and senior Physics levels, and has given presentations at several national and international academic conferences on TESSI and technology-related topics. In 1995, Alex and the other pioneer teacher, Robert, received the Canadian Prime Minister's award for Teaching Excellence in Science Technology and Mathematics, in recognition of their contribution to Science Education. He continues to revise the Physics 11 and 12 Study Guides while developing guides for Science 9 and 10. I provide a detailed description of the Study Guides in chapter five. Alex is in his late thirties and was in his 14^{th} year of teaching at the time of this study. He taught Physics and General Science for five years prior to joining the TESSI project. In September 1999, Alex was transferred to his current school, a newly constructed secondary school in the same district as his former school. Alex helped design two TESSI classrooms for the Science wing at the new school. The new classrooms were completed in February 2001. Alex teaches in one of the new classrooms while another teacher, Henry (who is keenly interested in implementing TESSI) teaches in the other room. Alex teaches Science 9 and 10, and Physics 11 and 12. Before joining TESSI, Alex described himself as a fairly successful traditional teacher who was doing well with conventional lecture-based classrooms, but tinkered with computer technology for lesson preparations, and classroom administrative and organizational purposes. He is comfortable with computers and enjoys the problem solving that accompanies the learning of new technologies.

Bob

Bob is one of two Chemistry teachers that joined the project in 1996. Bob has taught Chemistry, Physics, Mathematics and General Science at different times in the 10 years before joining the TESSI team. He became aware of the project while watching Robert, Alex, and Dr. Janice Woodrow, talk about the project on the educational channel via the Open Learning Agency's online videoconference in 1995. This program was aired to coincide with the provincial professional day in the fall of 1995. Bob was very impressed with the presentation as he told me during the first interview:

> I just thought it was such an amazing and neat innovation to what we can do in science. It captured my attention and it is really right down my alley because I had quite a strong interest in computers. You know it just kind of seemed to mesh together with the things I wanted to do, where I saw myself going.

One year later, at the end of his first year in the Master of Arts program at UBC, he attended a lecture by Alex and Daniel, another TESSI teacher who were presenting their work in a graduate class that they were taking together. Then he met with Janice Woodrow and expressed his interest in joining the TESSI team along with another Chemistry teacher. Bob's role in the TESSI project was to be that of a developer of relevant TESSI resources, particularly the creation of Chemistry Study Guides. Bob also helped to test and refine many of the procedures that the teachers in TESSI tried to implement, for example, the classroom LAN system, Interactive testing and Micro computer based laboratory (MBL). Dr Woodrow, the project director, opines that Bob, perhaps more than any of the other teachers, emphasized the need for flexibility in the design of TESSI and its resources. In 1999, Bob conducted an action research project as part of his M.A. thesis work to document the issues that a teacher faces in the use of computer-based activities. Bob has been a teacher at his school since 1986. Bob is in his forties and, like many teachers, his energy with the technology is fuelled by his desire to revitalize his teaching and do what is in the best interest of students. His reasons for joining the TESSI team were personal as well as professional. He said:

> Learning all about the new technologies that I could use in my science class, so thinking of those as being special development goals for myself, taking on an area that I saw myself going for the next five to ten years, ... it was something to revitalize my own personal interest in teaching. In terms of students, I thought that this was going to be a really good way to deliver the course content. It certainly gave me a wide variety of activities to engage students with. And in terms of the school, I thought this would be an innovative thing that the school could use like a bit of a jewel in the crown, something that the school could be proud of and then expose one of its own virtues, so to speak, along with many other things that go on in the school.

Peter

When Peter responded to my invitation to be a participant in this study, he had been a teacher for 9 years, the last three at his current school. He teaches Chemistry 11, 12 and 12AP and was in his second year of teaching a Physics 12 class.[6] Peter joined the TESSI project in 1999 with the intention of expanding what he had been doing on a small scale that was using technology with Mac Plus computers.[7] On the project team Peter was considered a major beta testing teacher for the Physics materials. He also assisted the Chemistry teachers in developing and refining simulations programs, as well as in adapting traditional laboratory activities to incorporate computer technology and making major contributions to the Chemistry test bank. In the first interview, when I asked him his reason for joining the project, he responded:

> I was interested in getting more equipment and expanding what I was doing in technology to include more things such as testing and that sort of stuff. I had sort

[6] AP means Advanced Placement. Students taking any AP course usually get exempted from the corresponding first year level university course. The academic rigour is higher that the regular grade 12 course and students who take it enhance their chances of getting accepted into the university of their choice.
[7] These are early configuration of Apple Macintosh computers.

> of a gut feeling about what it was like beforehand because I had done it before, on a small scale, with one or two isolated MBLs. It was nothing major but interesting in terms of how much more you could do with it, what else was out there, using computers, not just Mac Plusses but something you could get more out of.

Peter is in his late thirties and before teaching at this school he taught in a school where the work ethic among those students was higher than his current school, and the commitment to come in for extra tutorial time and work was much higher. Unlike the other members of the TESSI group who incorporated their interests in technology into their graduate programs, Peter took his Master of Education degree at UBC in the late eighties, well before becoming involved with TESSI. Of the three focus teachers for this study, Peter is the one with whom I am least familiar because he was the newest member of the TESSI group. I did not share with him some of the graduate students' stories and experiences that I shared with the other two teachers, who at one time or another have both been graduate students in the same department as me. This information is quite vital, because many of my conversations with Peter were more formal and I think more *guarded* than those with the other two teachers.

The Schools

Alex's School

Alex's secondary school was established in 1994 in a new, middle-class suburban neighbourhood. The school has a population of about 1200 students with a diverse ethnic population that includes a significant group of students of Asian origin. The school performs above average in the grade 12 provincial examination. The school administration has been very supportive of Alex's efforts because the administration was already aware of the success of the project before Alex joined the school. There are 23 science teachers in the school. Alex also enjoyed the support of his department head, who along with another science teacher, made efforts to implement TESSI with Alex's help.

Bob's School

Bob's school is a lower middle class suburban secondary school in British Columbia. It has a population of about 1400 students from a variety of socio-economic, racial and ethnic backgrounds. The school also has a French immersion program, and tends to perform below the provincial average in provincial examinations. The school has undergone massive expansion in the last five years and Bob believes that the infrastructure has not been able to match the increase in student population. As in the case of Alex's school, Bob's school and district administration were amenable to research studies carried out in their facilities. The school administration has particularly been supportive of Bob's involvement with the TESSI project, providing him with some funding in addition to encouraging him to apply for district funding from time to time. When the opportunity presents itself, the administration also proudly showcases Bob's work of enhancing his teaching with computer technology.

Peter's School

Peter described his school as an upper middle class school. The school has a population of about 1000 students and about 20 science teachers. The school is fairly new and borders a community college with which they shared facilities when Peter's school was being constructed. The school has generally performed well in provincial examinations. He describes the administration at his school as being very supportive. On at least one occasion Peter hosted the TESSI group meeting, with his vice principal providing lunch and making a brief appearance at the meeting to express his pleasure with the project.

The Classrooms

Alex's Classroom

Alex's classroom is in a new science building that was completed the year before I collected the data. This new addition was already planned for the school, but when Alex joined the staff, it was decided that the science room, rather than being built as a traditional science room, would be built with technology use in mind, particularly that of the TESSI model. Alex was allowed to work on the design with the architects. The final design consisted of two identical classrooms built side by side. There is an adjoining door between the two rooms and a small connecting rectangular area that extends across the rear of both rooms. This shared rectangular area is separated from the classrooms by a long glass window. Alex uses one of the classrooms and the Biology teacher uses the other. This classroom complex is state-of-the-art, and wired to use computer technology and its various peripheral hardware.

In Alex's classroom, four I-MAC's and three Power PC's are arranged around the perimeter of the classroom connected via an Ethernet LAN to a classroom server and the classroom's printer. Around each computer are triangular desks that can be pulled in or out and are built to accommodate three sitting students. The students' desks are arranged around the centre of the room and are moveable, allowing for traditional experiments and work with textbooks. At the front corner of the room is a multimedia centre composed of a 31-inch screen monitor, laser disc player and VCR. There is also a Liquid Crystal Display (LCD) projection panel in the room. In the rectangular area, are six Power PC's and one I-MAC computer. This room is used as an overflow area (for both classrooms) if there is a demand for more computers than the classroom is able to provide during a class while offering a quiet work area for students who are interested in working while another class is going on in the main classroom. This area is also the primary area used for interactive testing since it is semi-private allowing students to work quietly. At the same time the teacher can keep watch on what is going on through the glass partition.

The two most commonly used software packages in the Physics class are the simulation program, I*nteractive Physics*^{TM}, and the *LXR.TEST*^{TM} for student assessment. There is also a variety of data acquisition probes such as motion sensors, force probes, and photogates to name a few. The probes are relatively cheap so teachers tend to add to their collection of probes from time to time. Some of the probes use the PASCO^{TM} 300 interface while the others use the VERNIER™ Interface. Different general application software programs such as a word processor and a graphics package are also widely used in the classroom. In addition to the technology resources, all the standard traditional resources of a Physics laboratory such as ticker tapes, carts, and springs are also available in this class. Other resources such as the Study Guide resource package and the Physics textbook are also present.

Bob's Classroom

Bob's classroom is a windowless general science classroom located on the upper hallway of the inner core of the school. The classroom is outdated to the degree that it has no fume cupboard and the electrical wirings and connection for the computers is very poor. This room is equipped with standard science equipment such as glassware, sinks, gas lines, and dissection equipment. Student tables are arranged in five fixed rows across the room with sinks and gas tap attachments nearby. To create a TEI classroom, an array of technologies was added. At the front of the room there was a multimedia centre composed of a Power Macintosh 6500/AV computer connected to the school district's WAN (wide area network) and the Internet, and a 31 inch large screen TV connected to both the computer and a video cassette recorder. The TV and VCR were on a moveable trolley and sat to the right of the teacher's desk. Nine computer workstations (Six Macintosh LCIIIs, Two Macintosh Performa 5200s, and One Macintosh Performa 6360) were scattered throughout the classroom for student use. Six computers were placed on the right side and back countertops of the classroom and three were positioned on student tables in the middle of the room, one per row of student tables. Eight of the computers and all the sets of data acquisition equipment were furnished by TESSI project funds. The remaining equipment was purchased through a district level technology grant for which Bob had applied in 1996. The computers were all networked and have access to the Internet, a classroom server and the classroom printer. The teacher's computer located on a moveable cart doubles as the multimedia station, and has an LCD projection panel.

Each student computer contains several software packages including *At Ease*™ (for computer hard drive security), *Science Workshop*™ (for MBL experiments), *ClarisWorks*™ (for word processing), and *LXR*™ *Student Interactive* (for testing purposes). In addition, each computer contains *CHEMedia*™, a set of simulations that focuses on ten different topics in Chemistry such as thermodynamics and electrochemistry. *Saunders*™ *Interactive Chemistry* CD-ROM was used for some presentations of course material. An array of MBL equipment (including pH, pressure, voltage, temperature, and colorimeter probes with a PASCO™ 300 Interface) are available for use in experiments, but is kept in cupboards until needed due to space and security concerns. Typical resources such as student texts (*Heath Chemistry* for Chemistry 12 and *Nelson Chemistry* for Chemistry 11), and the associated teacher's resource packages are also available.

Peter's Classroom

Peter's room is a fairly new, fully wired, bright science room equipped with sinks, moveable chairs and tables, and standard science equipment similar to that present in Bob's room but with a functioning fume hood. There are eight I-MACs and one teacher's station in the classroom. As in all TESSI classes, the computers are arranged around the perimeter of the room. The computers in Peter's classroom are newer than in the other two classrooms as is the related equipment. In the far right corner of the classroom is a mounted TV screen and VCR that also serves as the multimedia station. The computers are all networked to a classroom printer and a server that also serves as the teacher's computer.

The available software is very similar to that in Bob's classroom. The software includes *Logger Pro*™ (for MBL experiments), *Microsoft Office* ™ (for word processing), and *LXR*™ Student Interactive (for testing purposes). The students also have access to the Internet in the classroom. The standard application programs are also available for student use. An array of MBL equipment (including pH, pressure, voltage, temperature, and colorimeter probes with a *Vernier* ™ Universal Laboratory Interface (ULI) was also available for use in experiments.

Typical resources such as student texts, Chemistry the Central Science by P.H. Nelson for Chemistry 12, and the associated teacher's resource packages are also available.

Roles and Relationships

The roles and relationships in any research project are important to discuss because of their influence on the interactions that occur in the research setting, and how each participant benefits from the process. What follows is an explication of the methods and ethics of the research process.

I begin by examining my own role within the TESSI project. In the manner of the teachers, I too was trying to understand the role of digital technology in teaching and learning. My responsibility in the project was primarily that of a researcher. From time to time, I took on minor roles as a member of the TESSI team researching and adapting software and other teaching materials for the teachers' use. I am aware of the various studies on the advantages and disadvantages of the use of different components of computer technology in schools. These studies informed my choices of recommended software. But I did not have any form of institutional authority over the teachers; hence they were free to choose what software to use in their classrooms. Sometimes they asked for my recommendations and sometimes they did not. Being part of the TESSI team did not mean that the teachers were obliged to participate in my study. They were free to choose to work with me or not. As a researcher and an active participant, I was engaged in classroom activities to the extent to which each of the teachers felt comfortable.

Throughout the study our thoughts, ideas, and feelings about the various aspects of the study were communicated through interviews, group discussions, meetings, informal face-to-face conversations and electronic interactions via e-mail. The partnership I experienced with the teachers as we worked together was a continuation of what we had been experiencing as members of the TESSI research group, with which I had been associated for several years as a non-teaching participant and researcher. As I became engaged in this study, I bonded more with these three teachers than with the other teachers in the TESSI group who were not part of my study. We frequently exchanged ideas about teaching and learning with technology, some of which were not necessarily related to my project. At times the teachers wanted to know what was new with research in technology use in science education. Another question was if some of my research readings resonated with some of their observations of their own students.

Many of the traditional boundaries between researcher and researched were also blurred as the teachers and I brainstormed together about different aspects of integrating the technology into classroom instruction. This study is based in part on the assumption that both my values and belief systems as the researcher and those of the participants will affect both of us over the course of the study (Janesick, 2000). As such, the study is not neutral in that we sought to exchange and share information and knowledge for both my benefit and that of the participants. With Alex and Bob, in particular, we talked about the changing roles and the shifting patterns of control, both for classroom process in addition to the construction of knowledge in the class. The purpose of these talks was to aim for closeness and disclosure. I did not try to keep my perceptions private, instead I viewed this study as a collaborative one in which the teachers sometimes sought my input as I aimed to understand their meaning making process. As I worked on this study, throughout the classroom visits, literature review and data analysis stages, I brought my sometimes shifting, positions and assumptions with me. Rather than pretend that I was *objective*, I outline in the next section some of the filters through which this study passed.

Reciprocity and Ethics

The social and working relationships that I established with the research participants were guided by ethical principles. Constant negotiation with the research participants regarding the schedule, activity, and discussion process occurred as the study progressed. Since I did not want to disrupt the teachers' schedules, the times and duration of my visits to the classrooms were scheduled with their consent. I did not pay them any surprise visits. At the time of this data collection, all the teachers had completed their graduate degrees. They were all full-time teachers who were interested in using technology in their classrooms. I had to negotiate entry into their classrooms. I also had to *sell* my research project to each of them in that I had to explain the perceived benefits of my research to them. I went into the classroom and decided to ask my questions based on established classroom practices with those teachers. There was no intervention on my part.

Before the first data collection, I asked each teacher: "if you had an extra pair of eyes, what would you like to know about your classroom from an outsider's perspective?" Two of the teachers wanted to know my view of how their classroom practices in TESSI compares to recent research in the area of technology implementation and science teaching. They felt that I was up-to-date on research about teaching and learning with technology. All three teachers were particularly interested in the successes and the difficulties of other technology initiatives, and how they compare to their own issues in TESSI. Another notable point was that the teachers saw me as a part of the TESSI community, as opposed to seeing me as an outsider who was interested in documenting what they were doing. Many times the teachers would ask how what "we" are doing was different from what is out there. I believe occupying this position enabled me to gain a different perspective, richer and more detailed than I would have gleaned from being an outsider.

The teachers shared many of their success stories with me and did not seem to me to be afraid to tell me their fears and perspectives on why, in some cases, they thought they were "failing". We had many informal conversations that the teachers felt comfortable enough to allow me to use as part of my data. Such was the trust within the TESSI group. I also think that because this research group has been together for some time before this study, a trusting relationship was already established. It was not something we started to build during the course of the study. Throughout the data collection period, I was in constant communication with the teachers through e-mail. I interacted with the other science teachers in the participants' schools during my visits with the participant teachers. Because of my relationship with the teachers, my role involved empathetic understanding, rather than detachment. The process rested on a premise of respect for the daily complexity of their pedagogical realities. For this research, I recognise that I have interacted with the teachers as a documenter and analyzer of their views, experiences and practices, and have not just surveyed their views from a distance at a particular instant in time. This stance has enabled me to provide a rich data that would enable the reader to have an appreciation of the complexity of the way in which the pedagogic contract was renegotiated.

Of course there are inherent tensions and dilemmas in such an approach, not unlike the ones teachers face as they attempt to share authority with their students. This meaning making process between the teachers and the researcher, according to Oyler, (1996) represents a fundamental shift in educational research, which has been dominated by notions of control and prediction arising from the positivist paradigm of the natural sciences. Oyler also contends that many educational researchers are turning away from such approaches, embracing instead methods and methodologies that seek to listen to teachers and students as they make meaning.

Even though I have shared my writing with the teachers and incorporated their feedback into this thesis, I am solely responsible for the final sense making of the data. Although I collaborated with the teachers and our process was open, honest, and trusting. I perceive that if they had written this thesis it would be a different one, focusing perhaps on other events and possibly arriving at different conclusions. However, there is likely to be more similarities than differences in the final outcome.

Regarding reciprocity, while I obviously stood to gain in one way or the other through the research process, one of my main concerns was that my research and presence in the class would benefit the teachers and the students. The benefit to the teachers was achieved by the collaborative nature of the study, and the feedback and exchange of information between the teachers and myself. With regards to the students, I tried to help the teacher as much as I could in the class by troubleshooting, especially when the students were working on an activity and had questions. If the teacher was busy with other students, I stepped in and helped the students. I think this was beneficial to the students, because it just seemed like at times they had "two teachers for the price of one." Because of these efforts at reciprocity, I did not feel as if I was exploiting the goodwill of the research participants for my own academic gains.

Data Sources, Collection Procedures and Analysis

Denzin and Lincoln (2000, p. 3) posit "qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret phenomena in terms of the meanings people bring to them." Understanding phenomena in their natural settings involves observing what occurs as well as asking the participants for their views and interpretations of actions (Altheide & Johnson, 1994). Qualitative researchers, therefore, use research methods such as interviews and participant observation to understand participants' words and actions. In this study those were my primary research methods.

Teacher Interviews

The qualitative research interview is a construction site of knowledge. An interview is literally an *inter view*, an *inter change* of views between persons conversing about a theme of mutual interest. The premise of this research is that to adequately present the teacher's perspectives it is imperative to listen to and talk with individual teachers in order to understand their points of view. These research interviews were professional dialogues based on the interactions of daily living in the classroom as teachers formed and renegotiated their relationships with the students. As such, the interviews were conversational in nature with the goal of exchanging and sharing information and knowledge between the teachers and myself (Limerick, Burgess-Limerick & Grace, 1996). My hope as a researcher was to engage in a discussion in which the participants and I were able to develop a shared understanding of the renegotiation of the pedagogic contract. Hence during the interviews, I sought to gain an in-depth, reflective description rather than a detached accounting of the activities described to me.

There were two formally scheduled interviews, which lasted between one and two hours with each participant. These interviews were embedded within a continuous series of informal conversations and exchanges between January and June 2001 and were audiotaped. In addition to these formal interviews were also several exchanges of information by way of e-mail and informal conversations that I wrote in my field notes. These broad ranging informal conversations also provided me with opportunity to refine my own interpretations of events with the teachers and to get their feedback on these interpretations, thus enabling an insight into the different ways the pedagogic contract was being renegotiated in the classrooms. The scheduled interviews were usually conducted at a place of the teachers' choosing. For Bob, the interviews were conducted in the science room and for Peter and Alex in the faculty rooms of their respective schools.

Classroom Observations

I observed different sections of Alex, Bob and Peter's classes from February to May 2001. The observations were bi weekly. For Alex I observed his Physics 11 and 12 classes, for Peter, the Chemistry 12 classes and Bob, the Chemistry 12 and sometimes Chemistry 11 classes. The students started provincial examinations in June and toward the end of the school year the teachers were pressed for time, so we decided it would be less disruptive for them if I terminated observations at that time.

The observations offered opportunities to learn more about the teachers and provided additional insights into the classroom. I took point-form notes during classes. These notes were later developed and expanded usually the same day, after the observations. I interacted with the students and participated in classroom activities, especially when they involved technology. In the process, I chatted with the students and occasionally the teachers. At times when going through the activities, if I did not understand some of the concepts, I asked the students. If the students and I were both unclear about what to do, we asked the teacher for directions. I believe being in this role of a learner helped both students and teachers feel more comfortable with me. I was not some kind of know-it-all university researcher, but made it clear that I was in their classroom to learn as well, since all the teachers had more secondary school teaching experience than myself. Further, since I was also a substitute teacher in British Columbia, I sometimes told the teachers that I would like to use some of their ideas in my classroom. The informal conversations that occurred often after, or sometimes within each observation period, provided opportunities for the teachers to reflect on their lessons and/or express their perceptions about teaching. These observations and discussions contributed to a harmonious rapport between the teachers and myself. Ultimately, the observation activity helped foster established agenda for conversation during the interviews. Overall, I observed classes of these three teachers typically every other week and sometimes once in three weeks over this four-month period.

Data Analysis

The data were analysed in three stages:

- Preparation of audio transcriptions and field notes
- Identification of emerging patterns and categorization by themes
- Search for linkages across data.

The first stage involved mainly recording, transcribing and organizing data. Transcriptions of individual teacher interviews were coded separately. Patterns were identified in the second stage. Key words and teachers' quotes were highlighted and listed in columns and rows. After completing the list, the data was categorized according to themes. The categories that I generated from the data were judged to be the most relevant to address my research interests and questions.

The interviews and field notes were coded into categories and compared against and integrated with previously coded data, resulting in the emergence of major themes for the study. The emergent categories were meant to help provide new levels of understanding by providing frames for thinking while still acknowledging the complexity of the data. The analysis involved repeatedly listening to or reading the audiotapes and transcripts, and continually re-thinking the codes that I had generated to sift and categorize the interview segments. In the final stage I summarized the data based on the categories, guided by the research questions. Major themes were then used in both the analysis of the data and in the narrative description of the pedagogic relationship between teacher and the students in a computer technology-enhanced classroom.

Data Presentation

The analytic focus of this dissertation is on the ways in which the pedagogic contract was renegotiated in the three participating teachers' classrooms. As a prelude to this analysis, in the next chapter I describe the general use of technology within the TESSI project in addition to the implicit assumptions about teacher-student relationships within TESSI. This description provides the necessary social and institutional context in which to locate the more specific analysis of the teacher-student relationship involving the three teachers.

Chapter Six is a presentation of the analysis. Since this study provides descriptive accounts of the teacher-student pedagogic relationship, the writing of thick descriptions is required. Thick descriptions aim to document participants' experiences and the setting adequately to allow the reader to enter a situation he or she had no opportunity to witness directly. It is the responsibility of the researcher to help the reader experience a sense of "being in" the research setting by providing this context. Eisner and Peshkin (1990) suggest the use of thick description to not only describe the context, but also to address the issue of validity in qualitative research. They claim that validity is achieved when the descriptions adequately represent the phenomena described.

Criteria of Soundness

There are questions that are central to all research and to the epistemological claims associated with research that always need to be asked. They include questions about the standard of evidence and reasoning used for making judgements, the validity of the research findings, and the need to generalize the findings: the criteria of soundness of the research in short. Some of these concerns have been addressed and woven throughout this chapter, but I now address them specifically. Qualitative researchers do not assume that an objective *truth* can be found through the process of research but that judgements can be made in ways that are not bound by an objective/subjective dichotomy. In this research, the process of selecting data and presenting evidence is aimed at developing a logical and comprehensive account and not so much at ascertaining 'the truth'. Therefore, for qualitative researchers, the value or criteria of soundness of a qualitative study is not found in traditional concepts of reliability, validity, objectivity and generalizability, but in the parallel terms coined by Guba and Lincoln (1981, 1982) of credibility, dependability, confirmability, and transferability of the study.

Credibility

The credibility of a study is ascertained by establishing the plausibility of the connection made between the data and the description (Guba & Lincoln, 1981, 1982, 1994). Janesick (2000) argues that in qualitative research, validity has to do with the credibility of the explanation. That is to what extent does the explanation fit the description. Thus, in establishing credibility, the goal is to demonstrate that participants and events are accurately identified and described. To enhance the credibility of a study, Lincoln and Guba (1985) suggest a number of measures the researcher can take in order to enhance the credibility of findings and interpretation, including the following that I used in this study:

- Prolonged engagement with the setting enough to understand the issues;

- Persistent observation; for the sake of identifying and assessing salient factors and crucial atypical events;
- Triangulation using multiple data sources; and
- Member checks with the participants in order to review negotiate and corroborate the interpretations.

Prolonged engagement is deemed necessary in order to be able to sufficiently understand the context and recognize distortions that may stem from misunderstandings of observed actions. Being on the research site for a long period and possibly observing the reoccurrence of various actions enables the researcher to gain a more accurate understanding of the different phenomena. In this study, prolonged engagement and observation were used to minimize any affects of my presence as the researcher on the actions of the teacher and students. Hence I collected data for four months and, in the case of Bob and Peter who were on a semester system, this period was one month short of an entire semester. This provided me with sufficient time to identify the characteristics of the participants and the context of the study and thus minimise any biases emanating from researcher and teacher.

Persistent observation requires that the researcher be attentive to all relevant aspects of a situation. While prolonged engagement provides breadth, persistent observation provides depth (Lincoln & Guba, 1985). This was established by my presence in the classes. Furthermore, in addition to the interviews, there were many informal talks with the teachers and some students during the data collection period. In some of those talks, issues were clarified and better insights were gained into some of the observed actions.

Triangulation involves either one of, or a combination of, the use of multiple methods of data collection, multiple researchers and multiple data sources in a manner encouraging convergent lines of inquiry (Yin, 1994). It provides a way to eliminate bias and corroborate multiple perspectives (Denzin, 1989; Hammersley & Atkinson, 1983). The use of multiple sources of evidence enhances the scope and clarity of the study. Thus any finding or conclusion based on such study is considered to be more convincing and accurate because multiple sources of evidence provide multiple measures of the same phenomenon. Triangulation also helps overcome the weaknesses and biases of a single method, which may occur when the researcher is the only observer of the investigated phenomenon. In this study, data was collected through interviews with the teachers, observations, and document analysis concurrently. Formal and informal conversations were scattered throughout the semester. These conversations enabled me to obtain insights and clarifications into the reasons for some of the actions that I observed or would observe in subsequent classroom activities with regards to the technology. I also used a reflexive journal to cross check collected data and the resultant descriptions and interpretations of the data.

Member checks involve the reasonable and accurate representation of participants' views (Denzin & Lincoln, 1994; McMillan & Schumacher, 1993). Since this study is about teachers' perspectives, it was very important to me as a researcher that I reasonably represent the participants' views. Hence I undertook a number of informal checks during the study, using informal talks with the teachers. The analyses were also shared with the research participants and feedback was encouraged in order to provide what Denzin (1989) calls participant verification. The prime purpose of the member checking process was to confirm that analysis of the data resonated with the participants in the study. The degree of resonance between researcher and participants in the final document indicates whether or not the accounts are a reasonable interpretation of the ways the pedagogic contract was renegotiated with each teacher. None of the participants requested any significant change to the analysis: instead all concurred that their views were fairly represented and that it resonates with their own understanding of their classroom practices.

Dependability and Confirmability

The basic question asked about the dependability of a study is: How reliable was the instrument? In a qualitative study, the researcher is the instrument and the aim of dependability is to minimize errors and biases in a study. Lincoln and Guba (1985) posit the use of a reflexive journal as one way to enhance the reliability of qualitative researcher as the research instrument. Lincoln and Guba (1985, p.327) described a reflexive journal as:

> a kind of diary in which the investigator on a daily basis, or as needed, records a variety of information about self (hence the term "reflexive") and method. With respect to the self, the reflexive journal might be thought of as providing the same kind of data about the human instrument that is often provided about the paper-and-pencil or brass instruments used in conventional studies. With respect to method, the journal provides information about methodological decisions made and the reasons for making them-information also of great import to the auditor.

Hence the use of a reflexive journal was an integral part of this study. Dependability is also concerned with the extent to which a study can be repeated and result in similar findings. According to Yin (1994), if two or more case studies are shown to support the same theory, replication may be claimed. To ensure the possibility of replication of the study, Yin (1994) and Merriam (1998) suggest detailed documentation of the research work. The detail presented in this thesis was predicated on these recommendations.

Lincoln and Guba (1985) also suggest the use of an audit trail which Yin (1994) called "a case study database" to ensure the reliability of qualitative studies. This audit trail is a formal assembly of evidence distinct from the final case study report that provides explicit links between questions asked, data collected, and conclusions drawn; in other words, a clear delineation of the methodological steps and decision points made throughout the study. Yin (1994) suggests that this trail should be kept with as much care and attention as one would give a financial audit, and should be available for review at all times. This procedure is recommended to ensure that all possible constructs were considered, and care was taken in the generation of sub categories, categories and themes during data analysis. For this study there were four levels of audit trail. The *first level* consisted of the audio master tapes for all interviews as well as all field notes of observations. The *second level* of audit trail consisted of verbatim transcripts of all interviews. The *third level* was the identification of similar responses by the use of highlighters of different colours. Different quotations were then extracted to form sub-categories, categories and subsequently themes at the *fourth level.* These different categories were extracted from the transcripts to form another word processing document, which was revised and re-revised. However at all points in the data reduction process, it was possible to retrace each step to locate the original location of a particular item or episode.

Transferability

Transferability or generalizability is concerned with establishing the domain to which a study can be applied. One of the decisions I had to make was how to prevent the case study from being a fragment of a case. Qualitative researchers are critical of those case studies that bear little systematic relationship to other cases and practices. Unfortunately, such studies lack the crucial breadth of purpose that are needful for a case study, which is to illuminate, explain and raise questions about the phenomena under consideration and to serve as a comparison to other related practices and contexts. The significance of knowledge specific to one context, especially in the depth that it provides is very important and should not be underestimated. I was concerned about the relevance of this case to other settings, other questions, other practices, and to theories about practice. My study is not meant to explain the teacher-student relationship only within the science classroom, but to enable this study to act as a springboard for investigating the effect of other innovative practices on teacher-student pedagogic relationships in general. My opinion is that the usefulness of the research should encompass more than the immediate context. The explanations and descriptions should be sufficiently adequate to have relevance to other contexts as a means of understanding and informing practice. Those outside the immediate practice context should be able to learn from the experiences, knowledge and conclusions emerging from the study. That is what I have sought to achieve with this study.

There are three levels of transferability of a qualitative case study. The *first level* of generalizability or external validity is when the researcher provides an index of transferability, that is, a database that makes transferability judgements possible on the part of potential appliers (Lincoln & Guba 1985). Teachers construct their own meanings, and these meanings vary from context to context. The goal in qualitative research is to understand the particular in depth, not merely what is generally true of the many (Merriam, 1998). This study, therefore, illuminates the different ways in which the pedagogic relationship is renegotiated within a technology initiative project. In order to provide a useful framework for readers who may be interested in seeking applications to their own circumstances, ample detail regarding the method used and the circumstances involved are included.

A *second level* of transferability is case to case (Yin, 1994). At this level, claims are made to support the notion that, for a context similar to that in which a case study was performed, the researcher claims that the same findings or knowledge claims would hold. Case-to-case transfer happens when readers can recognise essential similarities to cases of interest to them, and where rich descriptions allow the reader to assess the applicability of the study's conclusions to their own situation (Firestone, 1993). I believe that I have provided a rich case study for such purposes.

The *third level* is the generalization to theory. Yin (1994) asserts that case studies, like experiments, are generalizable to theoretical propositions. He refers to this kind of generalizability as "analytic generalization". While scientists hesitate to generalize to a scientific theory from a single experiment, case study researchers confront a similar kind of hesitancy in generalizing to a theory from a single case study. Unlike the use of samples for statistical generalizations, cases are not sampling units. Hence the use of multiple case study research method and replication of single case studies for analytic generalizations are highly recommended by Yin (1994).

In the context of this study, the three levels of generalization by Yin (1994), that is transferability, case-to-case generalizations and generalization to theory are claimed. The previous discussions and details concern the manner of the conduct of this study in a contextually rich fashion, especially with regard to different criteria about how the validity and reliability of the study serves to support this claim.

Geertz (1973) contends that transferability of qualitative studies is possible to some degree if ample thick description is provided to make possible a logical judgement about the possible degree of transferability of this study to another study. Schon called this description "underlying stories" (1991, p. 344). These are the theoretical frameworks, the points at which the generalizability of a qualitative research can be found. Schon suggests that the relevance of case material to other contexts may be found in the theoretical frameworks and underlying stories as they relate to the research questions and the methods of research. The detail of the underlying stories and the theory build on the ideas discussed in the review of literature and develops throughout this dissertation. One of the underlying stories on which this study has been based is the construct of pedagogic contract, an offshoot of the theory of social contract. One of the significant areas of generalizability of this research elaborates on the notion of the pedagogic contract by examining teacher-student relationships in technology-enhanced classrooms. This study also offers some propositions regarding the use of a pedagogic contract as a practical way of investigating social interactions within educational contexts.

Summary

In this chapter, I have highlighted the context of the study and have situated it within the TESSI project. I have provided a background of the participants. I have outlined the methodological approach adopted in the research described in this thesis. This has included a rationale for using case study research methodology, as well as a consideration of the nature of the data, the methods of collection and analysis and the roles and relationships adopted by those in the research.

The central argument that underlies the methodological approach thus outlined is that case studies that show specific pedagogical practices associated with the use of technology, and of the effects of such practices on classroom values such as the teacher-student pedagogic relationships provide rich details. These details can help educators understand the practical and conceptual problems associated with integrating computer technology into classroom practices. It is from such cases that one can clearly describe and capture the practices associated with the use of computer technology and the kind of changes fostered by such practices. This may provide one avenue for better identification and understanding of the ways in which integrating computer technology is affecting not only pedagogic practices, but also the culture of the classroom.

CHAPTER FIVE

THE TESSI CONTEXT

Introduction

This chapter provides a sense of the context in which the use of digital technology for teaching and learning has developed within the TESSI project and how and why changes to classroom practices have occurred since TESSI's inception in 1992. Providing details of the context allows an examination of some of the people, their motives and actions, the tools, and the institutional practices that form the basis of the changes to teaching and learning associated with the use of the digital technology as a teaching and learning tool.

Because the analytic focus of my study is the teacher-student relationship in three teachers' technology enhanced classrooms, an understanding of the key features that constitute the background details for the research focus is imperative. It is also pertinent to know how and why particular technologies were used or not used, and indeed how and why particular avenues for research emerged. This chapter is divided into two major sections. In the first section, my main concern is to examine those factors and conditions salient to the development and conceptualization of technology use in a TESSI classroom, and the role those factors play in the renegotiation of the pedagogic contract between students and the teacher. In the second section, I will provide a background to the different research studies in TESSI and provide a rationale for my study of the teacher-student pedagogic relationship, based on the premise that this has been an area that has not been singled out for examination within the TESSI project.

Salient Features of the Context

Calls for reform of public education in North America over the past two decades have included calls for greater incorporation of digital technology across the curriculum. In Canada, the Ministry of Education of the different provinces have a range of policies directed toward the use of computer technology in schools. Policy is one thing, a clear pedagogical purpose and workable set of practices is another. Consequently there has been considerable debate among educators regarding the educational value of technology and how it should be used in the classroom. The TESSI initiative represents one practical attempt to contribute to this debate. Thus, a key part of the TESSI project was to develop and articulate purposeful uses for and a critical understanding of technology in secondary science classroom teaching and learning. The TESSI project participants have understood the TESSI project as a pedagogical initiative, based on the belief that the integration of technology is primarily a pedagogical issue rather than a technological one.

Technology has been a key word in innovation in science and mathematics classrooms for the last two decades, (e.g. Knapp & Glenn, 1996; Linn, diSessa, Pea, & Songer, 1994). Many science teachers, probably encouraged by early studies on the use of technology in secondary science such as Brassell, (1987); and Mokros and Tinker, (1987) that demonstrated enhanced understanding of motion graphs, decided to introduce emerging digital technology into their classrooms. But because of the sparsity of studies that can serve as models of effective technology use, exactly how to effectively implement and integrate technology into the classroom in ways that the technology extends students' learning has been unclear. To this end, the TESSI project developed in response to the lack of exemplars for teachers willing to use computer technology in their secondary science classrooms (Woodrow, 1998).

In the TESSI program, traditional secondary science instructional formats that include hands-on labs, teacher and student demonstrations, text readings and problems are integrated with computer simulations, interactive laserdiscs, data acquisition probes and sensors, digitized images and video, and the Internet. Alternative activities are provided to address variations among learning styles when the use of more than one technology is appropriate. Interactive assessment is also used to support student self-monitoring. As a longitudinal technology integration research and development project in secondary science education, TESSI appears to be unique in North America. According to Shim (1999), TESSI's uniqueness is due in many ways primarily to its emphasis on the combination of:

- a multiple science subject focus: Physics, Biology, Chemistry and Integrated Science;
- integration into the existing mandated curriculum;
- active and ongoing development, primarily from the perspective of practitioners/researchers' collaboration;
- consideration of the "enhancement principle": technology is utilized only if it demonstrates its value to enhance, and not replace existing, effective teaching and learning methods;
- consideration of immediate accessibility (i.e., a small number of computers typically 8-12,) are in the science room, and are immediately accessible; and
- the use of commercially available software and the incorporation of a comprehensive range of commercially available technological components.

As implied earlier, the TESSI project developed in response to the lack of exemplars of teachers integrating computer technologies in their science classrooms in meaningful ways within the mandated curriculum. The TESSI project also attempts to bridge the gap between research and practitioner knowledge. Consequently, the TESSI project represents one effort to define and articulate the means by which computer technology integration in classrooms could be stimulated and fostered. It represents an approach in which the knowledge generated through academic research and professional workplace practice can be examined and understood by the practitioners themselves, the teachers. Hence, a central platform within TESSI is to support the development of a community of teachers as researchers who collaboratively explore the integration of digital technologies into teaching and learning science in meaningful ways that enhance learning rather than using the technology as just another *add-on* to an already dense curriculum. To this end, five TESSI teachers have either conducted individual or collaborative research within TESSI and have presented their findings at local and international conferences.

TESSI has been described as developing from a strong culture of collaboration and shared vision between practitioners and university researchers (Mayer-Smith, Pedretti & Woodrow, 1998a, 1998b, Woodrow et al., 1996). These collaborative activities include technical support, co-development work on student materials, the sharing of ideas, observing each other's classes, and constructive peer criticism. Consequently, the practices and structures were underpinned by the ideals of teachers/researchers and, to some extent, feedback from the students as the means of developing, justifying and articulating practices related to the teachers' innovative practices. The principles and practices guiding the TESSI program, therefore, include cycles of inquiry and reflection within the TESSI community, and the development of activities that promote the integration of digital technology. Hence, there were scheduled regular meetings between the TESSI teachers and researchers. Instead of a prescribed model for working with teachers, TESSI is guided by principles of engaged student learning in a technology enhanced environment and is responsive to the individual educator's teaching and learning situation and school context.

In the first year of the program, there was limited technology available, and its use was teacher-directed, mostly for classroom demonstration purposes. In the second year, more experimental work took place primarily centred on the introduction of student computers into the classrooms and of some student exploration. Many of the purely technical problems also diminished and the focus of the teachers shifted to concerns of pedagogy. Hence the second year began with a team commitment to further the use of computer technology as a learning tool for students' explorations and to build its use more substantively into classroom activities. The third year saw a more consolidated, yet still experimental, approach to the use of the technology. By that time, a sense of the pragmatic features, purpose and preconditions for technology integration into secondary school science had to a large extent been articulated and acknowledged. Nonetheless, it took time to learn to use the various software programs, develop Study Guides, articulate a pedagogic purpose and build the use of the technology more systematically into teaching practices. By the third year, it became clear that the reality and extent of the pedagogical changes involved in technology integration were greater than the teachers expected. The teachers worked to achieve an integration of the technology beyond that of merely replacing some non-technological activities with technological ones. The changes, then, were introduced slowly to the classroom.

To describe the way digital technology was being used in TESSI classrooms the teachers developed a taxonomy for the purpose of identification of the variety of the teaching styles supported by TESSI (Shim, 1999). They differentiated between Levels I, II and III. Level I is a teacher-led model based upon one classroom computer and presentation system where the materials are primarily used to supplement teacher presentations and demonstrations. Level II is a class-based model where the materials support the student use of computers and multimedia technology either in the classroom or a computer lab, and the students' progress through the units as a group. A student-centred model, Level III, is based upon a classroom set of 8-10 networked computers, where the materials are used to support individualized instruction, student self-monitoring, variations among student learning styles, goal setting and variable pacing.

All the teachers started at Level I and moved to Level II by the second year of implementation. Currently, most TESSI teachers tend to work at Levels II, III and somewhere in between. There are still a few TESSI teachers that admit that they are still working towards Level III technology integration even after almost a decade after the first introduction of the technology into their classroom. Some of the teachers however, are comfortable at the Level II mode and have no desire to move to Level III. The understanding among the TESSI project members is that the levels are for taxonomic purposes only, and there is some overlap but in talking with the teachers I noticed that there is some sense of a stage theory associated with the levels. I wondered then if the notion of levels was an adequate way of characterizing how each of the teachers implement technology-enhanced science learning. I discuss this more fully in chapter seven. Most of the teachers operate at between levels II and III depending at times on the particular topics they are teaching. For this study, enumerating the different levels of technology use within TESSI is vital to an understanding of the way the pedagogic contract was renegotiated in each of the participant teacher's classroom.

In 1999, seven years after TESSI started, Woodrow (1999) described the TESSI project as a success because her analysis showed that the teachers were using the technology in meaningful ways that enhanced students' learning. This said though, the computer technology integration process and associated changes to pedagogy within the TESSI classrooms was a slow process, somewhat unpredictable and at times laden with difficulties as a result of trials and errors of various aspects of instructional practices, especially during the initial phase. In the next section I describe in detail the participants and practices central to the development of the pedagogical initiative within TESSI. The description weaves together individual factors with features that are part of broader institutional and social norms.

Participants and Practices

The participants in the TESSI project – the teachers, students and researchers - are central to understanding the ways in which technology integration unfolded within TESSI and how the technology was used. In this section, I provide a brief introduction of the TESSI participants as a way of providing some background to the design and evolution of the project.

The TESSI project started in 1992, with two Physics teachers and the project coordinator, Dr. Janice Woodrow. At that time, the project was called the Technology Enhanced Physics Instruction (TEPI), with a view to further expansion into other science subjects. By 1995, two Biology teachers had joined the project, and a year later two Chemistry teachers became part of the project. In 1998, another Physics/Chemistry teacher joined the project, mostly as a beta tester for Physics and Chemistry materials. The addition of these new subjects helped to enrich the original Physics-based model because provision had to be made to accommodate varying curricular goals and subject-specific pedagogies.

At the time of my data collection, there were six teachers participating fully in TESSI: two Physics teachers, three Chemistry teachers and one Biology teacher. While the teachers are classified here by their subject specializations and main area of technology integration, most of the teachers have had very broad experiences teaching other science and non-science subjects at some point in their careers. Indeed, one of the Chemistry teachers continues to develop Study Guides in Chemistry, even though he now teaches Physics. Another Chemistry teacher has only one block of Chemistry and now teaches Math. All of these teachers have Bachelor degrees in Science and have obtained degrees in Teacher Education. All of the TESSI teachers at the time of this data collection had completed their Masters degrees in Curriculum Studies with specialization in Science Education. Most of the teachers came into the project with reasonable levels of technology that they had acquired through their own use of computers rather than through formal studies. In addition to these six teachers are also other teachers who use a limited amount of TESSI materials and strategies in their classrooms. The extent of the implementation of TESSI in these classrooms is limited partly due to insufficient funding for the necessary resources, in addition to the teachers preferences. A few other teachers have also joined and left the project since its inception for mostly personal reasons.

In 1995, two researchers from UBC joined the TESSI project: Drs. Jolie Mayer-Smith and Erminia Pedretti. They introduced themselves to the project team as "healthy sceptics". They conducted many studies as outsiders to the TESSI project. They referred to themselves as outsiders because they were not directly involved in the design of the project, but since

1995 many of their studies have informed the evolution of TESSI. They have since written several articles on TESSI, some of which I have drawn upon in this study. I also discuss some of their work later in this chapter. As a doctoral student and TESSI researcher, I have discussed my role in greater detail in the methodology chapter.

TESSI's position is that the key to whether or not technology is used appropriately in education is the teacher, and that the teacher's role is important in the implementation process. Mayer-Smith, et al. (1998b) reaffirm the central role of the teacher, and his/her experiences, perspectives and knowledge of the classroom contexts in guiding the technology integration process. However, there were a number of people and agencies, both inside and outside the immediate research team, who were instrumental in the design and implementation of the TESSI pedagogical initiative. These people and agencies provided considerable support, resources and ideas that aided the technology initiatives. For example, in the early years of the project, the publisher, Prentice Hall partnered with TESSI and subsequently published and marketed the first set of Physics Study Guides. Pasco™ and Vernier™ provided some free data acquisition hardware and software. CyberEd™ also provided free samples of software on the condition that teachers would give them feedback on the usability of the software.

Until they joined TESSI, digital technology was not used as a teaching and learning tool in the classrooms of the TESSI teachers. However, for all the people involved in the TESSI project, particularly the teachers, computer applications such as word processing, e-mail, and Internet were an increasingly ordinary part of their workplace practice. Some of the teachers also had a limited background in computer programming but none had any experience with educational software or applications. Thus a main goal of the project coordinator was to take responsibility for conceptualising an approach or set of approaches to the use of computer technology within the TESSI project. The initial aim was, in the first instance, to justify the experimental work that was taking place, and secondly to articulate a clear pedagogical purpose for computer technology use within the program. It became clear at the beginning of the project that the teachers had sufficient technological expertise to design and implement teaching and learning activities.

Without the benefit of prior models for achieving successful technology enhanced science instruction, the teachers experimented with alternative teaching and learning strategies, explored the impact of these strategies and continued to subject their convictions and actions to scrutiny. The project participants were able to draw on ideas and resources gleaned from their school administrators, the literature, conferences, and meetings with teachers and academics interested in digital technology, mostly from the faculty of education at UBC. The roles assumed by the TESSI teachers over the course of the TESSI project have included: teacher, resource developer, technician, network administrator, professional developer, technology consultant/advocate, student, curriculum designer and implementer and finally researcher. These different roles rather than being exclusive have been complimentary in the work that the teachers undertook. The participants did much to develop and articulate the learning principles associated with teaching and learning science with technology. The articulation of these learning principles was informed by a few guiding principles and procedures as I explain in the next section.

Guiding Principles

According to Woodrow, (1998), the conceptualization of TESSI was guided by three major principles:

1. Technology must be easily accessible and transparent;
2. Technology must be used within the mandated curriculum;
3. Technology must extend learning and should not be an add-on classroom feature.

I explain each of these principles in this section.

1. The technology must be easily accessible and transparent

A major goal of the TESSI project was to make effective and timely use of technology so that technology would become "transparent," or "just another tool". Thus, an essential feature of TESSI was the installation of the technology in the classroom allowing the students to have on-demand access as opposed to holding their science classes in the limited computer labs that were available at some schools. Only in this way would technology be considered seamlessly integrated and capable of impacting student learning. To this end, each TESSI classroom was equipped with eight or nine student computers with the expectation that frequent, on-demand access for students could be accommodated. This arrangement meant that a classroom ratio of students to computers of 3:1 and sometimes 2:1 naturally resulted in students working in groups with the technology. This grouping encouraged dialogue among the students and helped the students link verbal representations of concepts with the pictorial representations viewed on the computer screen.

The grouping also promoted task collaboration within the context of computer-supported learning and helped students confront and overcome preconceptions as they talked about their activities. It was not an uncommon sight to see several TESSI students at a simulation or an MBL activity discussing how the physical variables interact or what will happen when a variable is changed. This kind of interaction was also observed when students were working on traditional experiment in the class, since the classroom set-up was such that activities tend to be done in groups.

The teachers also discovered that in order to make efficient use of the small number of computers, classroom and student activities had to be modified. One major modification was to have a variety of concurrent activities from which students could choose, (i.e. student multi-tasking). A second modification was an instructional plan that enabled students to progress at different rates (i.e. self-pacing). These modifications were made at Level III implementation. With these changes, the eight or nine computers found in TESSI classrooms became a reasonable working number of machines. These instructional modifications eliminated the need for all 24 to 30 students to have access to the computers all at the same time or for all activities. This arrangement supported and encouraged student group work. At Level II though, the students normally all did the same activity at the same time putting severe demands on the computers. As a consequence, some of the teachers often had their students using the computers in the study room or sometimes in the computer lab depending on the activity, or alternately crowded the students together.

The option of having computers in the room because of easy access created another problem: computer labs are designed to house computers; science laboratories are not. In setting up the computers in their science classrooms, the teachers had to consider many options. For example, classrooms needed to have adequate space to accommodate the computers while allowing up to three students to sit near a computer monitor and still be able to perform experiments beside it. Other common issues that arose in the conversion of the science laboratories to technology enhanced science labs were access to electrical power and networking cables, and the use of a local area network (LAN) to speed up installation of programs and manage security and computer desktops. Variations in science classroom design ensured that many other factors contributed to the lack of properly set up classrooms, each presenting its own difficulties and each requiring a unique solution. The result was that some of the TESSI classrooms' infrastructures are better suited than others for the kind of pedagogy that TESSI promotes, such as collaborative work and adequate spaces for self-pacing, and quiet places for taking tests.

Since the TESSI Project classrooms were innovative technology pilot sites, funding was provided through various combinations of the school, the school boards, commercial and foundation sponsors, and research grants co-ordinated by the Project Director, Dr. Janice Woodrow. The earlier project sites required more funding than the later ones. These funds were used to cover the cost of the initial stages of development. Typically, teacher-related sources were purchased first, followed by student-related resources, as funds became available. The technical support that the TESSI teachers received was no more than what a typical teacher might experience in a School District where technical support for teachers is a low priority. The teachers became adept at finding alternate sources of technical support, including students and other "techie" peers.

2. Technology must be used within the mandated curriculum

The Technology Enhanced Secondary Science Instruction Project (TESSI) was conceived as an attempt to formulate a working model of how technology might be integrated into secondary science classrooms to meet the needs of established curriculum using state-of-the-art technology. Hence TESSI had always been concerned with technology integration within the mandated curriculum. This focus concurs with Baker, Herman and Gearhart's (1996) principle that "Technology use must be grounded firmly in curriculum goals, incorporated in sound instructional process, and deeply integrated with subject-matter content" (p. 200). Because of this focus, within the TESSI project itself, the differences between subjects led to variations in how the technology was used.

In Physics, for example, simulations and graphing applications are the most frequently used software, while in Biology, graphics and digitized video are emphasized and finally in Chemistry, the MBL technology is the most commonly used program. Each technology contributed its own benefits to the instructional model and each required adjustments to teaching strategies. The process of integration became more refined through experimental work and through developing a better understanding of the capabilities of various software programs. Throughout this process, there were few explicit expectations with respect to the ultimate form of the "product" of the technology-integrated classroom within TESSI other than the expectation that the integration include broad applications of the use of digital technology. The uses include providing a space for investigating ideas through the use of simulations, data acquisition laboratory activities, exploring and using the web, using multimedia to represent ideas, presenting ideas to a wide audience and, perhaps most importantly, fostering student-centred learning in the classroom, thus empowering the students with a sense of agency as designers and not simply as receivers of knowledge. These uses both align with existing curriculum requirements and provide opportunities for extending learning with the technology. I present a further discussion of this point fully in the next section.

3. Technology must extend learning and should not be an add on classroom feature

Before implementing technology into their classrooms, most of the teachers had an established, lecture-based, content-oriented, routine-based teaching style. Although the teachers were very comfortable with lecturing and traditional teaching strategies, there was a general feeling among them that more students could be reached if their repertoire of teaching strategies was broadened.

A special advantage of the TESSI model is that the teachers take advantage of the capability of digital technology in linking multiple representations of knowledge. Thus, the interconnectedness of the different kinds of representations -- verbal, numerical, pictorial, conceptual and graphical -- could be presented to the students. Simulations, for example, provide multiple modes of representation by linking dynamic, pictorial images of phenomena with their graphical and numerical representations, all of which are synchronized to maximize the simulation's effectiveness in facilitating the process of conceptual change. Indeed, the unique advantage of using computer-based simulations in science education is their ability to provide such multi-linked representations that can help students create in their own minds links among different representations of a phenomenon. Likewise, the real-time graphing techniques of the MBL probes enable the simultaneous viewing of a phenomenon and its graphical representation. The graphing software also facilitates the in-depth analysis of collected data while the activity is in progress. The technology is used to promote student understanding of basic ideas and concepts before and with the use of abstract symbols and formulas that are so characteristic of traditional science education.

The use of computer technologies in the classes was also developed and aligned with the capabilities of the computers. The types of programs used shaped and reflected the approaches to the technology. Teaching and learning strategies used in TESSI classrooms include small group and individualized instruction, frequent assessment with the help of computers, a choice of activities, pedagogical discourse with students and self-monitoring (Woodrow, 1998; Woodrow, Mayer-Smith, & Pedretti, 1998). Thus, within the TESSI project, computer technology was viewed as a viable means of broadening teaching practices. The question that arises though, is how much do all of these changes affect the teacher-student relationship? That question remained unanswered, even within the TESSI project.

The Study Guides

The changes in instructional practice within TESSI were reflected in the changes in learning procedures and the curriculum materials that were developed. One component of the pedagogical model that developed from an examination of other alternatives, and has been described by the teachers as probably the major distinctive feature of TESSI, was the student Study Guide (Shim 1999). (See Appendix A for selected pages of Chemistry 12 Study Guide)

The term Study Guides is used somewhat ambiguously in TESSI. More precisely, Study Guides and Activity Guides were developed. The Study Guide was an overview of each unit in the year's curriculum listing all activities, assignments, tests, text references, and reviews. In addition numerous Activities Guides were developed keyed to the Study Guides that outlined the activities (both technology supported and standard) for the students. The Activity Guides constituted the bulk of the development work whereas the Study Guides provided the overall structure of the course. But the TESSI teachers have always referred to both as the Study Guides, which is what I have done in this thesis.

The Study Guide acts as a flowchart to support student learning using various student activities. The Study Guide integrates the multiple technologies with existing curriculum and student activities, and supports guided, self-directed learning. The Study Guide had to be sufficiently explicit to give direction to the students yet with enough flexibility to encompass a range of learning styles and student abilities. The guide outlines the units' objectives, content, and completion requirements and includes sample problems, assignments, student and teacher simulations, laserdisc-based activities, labs, demonstrations, discussions, and self-checks for understanding. The format of this guide gradually stabilized as its use was evaluated. The layout of the guide, including the use of 'standard' icons to flag specific activities, has been kept the same in all the subject areas within TESSI. Students used this guide to work through the units either as a class or at their own paces, individually or in small groups. Most of the teachers tried to keep didactic teaching to a minimum, permitting the teacher to work with individuals or small groups, although as I will show later in my study, the level of didactic teaching varied greatly among the teachers.

In Level II classrooms, the guides acted primarily as an overview for the students as they went through the unit. If alternative activities were included, the teacher generally decided which one would be undertaken. Thus the guides provided for differences in teaching styles in addition to learning styles. In Level III, classroom group activities are generally restricted to teacher demonstrations, tests and some laboratory activities. In such classes, three or four different activities are able to be underway simultaneously depending on the students' rate of progress through the Guide. This structure allows students to assume some of the responsibility for their own learning, sometimes through allowing them choices of activities, but requires a careful *bookkeeping* system to track student progress.

Through this guide, the teachers adapted student workstations and a range of available software to fit the existing science curriculum. The rationale behind the Study Guide is to encourage more personal engagement with the concepts and the technology, to engender student autonomy and responsibility and to increase social interactions and discourse among students. Prentice Hall (Canada), Inc. marketed the first set of guides, the Physics Study Guides.

One of my concerns in this study is to examine how the intermediary nature of the Study Guides affects the teacher student relationship. In most cases the teachers do not give direct instruction to the student and are not directly involved with the management of learning. With most of the activities in the TESSI classrooms geared towards promoting student autonomy and responsibility, how does this affect the teacher-student pedagogic contract? And how have the teachers dealt with these effects? These are some of the concerns that my study addresses.

Research Studies

The roles assumed by the TESSI participants have included: teacher, resource developer, technician, network administrator, professional developer, technology consultant/advocate, student, curriculum designer and implementer as well as researcher. These different roles are not exclusive of each other but in many ways have been complimentary. Since TESSI has been an on-going longitudinal research project, various studies have been conducted by some of the participants. As I mentioned earlier, one of the goals of TESSI as a research project is to bridge the gap between research and practice. As a result of the increasing acceptance and appreciation by the education research community of teacher research as a legitimate form of inquiry (Clarke, 2001; Clarke & Erickson, 2003), the participant teachers were encouraged to inquire into their own practices. The insider perspectives offered by the studies conducted by these teachers have been valuable. In this section, I include a brief synopsis of the practitioner research studies and discuss how they provide the background to my study. Some of the studies conducted within TESSI include:

1. Researching and developing instructional strategies and classroom procedures that integrate the use of the latest emerging technology with student-centred

classroom instructional practice (Eichorn, 1997; Woodrow, Farenholtz & Spann, 1998);

2. Examining and documenting the nature of learning and teaching in a technology enhanced science classroom (Woodrow, Mayer-Smith & Pedretti 2000);
3. Investigating if students' responses to the substantive changes in technology enhanced science classrooms is gender dependent (Mayer-Smith, Pedretti & Woodrow, 2000);
4. Documenting the roles and perspectives of those participating in this project, i.e., the learners, teachers, and researchers (Hutchinson, 1998; Pedretti, Mayer-Smith & Woodrow, 1998; Shim, 1999; Woodrow, Mayer-Smith & Pedretti, 1996);
5. Periodic evaluation of the project (Woodrow, 1998, 1999);
6. Disseminating the results of the project to encourage teacher professional development in the requisite knowledge and skills to operate in technology-rich environments (Pedretti, Mayer-Smith & Woodrow, 1998; Mayer-Smith, 2003; Woodrow & Spann 1997).

Even though I have given examples of the studies within each category, the studies, as is to be expected, do not fit into any clear-cut category system. There is much overlap. Overall, the different aspects of TESSI and the different research studies that were conducted within TESSI generated considerable interest among educators in the potential of the technology in addition to providing a clearer picture of what was possible with the use of technology.

After about three years of implementation and research, in an overall analysis of TESSI, Woodrow (1998) concluded that that Computer technology use within the TESSI project was valuable and that technology did indeed extend students' and teachers' learning. She stated that TESSI demonstrates how:

- multiple technologies can be integrated successfully into daily classroom practice within the context of an existing curriculum;
- the use of commercially available technology can support flexible teaching practices;
- learning can move from a knowledge-transfer process to a knowledge-building process; and
- the acquisition of essential skills including time management, communication, problem solving, self-monitoring and assessment, self-confidence, responsibility, collaboration, goal setting, peer tutoring, and technology expertise can be supported through the proper application of technology (Woodrow, 1998, p.3).

Teaching and Learning Studies

Four TESSI teachers have conducted four major studies within the TESSI project as part of their graduate work: Eichorn, (1997); Farenholtz, (1999); Hutchinson, (1998); and Shim, (1999).

In a quantitative study, Eichorn (1997) examined if the use of TESSI in his Biology 12 class significantly increases students' achievement. He found that students in the TESSI course were achieving similar examination scores to those in a traditional classroom and that students' attitudes and ability to access the technology were independent of both their level of computer experience and their gender.

Hutchinson's (1998) "teacher-as-action-researcher" study described his experiences with technological innovation in his Chemistry 11 and 12 courses. This qualitative case study addressed some of the practical issues that arose as a result of innovative technology implementation. Hutchinson gave a detailed "insider perspective" into the early struggles he had in developing a technologically enhanced curriculum: finding support, managing new responsibilities, and linking curriculum with resources and student outcomes. He found that interactive communication with students and the role of the teacher were crucial to making decisions regarding technology innovation. He further reported a changing teacher-student relationship during his study, but because the teacher-student relationship was not his focus, he did not provide the reader with a sense of exactly how the teacher-student relationship was changing.

A qualitative study of six TESSI teachers' perceptions of the issues in educational technology implementation and integration was conducted by Shim (1999). In the study, he acknowledged and drew on his personal involvement, as one of the project teachers in TESSI to provide "insider" knowledge on the teachers' perspectives on technology integration within the project. His data consisted mainly of teachers' interviews. Shim focused on the "interacting conceptual and practical factors that are incorporated by teachers in developing approaches to technology implementation and integration into science teaching" (Shim, 1999, p. 4). In this study, Shim identified three major domains and relationships for examining technology integration: the student domain, teacher domain and infrastructure domain. He defined each domain as follows:

- **Student Domain**: the issues and concerns of student learning and pedagogical practice, student activities, student evaluation, and curricular and non-curricular concepts and issues;
- **Teacher Domain**: personal, professional, and pedagogical issues and conceptions;
- **Infrastructure Domain**: technical, physical and logistical concerns, financial and student resources, people resources, and administrative support. (Shim, 1999, p. 89)

Of particular interest to me is his discussion about the student domain. Shim found that during the initial stages of using the technology, the teachers felt that their classroom dynamics remained unchanged from those of a teacher-oriented classroom. However at about the second and third year of the integration, and as the teachers used the technology more frequently, He reported that the "student-teacher dynamics diversify and change" (Shim 1999, p.91). While mentioning that the learning environments changed, Shim's study did not provide an in-depth evaluation of exactly what these changes were and how they occurred. My study provides details of the change in student-teacher dynamics within three TESSI classrooms.

Drawing upon his experience as one of the TESSI pioneer teachers, Farenholtz (1999) attempted an operational definition of technology enhancement as it applies to instruction in secondary classrooms. This need, he argues, stemmed in part from the frustration that the literature failed to provide a common definition for technology integration. Farenholtz also contended that a prescriptive definition of what constitutes an effective Technology Enhanced Instruction (TEI) model would enable teachers to be able to assess the educational benefits afforded by technology integration and be aware of the operational criteria evident in effective TEI classrooms. To Farenholtz, who is a proponent of transactive learning environments, an effective TEI environment is one in which the students take more control of their learning and so classroom dynamics, including relationships, must necessarily change. My study takes this further to examine how the teacher-student relationship changed. Many of Farenholtz's operational definitions have informed this study.

These teachers' studies are not the only TESSI studies that have touched on student issues and inevitably their relationships with teachers. In a study of technology's impact on the social milieu of TESSI classrooms, Pedretti, Mayer-Smith, and Woodrow (1998) surveyed student perspectives and found that most students favoured the use of technology and were able to recognize and articulate the changes in their roles and the teacher's role in the TESSI classroom. Students also discussed metacognitive aspects of student responsibility and independence, self-pacing, collaborative work, and other aspects of learning that were well beyond the science curriculum. Implicit in these findings is an acknowledgement of a changing teacher-student relationship. But Pedretti, Mayer-Smith, and Woodrow (1998) also stopped short of going into much detail about this changing relationship.

The studies within TESSI clearly support the argument by Burbules and Callister (2000), that discussions of technology in education are complex. Examining this complexity and the multiple effects of the technology on various aspects of educational practices was a key part of the research studies conducted within TESSI. The findings of the different TESSI research studies also concur with the findings of Becker (2000), who claims that, even though technology use is still not prevalent in schools, significant learning gains are being made where it is being used. Hence, if computer technology integration does provide a unique way of teaching and learning, as implied by the studies discussed above then, an examination of the effect of this kind of pedagogy on the teacher student relationship is imperative.

Summary

The discussion in this chapter provides the framework for understanding the TESSI project and how computer technology was integrated in TESSI classrooms. I have described the context and background to the project in detail by highlighting a range of complex social and technological factors that affect how technology is being used in TESSI classes. I have also provided a rationale within TESSI for my research focus. The research questions, design of the research and my analysis, will be better understood in the light of the social and technological context that I have documented in this chapter. In the following chapter, I present the results of my analysis.

CHAPTER SIX

RESEARCH FINDINGS AND DISCUSSION

Introduction

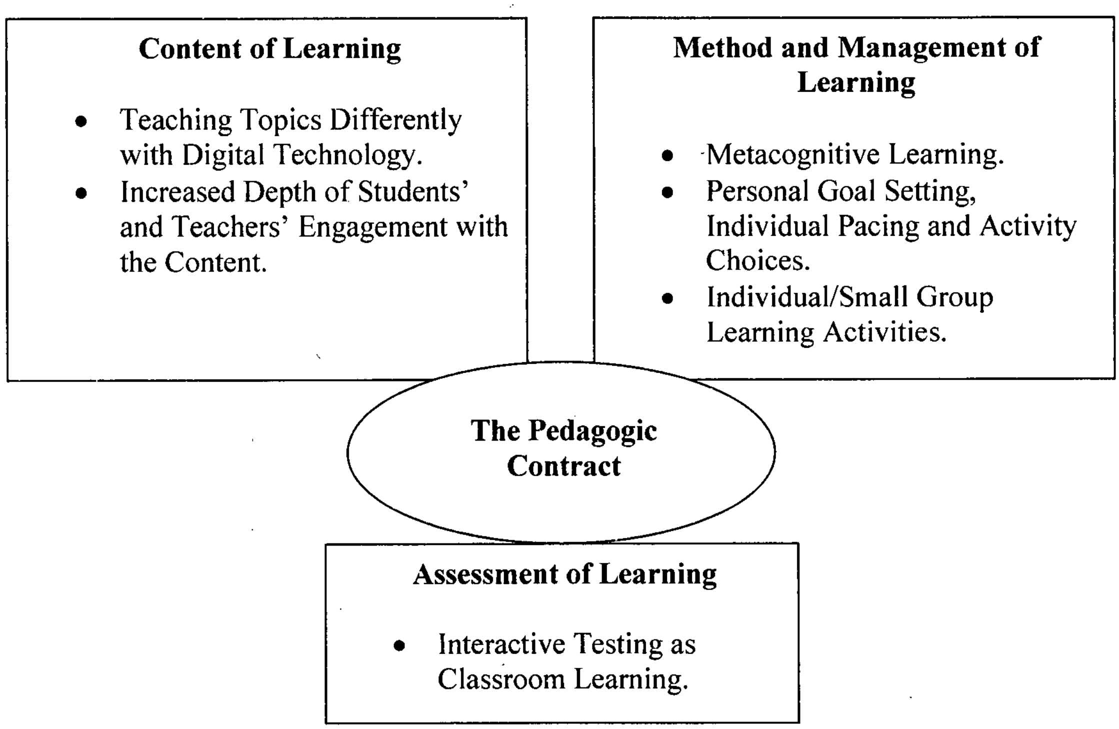
The effect of the introduction of digital technology into classroom teaching and learning on the teacher-student pedagogic contract, and the teachers' enactment of the changes was evident along three major dimensions of learning:

1. Content of learning;
2. Method and management of learning activities; and
3. Assessment of learning.

Two major attributes were further identified within Dimension One, four in Dimension Two, and one in Dimension Three as shown in Figure 6.1 below.

Figure 6.1

The teacher-student pedagogic relationship: Dimensions of learning



These three dimensions offer a view of classroom events in these teachers' digitally enhanced classrooms over the entire course of this study, through which changes in teacher-student pedagogic relationships in technology enhanced science classrooms can be examined. To be able to put the research findings in perspective, it is important to bear in mind the three levels of implementation of TESSI discussed in chapter five. Each teacher's approach to, and indeed the extent of integrating the technology depended on his level of implementation. According to Woodrow (personal communication, April 9, 2004), TESSI was never intended to find *the* way of implementing technology but to explore strategies of enhancing students' learning. Therefore, the teachers had the freedom to implement TESSI according to their individual beliefs and preferences. This said though, there was also an emphasis or an awareness of the need for the teachers to be willing to allow the use of the technology to challenge their individual beliefs and personal preferences. Hence the teachers were encouraged to subject their beliefs about teaching and learning to scrutiny in the light of the emerging capabilities and potential of teaching and learning with digital technology.

At the time of this study, Peter was implementing TESSI at Level II. He has always operated primarily at the Level II implementation by choice. He enjoys the sense of organization in his classroom. In the case of Bob, he operated at Level I for one year before making an accelerated change to Level III. He was not pleased with the myriad of changes to his classroom practices that resulted from implementing at Level III for two years, so he decided to adjust to Level II. He claims to be very comfortable with the Level II implementation. Alex was operating at Level III at the time of this study, and describes this as his comfort level. Even though the levels of implementation adopted in TESSI provided a common language of reference for what the teachers were doing, there were also some problems associated with the implicit assumption of a stage theory associated with the notion of levels. I discuss these problems in detail in the next chapter.

The results and analysis of the data are presented in this chapter in three main sections corresponding to the three major dimensions outlined above. Each section begins by highlighting the changes in teaching and learning practices and thus the relationship in the digital classroom through the attributes outlined within each dimension. I then describe how each teacher viewed, renegotiated and enacted the emerging changes, and identified what aspects of the changes in the relationship they valued. Individual teacher's enactment of the changing relationship is a combination of many factors, including their individual level of technology implementation, personal preferences, and their perception of their students' level of comfort with the changes.

Dimension One: Content of Learning

The use of technology as a teaching and learning tool, enabled modifications in teacher-student relationship practices associated with two content of learning attributes:

- Teaching topics differently with digital technology
- An increased depth of students' and teachers' engagement with the content.

The teachers found that the availability and capabilities of digital technology facilitated the teaching and learning of some science concepts in ways that would not have otherwise been possible. There were also concepts the students were able to learn in greater depth using technology, a depth that went beyond the mandated learning outcomes in the curriculum. These two modifications in the content of instruction enabled the teachers to renegotiate the pedagogic contract by creating increased opportunities for teacher-student conversations about science concepts. The teachers enacted the changes by exploring and encouraging alternate ways of teaching concepts in order to enhance students' learning and promote increased depth of students' engagement with the content. The modifications also facilitated the transformation of the teachers' role, from sole authority to that of a coach and facilitator. The modifications in teaching practices that relate to the content of learning are elaborated below.

Content of Learning: Teaching Topics Differently with Digital Technology

All three teachers talked about some topics in the mandated curriculum that were enhanced by the use of digital technology in their teaching, providing the students with a better approach to understanding the concepts. Prior to using digital technology, the teachers taught the students knowing that sometimes students did not necessarily always fully understand those concepts, but they knew enough to be able to answer required questions successfully on exams. For example, a good understanding of the mathematical relationship between variables is usually sufficient for success in answering questions relating to science topics involving quantitative relationships on the examination, but is not a guarantee that the student understands the concepts underlying the variables.

In the following excerpt, Alex exemplifies this gap between mere impartation of exam-passing skills and the teaching and learning of concepts:

> *Alex:* Another [computer simulation] activity has to do with space science. They have a satellite that is in orbit around the earth and they [students] are trying to launch a space shuttle to match orbits with the satellite. Intuitively, just like driving a car, you step on the accelerator and increase your speed and you will accelerate to reach it. But in fact when you increase your speed the size of your orbit decreases and it's completely counter-intuitive. They [students] do a lot of [computer simulation] exploration about what they think should happen when in reality the very opposite often happens. Then they use some Physics and some calculations to see that the Physics matches what they saw in reality. [They ask] how come it doesn't match their intuition? So they reflect on that in a more summative way, and their conclusion at the end of that exercise is discussing the problem at hand.
>
> *Researcher:* How would you have taught that without ... ?
>
> *Alex:* I didn't. I told them and they learned how to solve the problems that they would see on the exam. So that is an example where I think that if you look at the exam scores, the exam scores were the same but I don't think the exam measures a lot of the skills that these students are really developing.

Alex stated that this concept was one that was difficult to teach because its counter-intuitiveness makes it difficult for students to understand. Prior to using digital technology, he would emphasize only the mathematical relationships between the variables and solve problems by substituting values using the formulae. The ability to correctly solve the equations was usually sufficient in order for the students to do well on the examination. Digital technology afforded the opportunity to explore *what-if* scenarios and enhance students' understanding in ways that were not possible otherwise.

Bob also provided an example of a topic that technology enabled him to teach differently and more effectively. His example involves a topic in the Chemistry 11 mandated curriculum that, according to him, "often disappears" in traditional classroom contexts:

> ... the organic Chemistry section. To compensate for that, [now that I have the technology] I use the multi-media organic Chemistry package. So what I ended up doing is to assign that as a bonus activity. I've got a Study Guide made up for it and I would say, hey kids, you know here is a 5% or 10% bonus for you, you can do it on your own, follow through the Study Guide and do these multi-media sections.

Organic Chemistry is one aspect of the Chemistry curriculum that teachers often teach toward the end of the school year. According to Bob, the packed curriculum and the task of readying students for the examination do not usually leave him ample time to teach organic Chemistry. Prior to the technology-enhanced classroom, he used to give a short, dense, content-laden lecture, which by his own admission, was probably ineffective. He then asked the students to study it on their own, though he was aware that the available resources were not sufficient for that task. Through the availability of digital technology resources, he found that he was able to introduce this topic and then assign the multi-media organic Chemistry package as a bonus activity, confident that students would have adequate resources to work on their own. The students could then ask for individual clarifications, usually outside of regular class time. Because the resource was electronic and carefully chosen, the students could engage in the activity somewhat independently. Such an activity is novel to most students and hence the need for a renegotiation of the pedagogic contract.

Peter also had some examples of topics that digital technology has given him the opportunity to teach differently, thereby enhancing the students' understanding of the concepts:

> For instance, in Physics if I was doing [showing examples of] circular motion over my head where it was horizontal and level to the ground as opposed to circular motion which is perpendicular to the ground in a vertical plane, the technology such as Interactive Physics™ makes it much easier to dissect [show] what is happening in terms of tension in the rope. In a vertical, that would be much harder to do in a laboratory situation because of being able to measure how the tension changes from the 12:00 to the 3:00 to the 6:00 position. There is a topic that we would do generally as a pencil and paper analysis, [and see] mathematically what is happening. That is basically all Interactive Physics™ does. It takes a mathematical approach and provides you with a graphical representation, showing you how the tension changes. But that visualization for the kids to see the tension change is something that is much easier to do with the technology.

Peter also said that using the technology to teach circular motion enhanced the students' understanding in a way that was not possible without the use of the technology. Again, as in Alex's example, the mathematical relationship was all the students really needed to know to be able to answer questions about this topic on the provincial examination.

There are two universities in the area where Peter's school is located, and Peter usually considers the content of these universities' first year level Chemistry courses in his own instruction. He talks about first year university course requirements as a justification for teaching some of the topics that he teaches and to defend some of his classroom strategies to the students:

> They [students] are going to use the computer next year at UBC and SFU because both schools have labs devoted to MBL stuff. So in terms of their ease of use of the computers, being able to trouble shoot on their own, yes, it has to be better. They will do better next year in the lab because of that. They are a little more aware of all the little nuances of the program because SFU uses the same interfaces that we use, they use the same 'Logger Pro' software that we use here, so when they go to the SFU second semester lab, they are going to do much better because they are going to have that background. That is something that they would not have had unless I offered TESSI.

He further stated:

> Most of the kids in the Grade 12 course are going to go on next year [to college] and, for instance, SFU does all their problem sets on line now. They have no pencil and paper problem sets for first year Chemistry students. So it's like an LXR•TEST™ approach: they call it CAPA, but it's the same idea. So, they [TESSI students] have some experience with that. It's not going to be a brand new thing. Yes, they will have also had experience with pencil and paper problem sets.

Content of Learning: Increased Depth of Students' and Teachers' Engagement with the Content

The teachers also found that the availability and capabilities of digital technology facilitated the teaching and learning of science concepts in greater depth, one that went deeper than the mandated learning outcomes. An illustration of how technology enabled students to think more deeply and make connections between science concepts can be seen in Bob's anecdote about students' learning of equilibrium:

> There are activities to do with the computers in the equilibrium section, determining K_{eq} value. These activities enhance students' learning in the class. The simulation provides a graphical representation of the equilibrium process as it relates graphical, mathematical and physical relationship all at the same time. So, the student really pays attention to what is going on. They get a really good feel for all three aspects at the same time. Quite often [prior to using the technology] I would teach those separately, and they [students] may not make the connection.

For Alex, evidence of the depth of students' personal engagement with the content was apparent in the level of excitement and energy his students displayed as they participated in scientific investigations. He says:

> They will see me coming. The hands shoot up, the eyes are looking at me like they are on fire. They are excited and passionate and [say] "get over here!" So I go over there [and ask], "what is it?" [One student says] "Look, I think da da da" and the other student will say, "No, I think it should be da da da, and we can't seem to agree. What is it?" ... And they are very animated. Now if you can imagine, two students [are] arguing about the kinetic or static coefficient of friction. Good luck! It's friction; don't you guys realize what you are arguing about? But they don't, they become invested in it. That energy comes to me and pumps me up even if I am tired. That is what happens over and over again.

Alex referred to this display of student motivation as "an everyday thing and the nature of the class."

Peter says that because of the instantaneous output of the digital technology in graphically displaying and mapping out the relationships between concepts, students were able to spend more time thinking about the relationships between the concepts. As a result, they were able to gain a depth of understanding of the concept in a way that was not possible without the use of the technology:

> If the computer plots out right away for you, [students] you can immediately see the relationship and that night when you take the graph home, you can further dissect and try to understand what is happening to each [interrelated] part. Probably, if you don't have the computer plot it [the relationship between the concepts] out right away, what do you do that night? You spend that night plotting it out and trying to do the graphic stuff and you [students] don't spend as much time trying to process what the information actually tells you [the students].

In trying to process the information and come up with hypothesis, the students had to be engaged with the concept being taught.

The consensus from the three teachers is that digital technology-enhanced secondary science learning afforded the exploration of topics in ways that enabled teachers and students to observe trends and relationships between concepts. This exploration led to opportunities for teachers to teach topics in ways that gave students the tools with which to make connections between concepts, and thus promoted in-depth understanding, an understanding beyond that which was previously possible without the technology. In-depth understanding of many of these topics is not usually reflected in examination scores, so this is an example of a situation where examination scores do not reflect the full extent of students' true skills and understanding. This lack of significant improvement in examination scores has been attributed to the inadequacy of examination questions to probe deep understanding because they are frequently limited to straight recalls of definitions or mathematical relationships between concepts, in which case the students only needed to be familiar with the mathematical formulae.

The new approach to teaching in ways that promoted in-depth learning of concepts necessitated a different kind of teacher-student relationship in which the students were free to probe teachers' explanations of the concepts and also the relevance of the concepts. Students' probes of the teachers' rationale required a renegotiation of the contract. It is not the norm in secondary school classrooms for students to probe their teachers' rationale for teaching them certain concepts or in a certain way. Certainly the rapport between the teachers and the students in the TESSI classrooms meant that the students could do this. For example, the teachers constantly expressed their frustrations with the Grade 12 provincial examinations that all the students must take. According to them, because of the breadth of the mandated curriculum, many teachers in the province do not teach any Chemistry laboratory activity, and when they do, the average is about two or three laboratory activities for the entire year. In the TESSI classrooms, the students do an average of one laboratory activity every two to three weeks in Chemistry, and one or two each week in Physics. The grade 12 science examinations do not probe students' knowledge of laboratory activities, the students only need to know the relevant mathematical formulae and interpret graphs from experiments. For example they are not tested on how well they can generate a graph from an experiment. The students are aware of the examination practices too, hence when their own TESSI teachers promote in-depth learning and many laboratory activities, both traditional and technology enhanced, the students question their teachers, and ask if it is a good use of their time since they need to spend more time working to pass the exams. This situation definitely required a renegotiation of the pedagogic contract. The students need good marks to be able to apply to the colleges and courses of their choice. The teachers also explain to the students their need for a thorough understanding so that they actually do well once they reach college. While many of the students embrace the teachers' efforts, some of them resist it.

The students' in-depth understanding of the concept and engagement also fostered the teachers' in-depth understanding of both the science concepts and the use of the technology. The teachers all stated that their own learning also increased as a result of using the technology.

Teachers' Enactment of the Changes in Content of Learning

The three teachers viewed as positive the modifications in the two attributes of the content of learning that occurred as they used the technology. The teachers' views of the changes influenced which technologies they adopted for use in their classrooms and how these technologies were used. They also perceived that most of their students valued these changes as well. These teachers recognized that the modifications made in classroom practices with the use of technology led to increased opportunities for teacher-student conversations about science concepts and scientific understanding in ways that were not occurring in their traditional science lessons. For example, according to Bob:

> [Students] gain greater insights into the concepts we are discussing and develop stronger relationships or relationship-thinking about the concepts. … there are a lot of students who are gaining that.

Alex's awareness of the different kind of interactions he had with students is evident in the following excerpt:

> They are [working] at a very high level, reasoning and reading carefully. When I go to help them now in my teaching I have changed the approach. If they say, 'I have a question; I don't understand how to do this'. [I ask] what step of the procedure are you on? Very quickly they learn, [to say] 'I am right here, it's this part I don't understand'. Whereas, in transmissive classes what I hear from other teachers is [students] say 'Well I just don't understand the whole thing. I don't know what to do. I am completely lost'. … I find this much less [of this kind of student response] in this classroom.

This sentiment is similar to the situation Peter expressed to me:

> I am much more inclined now to stay with the Study Guides and interact with the students [and ask] have you done this and have you done this? They [the students] go no, well [I say] come back then and ask me once you have done that. Because they [students] just want to take the path of least resistance, so some kids go away frustrated, they [students] go [say] he just doesn't want to tell me. That again sort of goes back to a minimal amount of people [students]. Generally you [the teacher] are dealing with pretty good kids. You know, they are motivated, there are very few kids that will take Chemistry 12 that are not motivated.

Peter liked the increased depth of engagement. His response was to spend more time on problem solving in the classroom and allow the students to work more on their own:

> We, as students and teachers, spend more time on the problem solving, [we] concentrate on problem solving rather than spending time taking down notes. They [students] would get a package, here is what you need to be doing, I am going to be here on these days, and here is an interactive testing to see if you actually do know what you are doing. So that is good and that has to be and you have to have that leeway to be able to let the kids do that on their own.

Dimension One: Summary

The three teachers' words indicate changes in their teaching approach whereby they facilitate students' learning. These changes are clear evidence of the departure from norms of the classroom where the teacher is the dispenser of knowledge and is very much in control of the learning, rather than being a facilitator of the learning process. The teachers talked about how their students responded and learned to identify what part of the learning procedure they didn't understand when asked. The level of sophistication of the students' questioning, according to the teachers, is an indication of students' level of depth and familiarity with the topics that they were learning.

These modifications in the nature of learning practices in the digitally enhanced classrooms facilitated a change in teacher-student relationships. The teacher-student conversations changed: in these classes students argued with each other as they sought to understand the finer details of science concepts and called on their teacher to endorse and contribute to their discussions. These kinds of conversations are atypical in science classrooms. A prevailing classroom norm in secondary school science is that teachers must teach, expecting that students will understand the mandated curriculum. Students are aware of and also hold these expectations. Going beyond the requirement of expected curriculum outcomes typically happens only in gifted or accelerated classes. This study suggests, however, that in the digital classroom, technology makes *going beyond* possible for all students. The teacher-student relationship is changing as students assume new roles in this setting. This change in classroom practices and traditions illustrates how the original pedagogic contract is changing and is being renegotiated. The students also valued the changing contract. In these classrooms, students were involved in and excited about their own learning. Gone was the idea of students waiting for the teacher to disclose answers. Instead, students were talking about and debating science concepts. Alex's anecdote about students' personal engagement also illustrates a departure from one of Aspy's (1986) five important lessons children learn in schools: don't feel, as explained in chapter one. Clearly, in these classrooms students did respond to each other's feelings of excitement and sometimes disappointments. In the next section, I discuss how teaching and learning was managed in the classrooms.

Dimension Two: Method and Management of Learning Activities/Strategies for Learning

The second dimension of learning along which the teacher-student pedagogic contract was renegotiated is the method and management of learning activities or the strategies for the learning activities. In this study, the difference between the levels of implementation of TESSI is most evident in the method and management of classroom instruction and learning activities in each teacher's classroom. Early in the project, in order to make effective use of the technology and promote learning, the teachers planned teaching and learning activities designed to move technology into the hands of the students (Pedretti, Mayer-Smith &Woodrow, 1998). They lectured less and created Study Guides that assigned students' tasks associated with managing their own learning. The Study Guides supported the goal of all three teachers to have their students assume more responsibility for their own learning.

The Study Guides and associated Activity Guides are a very important aspect of TESSI as discussed in chapter five. See Appendix A for a sample of selected pages from the Chemistry 12 Study Guides. These guides facilitated the use of the technology and also influenced the method and management of instruction in the classes by enabling the Levels II and III practices. While the initial role of the Study Guides was to facilitate the use of the limited computer resources by indicating to the students what activities they could work on, while waiting for a computer to become available, they also revealed the structure of the unit to the student by indicating which assignments were upcoming, what activities they would be doing, how many tests were scheduled, and the corresponding approximate time they have to finish working on the units. These features gave the students some control over the pace of their own learning if they so chose. To some degree the changes in the practices of the teachers were aimed at helping the students make the best use of the Study Guides as well as the digital technology. The Study Guides also helped the teachers anticipate and prepare for areas where students might have questions, and devise strategies to address such questions. A statement by one of the other TESSI teachers underscores the significance of the Study Guide. James, who I interviewed during the pilot study, told me that he was not sure if it was really the technology or the Study Guides that was the single most useful tool in TESSI.

In encouraging the students to take more control of their learning, the new learning strategies employed were designed to facilitate:

- metacognitive learning;
- personal goal setting, individual pacing, and activity choices; and
- individual and small group instruction and learning activities.

For heuristic purposes, these three interrelated strategies are discussed under three separate sub headings as attributes of dimension two: method and management of learning activities.

With time, the teachers modified the strategies in different ways to fit their personal preferences and beliefs about teaching and learning, hence there are variations in the manifestation of these practices in each teacher's classroom based on their levels of implementation. At the Level II implementations, the classroom changes to the methods and management of learning activities were not as extensive as in Level III, but still represented a major departure from the norm found in most secondary science classrooms. The teacher-student relationship changed in that the patterns and the content of teacher-student conversations changed and had to be renegotiated.

<u>Strategies for Learning: Metacognitive Learning</u>

The first attribute discussed under the method and management of learning dimension through which the pedagogic contract was renegotiated is metacognitive learning. In TESSI classrooms, teachers devoted class time to discussions of how to learn. The teachers felt that in order for the students to work efficiently in a learner-centred setting, each student needed to understand how he or she learns best. This variation on traditional classroom talk did not go unnoticed. Students became aware of the importance of both metacognitive skills and focusing on thinking about their learning. This awareness was evident during the informal conversations students would have with the researcher. When asked about their use of technology for learning science, students talked more about how they were now thinking differently about learning and less about the digital innovations happening in their classroom. These students claimed that "meta-cognition" is a term they hear only in their technology-enhanced science classrooms. According to one of Alex's students "He [the teacher] says it so often in this class that you are thinking meta-cognition all the time." Learning to value "becoming metacognitive" required regular discussions and scaffolding of students' efforts by the teachers. The teachers claim that meta-talk needed to be an almost daily activity in their classes if they wanted students to understand and adopt this learning strategy. Time devoted to this type of talk, however, replaced discussion about science content and at times, created tensions in the teacher-student relationship. As one of Bob's students put it: "He [the teacher] mentions it [meta-cognition] so often that I get tired of hearing it". Scaffolding students' learning about meta-cognition is not the norm in secondary school science classes. The prevailing classroom norm is that teacher talk is primarily concerned with giving procedural directions, managing student behaviour in addition to teaching the science content. With these three teachers, teacher-talk directed at giving procedural directions and managing student behaviour were minimal as the students took more control of their own learning.

Teachers Enactment of the Changes to Metacognitive Learning

The teacher-student pedagogic contract was put under tension because teacher talk about meta-cognition constituted a departure from normal classroom practices, where teacher talk does not usually include metacognition. All three teachers valued metacognitive learning. According to the teachers, many of the students had not previously heard of meta-cognition. The teachers found that it took considerable time and effort on the part of both teachers and students to have the students thinking about and clearly articulating how they learn.

Bob's efforts at making his students aware of metacognitive issues, and his use of meta-talk as a way of scaffolding his students' understanding of such issues were not as successful as he would have liked. Bob perceived that most of his students were not convinced about the need for them to be aware of how they learned. Bob also said that, because his school is in a lower socio-economic class, his "clientele" is such that the concept of metacognitive learning was difficult for the students to fully appreciate, despite his many attempts at encouraging this way of thinking. The students did not expect teacher talk that explained why a particular way of learning was beneficial to them. They were not used to such conversations. These tensions that Bob perceived with the students contributed to his decision to minimize the use of digital resources for metacognitive activities. The frequency of teacher-student meta-talk also decreased.

Bob also cited the constraints of institutional norms and practices as another reason why metacognitive issues were not as successful as he would have liked. Because of the limited instructional hours of a semester school system, he said that there was less time for the students to conceptualize the science content, let alone metacognitive issues. He described:

> When we [my school] moved to a semester school [system] about five years ago, it seemed to me that meta-cognition got thrown out the window. We [teachers in the school] teach less, we have less time to conceptualise and understand the material and we probably do a poorer job in dealing with the metacognitive side of things.

Furthermore:

> The other thing too is that in a semester system if we can teach a concept like, let's say, in Solubility, you have got to do the solubility unit in about eight classes. Really, that is a week and a half, and if we did this as a long course, we would get three weeks for the kids to mull over, reflect on, and improve upon their thinking, ... so in an ideal world I would like to have my courses over the whole year.

Bob's view is that the students have less time to reflect on topics in a semester school system than in a yearlong system. This time constraint was also a major factor in encouraging teachers and students to focus merely on getting through the course and passing the examination. Hence, rather than on learning to enjoy the course, the focus was on the product rather than the process of learning.

Peter's school, like Bob's is on a semester system and so he confronted the same kinds of constraints. Peter also talked with his students about metacognitive learning but said that, as in many aspects of teaching, some students understand the importance of it and others do not. Peter's feeling is that there is evidence of metacognitive awareness in his class. His impression is that some students will not see the point of metacognitive awareness no matter what teachers do, because there are other factors affecting students' attitudes to learning, of which the teacher is not in control. Peter said that the level of metacognitive awareness in his class is lower than he would have liked, even though he realises that such awareness is an aspect of his practice that was almost non-existent before he started implementing TESSI.

Alex regularly engaged in meta-talk about learning issues with his students, encouraging them to approach learning beyond the mandated curriculum. One of his frequent sayings is that "In TESSI we're teaching the students how to learn and by the way, we're also teaching Physics." He refers to his class as a place to "learn how to learn". So rather than seeing his only goal as teaching Physics, facilitating students' learning of Physics became an example of how to learn for the students. For example, according to Alex:

> They [students] were reflecting a lot more on their learning, they are asked to do a lot of meta-cognitive exercises. Some of them in conclusions, and some of them in reflecting on their own practice, students will even use the language [of meta-cognition].

Alex saw the need for the students to be scaffolded through this process:

> I keep coming back to saying to the students, this [learning with technology] isn't better, it's different, and you are going to develop some skills in here that you couldn't develop in another classroom and vice versa. And so long as you have got both, you are ok.

Alex said that the time invested in helping the students learn this skill proved useful when the students were able to make choices about specific classroom activities based on their knowledge of how best they learned. During a classroom observation in one of Alex's classes, I noticed a student working alone while others were working in groups during a technology-enhanced activity. This student told me that he did not think the sequence of activity outlined by the teacher for the unit would work for him, based on the way he now knows he learns. He decided, then, to work alone so that he could do the activities in the sequence that suited him, even though there were times he chose to work in a group. This student's clear articulation of how he learns clearly showed that conversations about metacognitive awareness were an integral aspect of classroom talk.

Strategies for Learning: Personal Goal Setting, Individual Pacing and Activity Choices

The second attribute discussed under the dimension of method and management of learning activities consists of three distinct yet interrelated student learning strategies that affected the teacher-student relationship: personal goal setting, individual pacing and activity choices. These strategies were proposed by the teachers in the early years of TESSI to encourage students to take more control of their own learning.

The aim of personal goal setting is to minimise competition among students and allow them to compete with themselves as individuals by aiming toward or surpassing a personal best. The prevailing classroom norm in regular classrooms is that teachers set one goal for all the students, and students work towards that goal. Personal goal setting is a departure from the norm. Personal goal setting led to a different kind of teacher-student interaction such that conversation became about whether or not students achieved their goals, rather than focussing on the letter grade on examination scores.

Closely related to personal goal setting was the individual pacing of classroom activities and students' self-monitoring. To accommodate the various rates at which students learned with technologies, and because digital resources had to be shared by students, different activities were scheduled to occur simultaneously in TESSI classrooms. The students were also responsible for monitoring their own progress to see the tasks that needed to be completed before the end of each unit. When students were allowed to set their own goals, it was often necessary to allow them to work at their own pace and have the freedom to engage in classroom activities that would help them understand the concepts they were learning.

Students could also work in their classrooms outside of allotted class-times. Hence, there was more unstructured time in which interactions and dialogues took place between teachers and their students. Continual interaction throughout the school day became the norm. One of the distinctive features of continual interaction is that the students sometimes come into class to work while other classes are going on in the classroom. During such times, students tend to write their tests independently or work either in groups or individually on the computer. Thus prevailing norms changed as learning activities extended beyond and across class periods.

With regards to activity choices, in order to help students be more in control of their own learning, TESSI teachers decided to give students a range of activities from which to choose within a particular unit or concept. Students were sometimes given the choice of doing either a traditional experiment or using the computer for a simulation or an MBL activity, though this choice was frequently limited by the teacher in the Chemistry classroom due to safety considerations. Since students are not used to being given such choices, in TESSI classrooms students had to think in a different way about the kind of activity they preferred or that best fit their personal learning style. Occasionally some students choose to do more than one activity when they have the time or when they feel that they need to do another activity to enhance their understanding of the concept being taught.

The pedagogic contract was renegotiated as different types of working relationships and interactions became evident between teachers and students as these strategies were introduced into the classroom. Students learned to think of class-time differently in their digitally enhanced science courses. Teachers' relationships with their students extended to working with students throughout the school day, including time between classes, and during free periods when students opted to spend extra time in their digital classroom. Certainly an argument could be made that students also seek additional help from the teachers in traditional classrooms that do not involve digital technology. But the teachers report that the frequency of teacher-student interactions is higher in TESSI classrooms than in traditional classrooms. The increased frequency of interactions could be a result of a combination of the different changes in classroom practices that happen in the TESSI classrooms as I have already discussed in this chapter.

The implementation of these three classroom practices varied among the three teachers. Bob and Peter (both operating at Level II) experienced some obstacles in negotiating these changes, so they used these practices with caution and only at certain times, sometimes depending on the topics they were teaching. Some of the obstacles that Peter and Bob identified include:

- limitations due to the safety concerns of subject matter;
- physical limitations of the classroom, (Peter and Bob share their classroom with other teachers);
- their own personal preferences; and
- an incongruence of expectations between theirs and their students' expectations of how science classroom teaching and learning is supposed to take place.

I highlight the above limitations as I discuss the teachers' responses in the next section. At Level II implementation, Bob and Peter's students could pace themselves only when the activities did not involve laboratory work. Both teachers made more extensive use of the Internet more than Alex. They had practice questions and answers online for students to use on their own. Bob also posted the class assignments on his class web page allowing the students access from home. Both Bob and Peter allowed some individual pacing in that regard. Peter and Bob were also constrained by limited classroom infrastructure. When all the computers are in use, the students had to use either the computer lab or another lab to complete their work. These other labs were not designed for TESSI activities because not all the computers had the required software. As a result, the activities that the students could do outside of class-time were limited.

As a Level III TESSI teacher, Alex regularly used personal goal setting, individual pacing, and activity choices approaches to a significant extent in his class. The students were allowed to set personal goals -- with the guidance of the teacher -- setting grades that they hoped to achieve on unit examinations. Alex's implementation of individual pacing meant that his eight computers were generally enough for all activities except occasionally when testing was going on, in which case there was access to an overflow lab section with computers for students' higher demand. Alex's students usually had the option of pacing themselves within a given week or two to finish their work, including pacing their activities and having options as to when they would do the digitally assisted or traditional laboratory activities.

Teachers' Enactment of the Changes to Personal Goal Setting

Bob and Peter both encouraged students to set personal goals for themselves and monitor their own progress, but did not require it as part of regular classroom practice. Peter and Bob were only marginally committed to the idea because they felt that it was too much work for them to have to monitor so it was not an integral part of their classroom activities.

Alex valued personal goal setting, considered it an important aspect of his class and did what was necessary to implement and sustain this practice. The students set goals for their final marks on unit examinations. Alex provided individual and group feedback after each unit examination. For example, after marking unit exams, Alex met with each student to discuss how close or how far they were from their goal and subsequent strategies to help. If students did not meet their target mark, they were allowed to retest. The new mark on their retest usually overrode the previous mark.. When the students met or surpassed their goals, their reward was a handshake from the teacher. This handshake may seem like a trivial gesture for grade 11 and 12 students, but classroom observations revealed otherwise. During one of my classroom observations, I noticed that a group of students suddenly stopped working and gravitated towards the teacher's desk, patting a student on the back and telling him "well done." The student who got that handshake from the teacher was visibly delighted. I asked Alex about it and he said this student had surpassed his goal and was very happy about it. A sense of camaraderie among the students was evident that day. This is an example of one of the subtle ways that Alex successfully renegotiated pedagogic contract in his classroom. Alex continued to encourage goal setting of unit test marks in his class. He also encouraged students' self-monitoring, and provided a checklist for the students to use at the beginning of each unit. Appendix B is a sample of Physics 12 students' assignment checklist.

Teachers' Enactment of the Changes to Individual Pacing and Activity Choices

All of the teachers valued the continual teacher-student interactions that occurred throughout the school day, sometimes as a result of individual pacing and students' activity choices. Students worked in the laboratories before and after school in addition to working in between classes. Giving students these kinds of choices affected the teacher-student relationship because it frequently required teacher-student negotiations about available times and possible activities with minimal supervision. The continual interactions also represented a major shift in students' thinking about the organization of learning activities and learning time. The time to learn ceased to be the mere 75 minutes of allocated classroom learning and instead became the entire day.

In an e-mail conversation with Bob about introducing the course and setting the tone for learning in TESSI classrooms, he wrote:

> I describe my involvement with TESSI at the outset of each course telling the students that I will be asking them to do computer based activities and provide them with brief illustrations of what we will do. I usually introduce each piece of technology as needed – providing a brief introduction to the features of the software of MBL probes. I state to students that they will be expected to think in different ways and, in some ways, need to become better learners; more independent. Prior to TESSI, I would simply pick up the overhead pen and begin.

This kind of conversation with the students helps establish the tone and conditions for learning in Bob's class. This helps the students to become aware of the teachers' expectations of them and the need for a renegotiation of the pedagogic contract in Bob's class. This kind of conversation happens on a regular basis in each teacher's classroom.

In terms of interactions with the students outside of their allotted classroom instruction times, the semester school system, and having to each share their classroom with two other teachers, limited the amount of flexibility Bob and Peter wanted to have. The students came into the classroom to work on the computer usually before and after classes. The frequency of teacher-student interactions outside of class-times tended to increase when students had to make up a lesson or a test. In both classes, the students were free to pace themselves minimally and they were usually lock-stepped when they had to do laboratory activities. Both Bob and Peter said that because there were limited software resources for Chemistry, the students did not have the luxury of too many choices. Furthermore, most of the laboratory activities in Chemistry required the preparation of solutions, which have to be prepared as a batch, thus Bob and Peter did not consider self-pacing feasible at such times. Another major issue for the Chemistry teachers was a concern for safety in Chemistry laboratories where multiple and simultaneous laboratory activities might create a hazardous situation since many of the substances required special handling. Bob and Peter were concerned about using a flammable substance on one table while another experiment involving a hot plate was done on the next, as this kind of arrangement would create a safety risk. According to Bob:

> One of it is a safety issue. If some students are doing hands on lab and some are working on multimedia, do you make everyone wear safety goggles or what? The set-up of a Chemistry laboratory is very different from the Physics laboratory.

These two teachers' concern raises the question as to whether Chemistry laboratory experiments that might have a safety concern could be done as computer simulations, which would eliminate the safety issue. However when asked about this issue, the teachers indicated that teaching the students to handle such materials safely is an important part of learning Chemistry.

Bob found it personally challenging to manage the individual goal-setting, multi-activity, multi-paced classroom even though he valued these practices. He claimed it was tiring, because he had to oversee many simultaneous activities. He was also concerned that some of his students were taking undue advantage of the loose structure of the classroom and were not focused on their work. To enhance easier monitoring of the classroom activities and to ensure that the students stayed on task and learned the material, Bob felt it necessary to keep the students lock-stepped at least during the lectures and wet labs.

Bob is an engaging teacher who is known for his jokes. His opinion is that lectures are an important aspect of teaching. According to him: "It is the banter with students" he said, "the telling of stories" and the interjections of his lectures with jokes that make him enjoy teaching. In my conversations with Bob, sometimes he referred to himself as a facilitator when he compared himself with his teaching styles before and after introducing the technology. But most times, when talking about his practice, he tends to compare his Level II TESSI practices with his practices as a Level III TESSI teacher.

When Bob was implementing Level III practices, he found that he was not very enthusiastic about the changing power relationship in his class. He found the changing role, from being a transmissive teacher to that of a facilitator or a coach all the time, threatening to his teaching persona and to his beliefs about classroom teaching and the role of a good teacher. Bob sometimes used conflicting metaphors to describe his role at different times during our conversations. Sometimes he described himself as a "driver of the carriage, the one whipping the horses to get us going" then sometimes "a facilitator, but not a guide" and "a leader". He said:

> We are going to use technology for a number of different activities but we are going to do it in a lock-step fashion, I am going to be the facilitator and leader and teacher. I won't be the guide by the side.

By this statement Bob meant that he was a facilitator, creating opportunities for students to work collaboratively and solve problems, not being a "guide by the side", meaning that he was directly involved as a co-learner and co-investigator with the students. Being in control and in charge of the classroom was important to Bob and he felt that being a guide meant a loss of some of that sense of control. For Bob, teacher control was important for effective student learning. He also considered the role of the teacher as the leader, central to classroom learning:

> I really do believe the teacher is still the central motivating factor. If you don't have an effective teacher, technology won't mask that. In fact it probably will amplify the teacher's inability to teach. The teacher really is the central portion of the classroom and keeps everything moving along. Technology can't do that on its own and students, of course can't do it on their own. They need a teacher as a leader.

When I asked him if it was fair to say that he actively refused to fully integrate the technology in a way that totally changes his classroom practices, at this time, he replied in the affirmative and further explained: "I am not really ready in my own little empire to give up some of that control that I have in my domain." It is interesting that Bob referred to the classroom as his empire. Explaining further what he meant by being an emperor, he said:

> Well, there is really a control of the ownership of learning, and my feeling is that I outwardly would say that the ownership of learning belongs directly in the students' hands. My internal belief is that the ownership is shared between the students and the teacher and it's my job. I am not going to take ownership of the actual learning per se, but I am going to make sure that every possible opportunity to learn is there. I am worried about students not seizing the opportunities [to learn] in that technological environment.

Bob also argued that students actually preferred that he was transmissive rather than transactive. One of Bob's major reasons for changing to a Level II after approximately two years of implementing Level III were students' complaints about the innovative approaches to teaching espoused by TESSI. These complaints also confirm the presence of a contract with the students and the difficulty of renegotiating the contract. There was a clear dissonance between the new classroom practices and students' expectations about learning. He said:

> If you talk to the students they will tell you that they are not learning anything. They don't necessarily perceive that learning is taking place unless you overtly state that this is a different way to learn some of this material; they won't perceive the computer activity as being anything but filling in blanks or answering questions on worksheets.

Bob minimised the dissonance by scaffolding the students through the process and reverting to more traditional methods of instruction to augment the innovative approaches. Bob had another reason for changing from a Level III TESSI implementation to Level II:

> Using technology as a Level III TESSI person to me means that the classroom environment would be more sterile and that is just not going to be the way I approach it. So for me, what TESSI has done in the big scheme of things is given me a lot of professional opportunities, it has given me an opportunity to use a wider variety of activities in my class but it hasn't pulled me out of the traditional lecture mode mentality.

He explained further:

> For me, I haven't really been able to step out of that traditional mode of thinking very well. Although, the computers have provided a great deal of alternative ways of having kids become involved and engaged in activities, ... I still felt that I have been that traditional person. In terms of the operation of my classroom, there has been a shift in the way that I do things in terms of providing a wider variety of things for kids to do ... I think I probably refer to myself as a TESSI Level II type person.

This description indicates Bob's unwillingness to continue employing strategies that did not fit his personality. He experienced a dissonance between his approaches to teaching and the approaches promoted by Level III implementation of TESSI. He found Level II to be his comfort level.

Peter gave some leeway to his students, but his students tended to be doing the same classroom activities at the same time. His reasons are similar to Bob's:

> They [students] are basically all on the same page at the same time. Unless it is at the beginning and they are doing the preview, then they are all at different points, then as we go through, they are all pretty much the same point. I know I wouldn't

> want in Chemistry for sure, kids at different points doing different labs on different days, because I personally think that is just way too much work for me. And there is a safety issue of having different labs going on at different times. Hot plates that we may be using one day, are not good with the organic flammables next day. I don't think the kids will ever be in my lab at different points. They could be a bit on their own but not in terms of huge leaps and bounds and putting up their hands and saying I am ready to do this lab now, that won't happen. Because they know tomorrow, Friday, is preparation of soap in Chemistry lab and we are all doing that lab that day and that is it.

Like Bob, Peter also found it challenging to mandate individual goal setting, multi-activity and multi-paced teaching as part of the practices in his Chemistry class. The students were free to engage in these practices on their own; for example they could go at their own pace as long as there were no wet labs involved, but he stopped short of requiring it as part of regular classroom practice. The consequence was that some of the students did not take advantage of these learning practices.

Peter's overall goal in TESSI was to empower his students to acquire some of the necessary skills and academic knowledge that will enable them to succeed in post-secondary schooling. One of those skills, according to Peter, is for the students to take more responsibility for their own learning. By facilitating learning strategies such as optional interactive testing, and self-pacing, and activity choices, Peter expected the grade 11 and 12 students to be in control of their own learning. He said:

> I guess the big thing is having more of the independence and responsibility, in other words I am not 'beating' them [students] all the time, they are taking some initiative on their own.

Peter always considered himself to be a facilitator of learning, even before he used digital technology in his classroom. He said that using the technology has provided him with more freedom to continue along that path. According to him:

> I am much more of a facilitator; other than sitting there hand in hand, this is exactly how you do it, it hopefully gives them a little bit more independence because they come in, they have a bit more responsibility on their own part.

Peter also alluded to the implicit teacher-student pedagogic contract. The existence of a contract became obvious when some of the kids opposed the independence and self-directed learning that Peter was trying to promote in the class. Peter found the students' actions frustrating because, for these students, a transmissive, teacher-centred classroom represented a good learning environment. He said:

> Another frustration is when I find kids who have been used to being spoon-fed, so they are all uptight. [They say] Mr. Peter is not teaching me anything; ... he is letting me work on my own. I think kids like that who I would call clinging kids don't work on their own. They want to be constantly told what to do, they can't do independent work. So they [these students] really experience frustration. He's [the teacher] not doing anything in class, he's not going over stuff, he's letting me work on my own, it's a study course and I could do it in correspondence, yada yada. But once the kids get used to it, they realize that it is a resource set of notes and it saves them time that could be spent doing other things. So I think its just kids who are used to taking notes and so their idea of doing something is to write notes whereas mine is more, you look at it first, you ask questions you have problems with it and you ask me. Some people understand it right away and some people cannot.

Peter' s strategy in dealing with the students who oppose the independent learning being fostered by the technology was to provide choices for students who would rather not use the technology.

> They [some students] just choose not to, and I don't have a problem with that. I never force them to choose it [the technology]. The only time they are forced to use it is if they have a simulation that they have a worksheet for and I collect that worksheet and that is the only time they are actually forced to use it [the technology]. But with the MBL even with the worksheet, they can partner up with someone who is comfortable and work with that person as they go through.

Peter was concerned about the amount of work and energy required to integrate digital technology into the classroom and foster these many learning practices. He stated:

> For an average teacher, the amount of extra work that it requires sometimes to keep the technology up and going, as opposed to just doing pencil and paper, is way more work. It is a different way to do it and it is a whole lot of work for sometimes what the kids are getting out of it. To be quite honest, I am still doing all the work I normally do plus the extra stuff.

According to him, most of the changes and modifications in classroom practices were made easier by the use of the technology but these were changes that he had been aiming to implement or was already implementing in modest ways. He said:

> For me all the technology has done is has allowed one more avenue the kids can work through, they are not just limited to paper and pencil, they are not just limited to textbooks, they have the interactive testing, they have the CD ROM

> material, so they have other sources of information, other ways to access, other ways to test, other ways to test their information. They are not just relying on pencil and paper; they are relying much more on an independent nature.

In short, Peter found most of the changes fostered by the use of the technology empowering to both him and his students. The pedagogic contract was certainly affected by the use of the technology in Peter's class. He has renegotiated the pedagogic contract to some extent in his classroom. Using the digital technology as a teaching and learning tool fostered the renegotiation of the pedagogic contract.

Alex's students tended to have a variety of activities from which to choose within units. This situation arose partly because of Alex's personal teaching preference and partly because there are more technology-enhanced activities available in Physics than in Chemistry. Furthermore, because the safety concerns in Chemistry do not exist in the same way in Physics, Alex had no problems with allowing simultaneous classroom activities. This aspect of classroom practice was consistent with Alex's emphasis on metacognitive learning. Alex found that for students who are more aware of how they learn, individual pacing and choice of classroom activities tended to be easier, and they appreciated having that choice. Consequently his students worked on their activities at different times during the day. This arrangement was facilitated by the fact that Alex does not share his classroom with other teachers and also has an anteroom where students can work even if another class is in session. Alex was proactive in promoting this. In the year before this study, Alex's school was building a new laboratory block to accommodate the growing number of students. Alex worked with the architect to design his *state of the art* classroom specifically to facilitate this broad range of activities – a luxury not often given to teachers. He said he received most of what he asked for and his suggestions were all based on his previously established TESSI practices and ways in which the classroom infrastructure can support those practices. Alex encourages continual interactions with the students throughout the day.

According to Alex:

> They [the students] start thinking about the entire day as a time to learn so they organize their schedule to come in during their spare blocks during the day or after school, like we just had now. So the students start to use the resources, I think in a more realistic way, closer to how the whole world operates, using the resource when it is available, to organize your time to meet a deadline, hence, our interruptions here after school.

The aside "interruptions after school" refer to various times I had scheduled interviews with Alex and meetings after school. During my conversation with Alex, we tended to be interrupted about once every 10 minutes even though the interviews were taking place in the faculty room that is about three doors down the corridor from Alex's science room. The students felt free to interrupt our conversations and ask for help with their work or clarifications. The after-school interruptions, according to Alex, were normal. Alex spent considerable time teaching his students the importance of effective time and resource management. Because of Alex's insistence and evident belief in students taking more control of their learning in individual goal setting, pacing and activity choices, many of the students accepted his views and it became an integral part of classroom practice.

<u>Strategies for Learning: Individual/Small Group Instruction and Learning activities</u>

The third attribute within the dimension of method and management of learning through which the pedagogic contract was renegotiated is the fostering of individual and small group instruction and learning activities. The norm in most secondary school science subjects is to give one lecture to the entire class. All three teachers emphasized small group instruction and learning activities much more than they did before their use of the technology Evidence of the small group learning tasks can be seen in the excerpt from the Study Guides in Appendix A.

Sometimes when the students have already been introduced to a unit, as soon as the students come into the class, they proceed to work in groups of two or three spontaneously, whether they were asked to do so or not. In most cases, the teachers said the groups are self formed unless there are problems with the group formation and then the teachers may intervene and shuffle the groups. During small group learning activities, the teachers would circulate and interact with groups of students, stopping when they requested help or just to probe students' understanding and offer encouragement. Students were encouraged to rely on each other as the primary source of information and answers about technologies and science concepts. The small group learning arrangement meant that the students had to work co-operatively. As a result, one of the skills the students had to learn quickly was to be able to work together.

Small group interactions gave rise to a different kind of classroom environment that required renegotiation. Peer interaction and camaraderie among the students were evident. There were students who were excited about what they just discovered and students who were frustrated with the computer, the activity or their peers. Class became a place where emotions were expressed freely. Generally the classes were anything but quiet during individual and small group learning activities. With these changes, the teacher-student relationship had to be renegotiated. This kind of classroom atmosphere required a renegotiation of which kind of noise was acceptable and which wasn't. A quiet class was not an option. Traditionally, effective class control has always been viewed as a set of students who are doing their work quietly with minimal interruptions. With these three teachers, interruptions were the norm. Students interrupted each other if they needed immediate clarifications, or if they wanted to demonstrate something they had just learned. The teachers conceded that sometimes this flexible classroom structure seems disordered, so they found that they were constantly making decisions about when to tell the students to be quiet or sometimes when to let them revel in their accomplishments. Hence, teacher control was more in the form of talking with the students and asking them to make the judgement about what to do when they feel they were getting off task, rather than incorporating "yes" or "no", "stop" or "start" kinds of commands. Thus the teacher's role is that of a facilitator rather than a dictator of acceptable classroom behaviours.

Another way the small group interactions necessitated a renegotiation of the pedagogic contract was that the individual/small group learning was not always problem-free. The co-operative learning groups did not always work; hence the teachers became mediators of students' disagreements and gave advice to the students on cooperation with peers, fairness in working together, and the principles of group interactions. This kind of teacher-student interaction is an evidence of a changed teacher-student relationship.

The smaller group interactions also gave most of the students more access to the teachers. Some of the students complained that the quieter students tended to be overlooked since the more outgoing students usually initiated most of the interactions in the individual/small group-learning environment. The more outgoing students were also usually quick to call the attention of the teachers. The introverted students usually required the teacher to draw responses from them because even when the teacher asked how they were doing, the standard answer was "fine". In a multi-activity classroom it is difficult for the teacher to be able to take that much time. The teachers all said that working with students in small groups helped them learn from the students. Often some groups would have a better way of working on an activity or have different ideas than those suggested by the teacher, or detect a *bug* in the program that they are using and sometimes fix it themselves or show the teacher why certain programs do not work the way it was supposed to.

The changes and the renegotiation described in this section varied according to each teacher's implementation level, personal preference and students' reactions, as I explain in teachers' enactment of the changes in the next section.

Teachers' Enactment of Individual/Small Group Learning Activities

The three teachers valued the small group learning and nurtured the idea to varying extents in their classes. The Level II teachers assumed the role of guide or facilitator of the learning process in a similar fashion to the Level III teacher but not as extensively. In my conversations with Bob and Peter on individual/small group learning, however, most of the discussion focused on how their practices differed from the Level III TESSI practice, and they highlighted some of the challenges they experienced with small group learning.

Peter said that before integrating digital technology his students worked occasionally on laboratory and selected activities in small groups, but not to the extent that they now do in his technology enhanced classroom. However, he concedes that there is still more whole class lecture than small group instruction in his class. His concern with small group lecture was that students sometimes had a hard time staying on task when left to work in small groups. In a lecture situation, however, the students are forced to pay attention since he is able to quickly notice off-task behaviours:

> If I am lecturing, you are paying attention and I will make sure you are paying attention, by asking you a question. But when it's time for that computer work, when they are doing an MBL, they are not just focussed, they are talking to their partner and asking their partner a question or doing other things or as a group doing different things. It's [small group learning] much more independent, but if I am going to be wasting my time, [lecturing] up front, then you [students] are going to pay attention and that is it.

Having tried Level III implementation for two years during which he placed more emphasis on small group instruction than whole class lecture, Bob now emphasizes more whole class lecture than small group instruction. One of his reasons was his perception that his students prefer a whole class lecture structured setting. He is concerned that students' learning is not optimal in the individual/small group lecture setting. He considered it his responsibility to provide the students with the best learning environment. According to him:

> There is no way that I am going to hand over the Study Guide, give an hour long or an hour and one half long lecture, and then stop the kids periodically and have either a large or small group lectures. I just don't see that as being part of my teaching persona and how I approach teaching in general. To me the most important component of any classroom is really the instructor.

Unlike Alex, Bob was uncomfortable about the quieter students who did not initiate discussions and so tended to receive less attention than their more outgoing peers. He said that the traditional lecture method enabled him to be able to make eye contact with all the students and encourage the introverted students to participate, by calling on them to answer questions. Bob also said that there were fewer opportunities for students' off-task behaviours when he lectured because he could make eye contact with the students. Consequently he said he was more aware of those students who were paying attention and those who were not. When I observed some of his classes though, I noticed that, during the lectures, the few students sitting in the last two rows did not pay attention most of the time. These students were not disruptive but exchanged papers, pictures, and knowing glances between themselves. When I asked Bob about this incident, his response was that, that group of students is not very serious with their studies anyway and conceded that there will always be such groups in a classroom. Unfortunately this conversation took place late in the term so I could not ascertain if these were the same students who tended to be off-task during the technology-based lessons.

Small group learning was enhanced by the technology, but was not limited to technology-enhanced activities. Bob acknowledged that whenever the students worked in groups there were more student-student interactions. He considered these interactions beneficial for students' learning and his own learning as a teacher. Because he had to think of different ways of communicating the content and concepts to the students, he felt he had a better understanding of the subject matter and of the students' understanding of the concepts. This knowledge enabled Bob to feel confident enough to chart his own course of professional development activities and also to make judgements regarding what constituted a good use of technology in the classroom. He said:

> If I don't find the technology for example, serves any very poignant useful purpose, I don't bother with it, so I have much more of a bottom line approach than I ever have had before.

Alex also liked the small learning groups in the class and nurtured the idea. As a Level III teacher, his class usually begins with a 5 to 20 minute teacher presentation or lecture, and the remainder of class time is devoted to students working at their own pace on classroom activities either individually or in groups of two or three. During classroom activities, the students frequently relied on their peers for clarification. For example, during a classroom observation, a group of students were arguing about an interpretation of their computer simulation. In order to resolve their conflicting ideas they called the teacher in. He came and quietly listened to them present their cases, not directly to him, but trying to convince other members in the group. Finally one student was able to convince the group and he turned to the teacher who was still listening and said, "we don't need you anymore." Alex nodded, said "good" and left. When asked later about this incident Alex referred to it as:

> Part of it is the empowerment that happens when they [students] learn something. It is [the learning] really internalized, not this external concept that somebody is lecturing about.

He called this kind of student exchange "a common occurrence" in his class. This sort of interaction observed in Alex's class exemplifies a blurring of the power dynamics in the classroom in which the students assumed very active roles in the learning process and were quite confident in their new roles.

Alex valued the new kind of interactions he had with students made possible by students working in small groups, which, according to him was "very different" from what he was used to before he was involved with TESSI. When Alex worked with the individual or small groups, he was able to tailor explanations to the needs of individual or a small group of students at a time. He said:

> Now they know they are getting a very individual focussed attention. You are making eye contact and there is a personal connection that I didn't have as much when I lectured, so I think I interact more with them. We bounce [talk] about other things hence I am able to make a more personal connection with each student.

Alex described the change in his relationship in terms of the personal connection that he was able to make with students.

Alex also acknowledged some of the disadvantages of the new classroom practices he was fostering as a result of using digital technology. For example, with the emphasis on student directed learning, teacher-student interactions are frequently student initiated, which could be a disadvantage for students who are introverts. One of those students commented to me that the teacher always seemed to pay more attention to the "loud ones." Alex admitted that he has not been as sensitive to those students as he could have been because of the intense level of activities in his class. Alex acknowledged the fact that he interacted less with the quieter students is a dilemma. He does try to initiate dialogues with those students but he admitted that this is a shortcoming of his instructional method. According to Alex:

> Is it a bad thing that I haven't been to those students regularly? Absolutely. But what do you want me to do about it? I feel more comfortable in saying that, as opposed to feeling that I should always be doing something to meet the needs of every single person in every single way. There are limits to what I can do.

Alex recognised the disadvantage about the other quieter students who tend to be overlooked in a small group instructional setting. His response was that, this is one shortcoming of this method of teaching that he has accepted as a compromise.

Dimension Two: Summary

All the teachers agree that the attributes of the method and management of learning in the digital classroom, that of personal goal setting, individual pacing and activity choices, (see figure 6.1) are positive. These skills help the students develop life skills such as independence and decision making strategies. The changes in the method and management of learning activities required active students' participation and renegotiation. The teachers had to, at different times, negotiate explicitly with the students regarding each attribute of this dimension and try to *sell* the ideas to the students. These attributes also required a response from the students in the form of actions and talks with the teachers.

The teachers and the students engaged in conversations about metacognition, personal goal setting, individual pacing and activity choices. In these renegotiations sometimes the teachers views prevailed, sometimes the students did. The students prevailed when they are able to convince the teacher explicitly or implicitly by their sheer resistance, to change the teaching practice to conform to students' preferences. The teachers prevailed when the majority of the students accept the new or modified practices. I have merged the particular instances into my discussions of each attribute within the dimension. For example, Bob and Peter's decision to limit metacognitive talks and activities in their classroom was largely due to students' resistance. What was a little difficult for me to ascertain was which aspects of the acceptance of new practices were contrived or genuine. A study on students' perspectives will likely shed more light on that question. The final dimension is an examination of how the assessment of learning was renegotiated in the classroom. In the next section I discuss this third dimension.

Dimension Three: Assessment of learning

Interactive Testing as a Learning Tool

The only attribute discussed under the third dimension, assessment of learning, along which the teacher-student pedagogic relationship was renegotiated, is the use of interactive testing as a learning tool. With learning becoming more student-centred in TESSI classrooms, the teachers felt they needed to place more emphasis on formative assessment to monitor individual students' learning. They chose an interactive, computer-based testing program that provides instant feedback to the students, LXR•TEST™ as one of their formative assessment tools. The interactive testing was student-directed. By allowing students to take more control of their formative assessment, students also took more control of their own learning. Students' responses were positive: students frequently took the interactive tests when they felt they needed to assess their own mastery of the units' content. All the teachers used the interactive tests for formative assessment. As the teachers realised the potential of computer interactive testing, they encouraged its use as a learning tool in the classroom. According to Bob:

> I use it [interactive testing] for practice situations. I think the interactive test is wonderful, so no problems.

Peter said he had always valued formative assessment prior to TESSI except that it was never computer based. For Alex, the introduction of digital technology enabled him to consider formative assessment. According to him:

> My assessment was not nearly as valid as it is today. I didn't even consider issues such as formative assessment [before using digital technology]. Assessment was just a mark on a test and I would add all the numbers together and at the end that was the grade. So I never really thought or reflected about the validity of my evaluation or the things I could do to improve it.

The above indicates that Alex made a definite change in his classroom assessment practices to include formative assessment, something he never did before he started implementing TESSI.

For summative assessment, all the three teachers relied on the paper and pencil methods, but they used digital technology as an assessment management tool. The management tools involved recording and analysing students' marks on the computer using programs like LXR•TEST™ and other specific software adopted by individual school districts. The marks were analysed so that teachers could provide comprehensive feedback to the students.

The use of Interactive testing was a marked departure from regular classroom practices in which assessment was more or less the domain of the teachers. By letting the students be more in control of the interactive testing, the students felt more empowered and responsible for their own learning. One of the far-reaching ways in which the interactive test was used was that it provided instant answers to the students. They are given the answers to each question as they move along. The instant feedback, according to the students, is the best part. They know how they have done on each test and they are able to map out their strategies for achieving their goals. The teacher-student relationship changed in that the students were able to solicit the teacher's help in particular units and sometimes when they made mistakes they asked the teachers to explain why. The nature of the teacher-student conversations was also different. The students' scores are automatically recorded on the teacher's computer, which is also usually the classroom server. So both the teacher and the students were able to keep track of their scores. The students were also able to log on the computer at anytime with an individual password to see their cumulative scores.

Teachers' Enactment of the Changes in Assessment Practices

All of the teachers viewed as positive the use of formative assessment practice afforded by the new technologies. They also perceived that their students valued this practice as well. However, the three teachers differed in how they enacted the interactive testing in their classroom and the extent to which they have allowed the interactive testing to affect the overall classroom assessment practices. At Level II implementation, the interactive testing is optional for the students, but at Level III implementation, interactive tests were a required component of classroom activities.

As Level II teachers, Bob and Peter used interactive testing only as an optional assessment activity, as an aid to help the students master the course content. They both retained the paper and pencil, traditional method of formative and summative assessment. Because the interactive test was optional, the marks were not part of the final grade in the subject. The teachers occasionally interacted with the students after they took such tests, especially when the students had specific questions. According to Bob:

> Other than utilizing the computer activities and then using them as assessment tools, I haven't really changed my role of assessment of the students in a real significant way.

Peter's response was similar to Bob's:

> I don't do testing that counts for marks on the computer...The kids right now do all the quizzes and tests at the same time on pencil and paper.

Peter gave pre-unit quizzes as a formative assessment strategy. The pre unit quizzes were paper and pencil. In Peter's classes the students tended to work on the interactive tests outside of class-times because he encouraged his students to be self-sufficient in that respect. According to him, there is usually an increase in the number of students who came in to the class to work on practice tests on the computer outside of their regular class times when a unit test or examination is pending. In his class he usually gave the study guides as a package for each unit and lets the students work with those. He said:

> They [students] would get [Study Guide] as a package, here is what you need to be doing, I am going to be here on these days, and here is an interactive test to see if you actually do know what you are doing. So that is good and that has to be and you have to have that leeway to be able to let the kids do that on their own and the kids have to be mature enough to work on their own.

In this context, Peter is also using the interactive test as a learning tool, in addition to it being used as a formative assessment tool.

Alex changed his assessment practices to include the interactive test in such a way that it significantly changed his relationship with the students. In Alex's class, each student was allowed to take computer generated practice tests as many times as the students wished before informing the teacher when he/she was ready to take the test for marks. Alex said:

> The evaluation that I do where I get a sense of how they are doing is their unit exams and their interactive test scores.

Using this formative assessment tool has changed the teacher-student relationship in Alex's class because he found that it provided opportunities for dialogue with individual students, since he had a better idea of each student's levels of understanding. There was increased feedback and conversation with students about their performance.

Alex took the management of summative assessment to another level, where he would compile various computer-generated statistics about individual students' marks on unit exams using LXR•TEST™. (See Appendix C, a sample of the computer generated physics 12 individual mastery report). He would then meet with individual students and provide feedback about their performance and sometimes allowed the students to retest on their identified areas of weakness as analysed by the computer. He said:

> On the unit exams, [I] use the LXR•TEST™ to grade them and it combines the multiple choice and the open-ended question scores together by topic, or concept. So when the students get their mark back, not only does it show the total mark, but it gives a breakdown of how they did according to concept. So when I return the exam to them, it is an opportunity to have a positive conversation with them and say, you are smart, you can do this. These other ones just aren't done yet.

> What we need to do is to try to bring them up, are you interested in even doing that? You know, you [the teacher] have a proactive dialogue.

Alex used the test data as an opportunity for individual dialogue with his students. He also shared a computer-generated, whole class unit summative assessment data that he discussed with the entire class as a group. (See Appendix D, a sample of whole class objectives summary report, and Appendix E, a sample of the whole class statistics summary of a unit assessment). Alex's students responded positively to the assessment strategy in his class and many of them with whom I spoke felt that interactive testing affected their relationship with the teacher because they felt they had a better rapport with him. They found the individualized feedback very useful and one of the students commented: "It helps me to map out my next strategy". The individualized feedback helped students identify their areas of weakness.

In short, the modifications and changes in assessment of learning practices affected the teacher-student relationship with all the three teachers by increasing and changing individual teacher-student interactions and dialogues. In Bob and Peter's classes, the teachers are able to interact with the students who take the optional interactive testing and have conversations about students' performance and understanding of the content. In Alex's classes, since interactive testing is a required aspect of class, teacher-student one-on-one conversations significantly increased and the type or the content of the talk also changed.

Other Pertinent Issues and Summary of Teachers' Overall Responses to the Changes

A recurrent theme within each of the three dimensions discussed in this chapter is students' empowerment in the learning situation, because all the strategies within the three dimensions foster student centred learning. This empowerment perturbed the teacher-student power relationship. This changing relationship facilitated changes or modifications in classroom roles and required a renegotiation of existing norms and classroom practices on the part of both the teachers and the students. Adapting to the changing roles and relationship was not easy for the students or the teachers. The changes were seen as a breach of expectations, but more so for students than for teachers as the teachers were trying to implement these changes by choice. For the most part, the teachers valued the changes because they were convinced that the overall objective of empowering the students to take more control of their learning was worthwhile. On the other hand, the teachers did not anticipate the extent of the change in roles, so they struggled with their changing roles and questioned themselves about the relative advantages and disadvantages by way of their own teaching preferences. Understandably, the extent of changes or modifications in practices varied in each teacher's classroom.

A consequence of an increase in students' empowerment is an increased questioning by the students for the justifications of various classroom activities. For example in an e-mail to me Bob wrote:

> I seem now to try to rationalize all the activities we do in the TESSI class, even if it is a traditional activity. … I try to provide more comment [to the students] as to why we do the things that we do in class. I never worried about that as much before. Working in a TESSI environment has forced me to think and explain the reasons why we do the stuff that we do.

All of the teachers have come to accept the questionings and have viewed the questions more as a pleasant collaboration rather than a clash of wills. Bob and Alex said it minimised the students' perception of the teachers as the sage on the stage that all students look to for answers and students recognize equally that they can help each other too. This questioning led to a different kind of teacher-student conversations in a way that affected the teacher-student relationship. The changed relationship also changed the students' views from the traditional notion of teacher as expert and student as novice to one that portrays teachers and students as partners in learning.

All the teachers were also aware of the presence of an implicit contract in the sense that Aspy (1986) used it, even though none of them used the term pedagogic contract. In their conversations with me they alluded to the notion of a contract or students' expectations that they actively tried to change through renegotiation. They encouraged the students to become active participants in their learning.

According to Peter, the existence of a contract became obvious when some of the students opposed the independence and self-directed learning that Peter was trying to promote in the class. Peter found the students' actions frustrating because, for these students, a transmissive classroom represented a good learning environment:

The realisation that there is a contract was why Bob talked about fighting a subtle norm, "You can't see it", he said, "but you know it's there".

In Alex's case, he mentioned that his students expected to come to class, "sit down and shut up". But he encouraged them to participate in the learning process:

> I try to encourage an approachable atmosphere. You know which is different than a lecture, sit down and shut up I have something to say. And at the appropriate point in the lecture, I would like you to interject. This [class] is very different.

The presence of a contract is evident in all the three dimensions of learning, and underlies the approach to classroom teaching and learning. Students do not come to class expecting to renegotiate their tried and true ways of learning, especially in their last year or two of secondary school.

All of the teachers agreed that all the attributes of the three dimensions identified in this chapter are positive and worth the effort to implement. According to them, the skills that the students were able to develop as a result of being in control of making these choices were examples of benefits of learning with technology, benefits that are valuable but un-quantifiable. This kind of learning is not easily measured and consequently does not normally show up on exam scores. These skills help the students to develop life skills such as independence and decision-making. The fact that this learning was related to skills that are not measurable on standard exams is why it was sometimes difficult for students to understand why they had to spend time on "something" on which they will not be tested in their provincial exams. This attitude contributed to some students' resistance to some of these learning strategies, hence the need for teacher-student negotiations.

In terms of the teachers' own learning, the teachers all said that their individual education and expertise evolved a lot as a result of implementing TESSI. For example, in developing multiple activities on the same concept, the teachers felt that they had to really understand the concept and also think of multiple ways of presenting the same concept without sacrificing the real essence of what the students had to learn. They all felt that it was sometimes possible to lecture around a topic that the teacher does not know very well, but in developing activities, the teacher has to really understand the topic. Hence the teachers said that they became more creative than they used to be because they had to think of different ways of using computer technology to foster student learning and also for classroom administrative purposes. The effect of this change on their relationship with students has been a less defensive feeling about their work and a greater willingness to learn from the students, particularly in designing learning activities.

Each of the teachers renegotiated the pedagogic contract in their class because along with their students they were able to establish new classroom practices and norms for learning. The new contract was renegotiated based on the teachers' comfort level and their perceived level of students' comfort and acceptance of the changes. The teachers enacted the changing roles that were enabled by the use of digital technology differently.

Peter did not mind the changing power relationship in his classroom. His attitude was that the changing power relationship was a result of efforts to encourage the students to take more control of their own learning. Peter always considered himself to be a facilitator of learning, even before he used digital technology in his classroom. He said that using the technology has provided him with more freedom to continue along that path.

As a Level III TESSI teacher, Alex responded favourably to the changing power dynamics associated with the teacher-student relationship. He considered it a "freeing" experience and so encouraged a classroom atmosphere in which students were sufficiently confident to be active participants in charting the course of their own learning and negotiating some learning activities with the teacher. He indicated that though digital technology was not the focus of his classroom, many of the activities were made possible through the use of the digital technology. He said:

> Technology has afforded me the chance as a science teacher to change my practices. ... It is not the technology itself, it is how it impacted, how it afforded me to change my teaching style that I wouldn't have had to change.

Bob struggled with his role when he implemented Level III TESSI. The difficulty for him was in maintaining control in his classroom. He said:

> I feel that if I do not maintain my current position, I can't ensure that those students will master the material effectively. Maybe there is a little bit of holding on to the power relationship of the classroom. I would have to deal with it, but I am most concerned that those students get the results we would like.

He said that he needed to ensure that all the opportunities to learn did exist, and that his way of doing that was by being in control of students' learning. He was happy to be at the Level II implementation because he felt that gave him the permission to maintain some form of control of his classroom while fostering student's centred learning.

For each of the three teachers, the pedagogic contract was renegotiated in their classrooms, as discussed within the three dimensions outlined in this chapter. Perhaps the dimension that required the most active renegotiation with the students is the method and management of learning activities. The attributes within this dimension is one in which the students can subtly or explicitly refuse to renegotiate the contract. For example in providing activity choices for students, they can choose to continue taking the traditional science laboratory activities rather than the technology enhanced ones. Furthermore in encouraging the students to think about how they learn, since the teacher has limited ability to enforce it, the students can choose to ignore the teacher's promptings. As I indicated in my earlier discussion, some of the teachers' decisions to continue implementing each of these strategies were affected by students' responses and the renegotiation. The other two dimensions, the content of learning and assessment, tend to be mostly dependent on teacher decisions.

For the Level II TESSI teachers, Bob and Peter, there were definite shifts in the classroom norms leading to the renegotiation of the pedagogic contract in modest ways in their classes. Alex, the Level III TESSI teacher, reported a marked difference between the teaching and learning activities in his pre and post-digital technology classrooms. From my classroom observations and conversations with the teachers, they all maintain that the use of digital technology was not the focus of their classroom, but that the changes in classroom practices were made possible or in some cases made easier because of the technology.

Summary

In this chapter, an examination of how teaching and learning with digital technology enabled the teachers to renegotiate the teacher-student pedagogic contract resulted in the identification of three dimensions of learning in which the teacher-student relationship were affected. Specific strategies that were renegotiated were also identified as attributes within each dimension. These interrelated dimensions of learning portray the complexity of the changes in classroom practices, norms, and the teacher-student relationship. The teachers' enactments of the changes were also discussed.

CHAPTER SEVEN

CONCLUSIONS, DISCUSSIONS AND IMPLICATIONS OF THE STUDY

Introduction

The purpose of this study has been to understand and document some of the salient features associated with how the introduction of digital technology in secondary science classrooms enabled three teachers to renegotiate the teacher-student pedagogic contract. In responding to this purpose, I have taken the stance that the expectations of norms and practices that define the teacher-student pedagogic relationship constitute the teacher-student pedagogic contract. Such a perspective has been useful for examining the complexities involved in understanding the teacher-student relationship and the effect of innovative teaching practices on this relationship. There are three sections in this chapter. The first section is a discussion of the conclusions emanating from the research questions. In the second section, I link my findings to the arguments and critical issues raised in the literature review. The third section explains the implications for practice and suggestions for further research. At a time when teaching and learning continues to be affected by digital technology, this closing chapter highlights the implications of some of these effects. Meaningful integration of digital technology in a way that promotes effective teaching and learning is demanding and difficult, even for the most technologically adept teachers. Hence, this last chapter also highlights some of the indispensable forms of support that are needed for teachers if effective teaching and learning with digital technology is to succeed and be sustained.

Conclusions Emanating from the Research Questions

The two-part research problem that guided this study is: How have digitally enhanced classrooms enabled three teachers to renegotiate the teacher-student pedagogic contract, and how do the teachers enact the changes? For the most part, answers to these questions have already been presented in the analysis in chapter six.

With each of the participant teachers, digital technology enabled the renegotiation of the teacher-student pedagogic contract along three major dimensions of teaching and learning. The dimensions were:

- Content of learning;
- Method and management of learning activities; and
- Assessment of learning.

Various attributes of learning were identified within each of these dimensions: Two attributes were identified in Dimension One, three in Dimension Two, and one in Dimension Three. The research question was answered within each of these dimensions. Changes in all the dimensions were manifest in each teacher's classrooms, albeit to varying degrees. The major differences were seen in the way each of the teachers enacted the changing relationship. In some cases they encouraged some of the changes and in other cases, they were unsure of the changes and sought ways to minimize the effects of these changes on their classroom practices. In the following section, I discuss each part of the research question as they relate to the three major dimensions that were identified in the study.

Dimension One: Content of Learning

Using digital technology as a teaching and learning tool enabled the renegotiation of the teacher-student pedagogic contract and led to modifications in practices associated with two content of learning attributes:

- teaching topics differently with digital technology
- an increased depth of students' and teachers' engagement with the content

All the three teachers reported modifications in the content of learning in their science classrooms. The use of digital technology enabled them to teach some science concepts in ways that they would not otherwise have been able to without the technology. I have provided some examples in chapter six. Teaching topics differently with the technology also contributed to students' and teachers' in-depth engagement with the content. All the teachers claimed that they were able to increase their repertoire of teaching strategies as a result of using the technology since they had more options for presenting the concepts with and without the use of the technology. The teachers did not have any *hard* evidence of an increase in students' understanding of the science topics in terms of exam scores, but based upon their interactions with their students and the quality of the teacher-student discussion about the science concepts, they felt that the students displayed a more in-depth understanding of a number of concepts in a technology enhanced classroom than when they taught those concepts without the technology.

The two changes in the content of instruction affected the teacher-student relationships by enabling increased opportunities for teacher-student conversations about the science concepts under consideration. Because the teachers and the students displayed more in-depth knowledge of the science topics, the changes also facilitated the transformation of the teachers' image and role from being the sole authority and gatekeeper of knowledge to that of a coach and a facilitator of learning. The extent to which this shift occurred varied among the teachers.

The teachers enacted these changes by exploring and encouraging alternative ways of teaching the science concepts in order to enhance students' learning, to promote increased depth of students' engagement with the content, and to achieve more in-depth learning. All of the teachers appreciated the opportunity that the technology afforded them to expand their own learning and their repertoire of teaching resources and strategies. They found it rewarding to listen to the students discuss science concepts in-depth, even at times outside of regular class-times. They welcomed these changes because they felt that increased students' engagement with the content was an indication of effective teaching. On the other hand, the teachers were frustrated when they felt that the available software was insubstantial in content and did not extend students' learning in any significant way. Such was the case with some of the available Chemistry software. Bob and Peter enacted the changes by ensuring that the resources were available for students' use, but made it optional for students to use on their own time. There is an acknowledgement within the TESSI group, and certainly among science educators in general, that currently, Physics as a subject matter lends itself more to teaching with technology than the other science subjects. Therefore more appropriate software programs are currently available for Physics than for Chemistry or Biology. Therefore Alex had many opportunities to teach topics differently with digital technology and did so enthusiastically.

Dimension Two: Method and Management of Learning Activities

Early in the project, TESSI project teachers and researchers advocated fewer teacher lectures and created Study Guides that assigned tasks to students associated with managing their own learning. The three teachers in this study followed this pattern, but they each adapted it to fit their own classrooms in significant ways for their students. These new learning strategies were intended to facilitate:

- Metacognitive learning;
- Personal goal setting, pacing and activity choices; and
- Individual and small group instruction and learning activities.

The major goal of these strategies was to promote students' autonomy in taking control of their learning. All three teachers said that they employed these strategies more in their technology-enhanced classroom than they did before they started using the technology. Although the extent to which these strategies were used varied in each teacher's classroom, they all stated that the use of the technology facilitated these strategies and led to a renegotiation of the pedagogic contract.

The new learning strategies promoted student directed learning and blurred the teacher-student power relationships. The students were empowered to take greater control of their learning and there were more opportunities for meta-talk and subsequent scaffolding of students' knowledge in the particular subject domains of each teacher. The initial pedagogic contract had well defined boundaries of teacher-student power relationships in which the teacher controlled what, how and when to learn. The blurring of this boundary called the contract into question and required a renegotiation on the part of the pedagogic contract. The teachers claimed that the majority of their students were not comfortable with taking more control of their learning. The prevailing classroom pedagogic contract is that the teacher is in control of students' learning. Therefore the method and management of instruction required active renegotiation with the students. The students had to be scaffolded through the process.

New learning strategies were most evident in Alex's Level III classroom. As discussed earlier, Alex was the most experienced TESSI teacher in the study and had helped shape the structure of TESSI. Consequently, Alex had a greater sense of ownership of the direction of the project and the decisions made about the project than did Peter and Bob. He seemed very keen on ensuring the success of the project. But perhaps the major reason why particular learning strategies are not as evident in Bob and Peter's classroom as in Alex's is because of each teacher's personal preferences. Bob and Peter were not enthusiastic about individual pacing, and so although were supportive of their students' efforts to self-pace when there were no laboratory activities, these two teachers did not actively promote self-pacing in a general sense. Their reasons for this decision were related to subject matter differences, and their students' and their own personal preferences. Both Peter and Bob believed that their students preferred to be lock-stepped and actively resisted taking more control of their own learning.

For Bob, helping the students to understand the benefits of self-directed learning was challenging. Bob's school is one of the lowest SES schools in the district. According to Bob, many of the graduating class of students were already talking about grad night in September during classes. [8] He felt that as many of the students do not intend to go to the university, they would scoff at talks about metacognitive learning and taking more control of their own learning. For them, such concepts did not seem relevant.

The teachers enacted the changes by renegotiating the pedagogic contract such that they determined how much power the teachers would concede to the students over their own learning. The teachers found that it took considerable time and effort on the part of both teachers and students to have the students think about and clearly articulate how they learn. Alex viewed all the three new learning strategies positively and encouraged these in his classroom. Bob and Peter encouraged metacognitive learning but found that their students were impatient when they engaged in meta-talk in the class. Hence, meta-talk decreased in these classrooms and both teachers acknowledged that metacognitive thinking in their students occurred at a lower level than they would have liked. Personal goal setting, individual pacing and activity choices are interrelated strategies that were employed minimally in Bob and Peter's classes. The teachers attributed their individual response to these strategies to the nature of their primary instructional area, which is Chemistry, in addition to their own personal teaching preferences.

Bob described the changes in his teaching practices as two steps forward and one step backwards, but he felt that he made a big leap early in the project before appreciating the full impact of the changes. He then decided that he was not willing to allow a totally radical change in his classroom practices as a result of the introduction of digital technology. Peter described himself as a facilitator before the use of digital technology so using the technology allowed him to continue moving in a similar direction in terms of his classroom practices.

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[8] Grad night is a social event for the graduating class. It is usually a day of merriment, limousine rides and all night partying. It is considered an important graduating social rite.

Despite this movement though, I still perceived a sense of caution in Peter's integration of digital technology during classroom observations and interviews. Alex, in comparing his teaching before technology to his teaching with technology, said: "it is like night and day" and that he implements all of these strategies in his classrooms.

All three teachers employed individual and small group instructional strategies to varying degrees depending upon subject content and pedagogical preference. Bob and Peter both said that they tend to do more small-group lectures with the use of the technology than before they started using the technology, even though their classroom practices still tend towards whole class lecture rather than individual or small group instructional practices. Because of Alex's preferred teaching style, he gives more individual and small group lectures than whole class instructions.

Dimension Three: Assessment of Learning

With learning becoming more student centred in TESSI classrooms, the teachers felt they needed to place emphasis on more regular formative assessment practices to monitor individual students' learning. As one of their formative assessment tools, they chose an interactive computer based testing program, LXR•TEST™, which provides instant feedback to the students. The interactive testing program was used as a learning tool in the classroom, with students frequently using it to assess their own learning and determine if they needed further revisions of the concepts they are studying. As students took more control of their formative assessment, they also took more control of their own learning. This contributed to a sharing of power between the teacher and the students. This revised power sharing constituted a renegotiation of the pedagogic contract.

The dominant thinking about assessment is that it is the measurer of change, that is, the indicator of what students have learned through various instructional innovations. But an emerging way of thinking about classroom assessment is as part of the change in itself. Within the TESSI group and in this study, assessment became part of the change and a direct precipitator of learning. The change in assessment practices is one that is difficult in the secondary school setting because of the externally imposed curriculum and assessment.

The assessment practices significantly altered the teacher-student pedagogic contract such that the teacher-student power relationship changed. Students assumed more control over their own learning. In Alex's classroom, on some unit tests, the students had the option of deciding when they were ready to be assessed via LXR•TEST™ test for each unit. Such options were not available in either Bob or Peter's classrooms. In Bob and Peter's classes the computer assisted LXR•TEST™ formative tests were optional and used only as monitoring tools for students to test their knowledge of particular units. Thus, while teacher-student conversations about assessment changed in all three classrooms, in Alex's class there were more one-to-one teacher-student conversations on marks and on the attainment of students' goals pertinent to their score on tests and exams.

All of the teachers had a positive view of formative assessment. They also perceived that their students valued formative assessment as well. But the three teachers differed in the purpose of the interactive testing as a formative assessment strategy. In Alex's class, the interactive tests were a required part of assessment and were weighted as part of students' overall marks in the course. Bob and Peter encouraged their students to take the tests but the tests were optional and did not count for marks.

Assessment is traditionally seen as a currency for learning. Students entering these teachers' classes were not familiar with formative assessment, especially in the way the LXR•TEST™ works, as a learning tool. Thus, this view of assessment in the three teachers' classrooms constituted a change in the teacher-student pedagogic contract. In Peter and Bob's class, fewer students took advantage of the LXR•TEST™ program because it was optional and thus interpreted as less important by the students even though the students liked it. Another reason for fewer usages in Peter and Bob's class was that both teachers said that the

Chemistry test banks were not as well developed as the Physics ones, making them more difficult to use.

Discussion of Critical Issues Arising from the Study

In this section, I discuss some of the claims made in the previous section in light of the review of literature in chapter two and three in addition to some of the more general literature related to teacher-student relationships, technology and learning. My main purpose here is to highlight questions and discuss critical issues that emerged from the analysis as it relates to literature. Teacher-student relationship has frequently been portrayed as peripheral to the use of technology and the changes in the roles of teachers and students as one of the un-intended outcomes. This study presents a view of the teacher-student relationship as an integral part of change. The participant teachers in this study viewed their relationship with their students as a vital part of their consideration of the how and why of their innovative practices. Hence, I draw important conclusions from Alex, Bob and Peter, since their cases present a rich context where technologically competent and experienced teachers used digital technology as a teaching and learning tool in secondary science classrooms. The specific knowledge claims are italicized.

Effects of Digital Technology on Classroom Teaching and Learning

In the review of literature in Chapters Two and Three, I have explicated that technology cannot be implemented independently of the classroom context and the social relations therein. Agreement between the teachers and their students on the underlying values and forms of governance that determine how and why the technology is being used is equally important. Using digital technology as part of classroom teaching and learning can provide an impetus for some teachers to reconsider their instructional strategies (Duhaney & Zemel, 2000). As Sandholtz, et. al., (1997, p. 176) explain, "the benefits of technology integration are best realized when learning is not just the process of transferring facts from one person to another, but when the teacher's goal is to empower students as thinkers and problem solvers."

The process of this empowerment is fraught, however, with constant renegotiations. New strategies are being employed, along with some more familiar ones, to achieve the desired learning objectives.

The strategies adopted by Alex, Bob and Peter resulted in learner-centred activities in which the students are involved in determining the sequence and strategies used in directing classroom activities, albeit to varying degrees. Learner-centred activities necessitate a change of roles and result in a dynamic exchange between teachers and students. Therefore, it is important to understand how the adoption of digital technology affects the teacher-student dynamic exchange, ensuring that the resultant effect is not attributed to the technology alone. Appreciating these issues will contribute to the effective use of digital technology such that the technology is used to its full potential in classroom teaching and learning. Therefore, I argue that it is the overlap between research on technology integration and research on teacher-student relationships that has provided the significance for this study.

The results of this study support my earlier analysis from the literature review that the benefits of integrating digital technologies are more about the issues of learning rather than with the technology itself. For example, in science education, research has shown that using digital technology as a teaching and learning tool has the potential to make scientific concepts more accessible through visualization and multiple representations by helping students form their own dynamic mental models (Linn & Hsi 2000; Williamson & Abraham, 1995). In this study, Bob particularly liked the *CHEMedia*™ simulation unit on the rates of reaction because students were able to see and manipulate the variables. Alex also said that the simulation program Interactive Physics™, extended students' learning of Physics concepts. Alex, Bob and Peter all felt that having these multiple representations provided students with a deeper understanding of the concepts as explicated in my discussions of Dimension One. In my various discussions with Alex, Bob and Peter, they expressed more concern about the issues of teaching and learning, as I have shown in the presentation of the findings in the last chapter than about the use of the technology in itself. They rarely mentioned increased technological competence as the major advantage of implementing technology. Therefore, I reiterate my previous assertion in chapter two that as more teachers make effective use of digital technology for teaching and learning, *the future of technology integration portends potentially far-reaching changes that reflect that of a transformed pedagogy.* Major attributes of a transformed pedagogy as outlined by Somekh and Davies (1991) were exhibited by each of the three teachers to varying degrees.

Studies have shown that the use of digital technology as a teaching and learning tool affects classroom practices in a number of significant ways. Some of the changes related to the effect of digital technology on teaching and learning practices that were summarised in Table 3.1 were also corroborated by this study and they include moving from:

- student passivity to activity;
- teacher centred activities to student centred activities;
- whole class instruction to individual and small group learning; and
- emphasis on summative assessment to formative assessment of learning.

Unfortunately, these changes have often been portrayed in the literature as automatic results of using digital technology as a teaching and learning tool. This simplistic view of the use of digital technology underestimates the influence of the mediating factors that affect how the technology is used. My study shows that using digital technology as a teaching and learning tool is complex, and that there are optimum conditions that are necessary for effective technology integration to occur. One of those conditions, as explicated in this study, is the renegotiation of the pedagogic contract.

One of the strategies used in TESSI as discussed earlier is the small group and collaborative learning. Jones and Carter (1998) contend that small group learning has been shown to mediate learning, scaffold the construction of knowledge, and facilitate critical thinking in science classrooms. Because peers tend to be at similar developmental levels, they are sometimes more effective than adults in the construction of meaning. An example of the effectiveness of student co-construction of meaning was the episode in Alex's class described in chapter six. A group of four students were having a spirited discussion about the logical conclusion of their simulation activity. They called on the teacher to arbitrate, and while the teacher was listening to their discussion without intervening, the sceptical student was convinced, and he turned to the teacher and said, "we don't need you anymore". Similar peer-to-peer construction of knowledge also occurred in Bob and Peter's classes. The results of this study concurs with Jones and Carter's (1998) argument that small groups provide opportunities for students to share ideas and experiences, argue hypotheses, and increase their understandings of different perspectives. Hence, peers can mediate one another's learning in ways that are different from the teacher's methods (Jones & Carter, 1998). Means (1994a) also contends that in using technology to advance educational goals, complex authentic tasks such as those being actively promoted in science learning lend themselves to collaborative work.

My study, like Becker (2000), Jonassen, Peck and Wilson (1999), Linn and Hsi (2000), also found that the teachers integrated digital technology in meaningful ways that resulted in significant changes to their classroom pedagogy and relationships. Peter, Bob and Alex sought to use technology in ways that maximized the potential of the technology such that the culture of their classrooms changed. *Because of the renegotiated pedagogic contract, the students came to class expecting a different culture or atmosphere for learning.*

The Changing Role of Teachers

The changing role of teachers is an important aspect of the current wave of educational change. The tendency towards constructivism and social constructivism has fuelled a questioning of the role of teacher as the authority and information provider. Many studies have suggested that the use of digital technology tends to foster constructivist approaches to learning. My study concurs. For example, see Becker (2000), Cadiero-Kaplan (1999), Edelson and Lento (1996), Means, (1994a, 1994b), Ravitz, Becker, and Wong, (2000), Schofield (1995), Tapscott (1998). Maor and Taylor (1995, p. 845) contend: "a constructivist pedagogy provides enhanced opportunities for the development of students' higher-level thinking skills." Constructivist and social constructivists advocate a new role for the teacher as a guide, facilitator and a motivator (e.g. Lampert, 1990; Resnick & Resnick, 1991). For example, Edelson and Lento (1996) presented exemplars using case studies from the CoVis project that demonstrate the potential of digital technology for supporting and guiding teachers' role transformation. They found that digital technology played an important role in advancing teacher-student partnership. Researchers such as Laferriere et al. (2001), Linn and Hsi (2000), and Woodrow et al. (1996) also argued that using digital technology has the potential of supporting and guiding a teacher's role transformation. My study concurs. My study also shows that, using technology as a teaching and learning tool *enables a questioning of teachers' role in a way that teachers can reflect on their roles and make changes.* For example, Alex noted that the technology has afforded him the opportunity to question his role and change from an information provider to a coach or facilitator. Bob also remarked that the technology afforded him the opportunity to change his role to the extent that he did, but he chose to resist a further transformation. Peter referred to himself as a facilitator prior to using the technology but said that using the technology enabled him to evolve into more of a facilitator.

With regards to science education specifically, Linn, diSessa, Pea and Songer (1994), suggest that it is important that technology plays a central role in current science education reform initiatives. For this to happen, they recommend: "both the science curriculum and the role of the science teacher need reformulation" (Linn, diSessa, Pea & Songer 1994, p.7). In chapter two I questioned how easy it was for the role of the science teacher to be reformulated in technology-enhanced classrooms. In this study, all of the teachers said that the students resisted the change of roles and had to be scaffolded through the process. The idea of roles inextricably involves relationships; therefore a change in teacher's role involves a change in the students' roles too. Results from my study show *that changing the teacher's role in a technology enhanced classroom involves, among other things, a process of negotiation between the teacher and the students.*

The Role of Teacher Beliefs in Technology Enhanced Instructional Practices

Research shows that teachers' beliefs play an important role in teachers' classroom practices (Briscoe, 1991), including the way teachers implement technology (For example see: Datnow & Castellano, 2000; Sandholtz, Ringstaff & Dwyer, 1997; Woodrow et al. 1996; Yerrick & Hoving, 1999). In my study, teachers' beliefs about their roles influenced the classroom practices and the way the teacher-student relationship was enacted in each classroom. For example, even when Bob followed the practices suggested by the TESSI group for a while, it appears that his beliefs about the role of the teacher as the giver of knowledge and his preference for a teacher centred classroom still prevailed, and he reverted to some aspects of his prior teaching practice such as more whole group predominantly lecture teaching methods. Alex's beliefs about constructivism contributed to sustaining his practice. In attempting to adjust his practices, Alex's main focus was to foster student-centred learning and his role as a coach or facilitator of learning. This belief was evident when he said: "I am really teaching the students how to learn, and by the way, I teach Physics." He was committed to his students' development as learners, and teaching Physics provided the context for him to be able to do that. For Peter, his belief as a facilitator of the learning process was one of the major factors that guided his classroom practices. Hence this study supports the view that the individual *teacher's beliefs play a key role in their classroom practices including the renegotiations of classroom norms.*

In a study that extends the work of Cobb, Yackel and Wood (1992), Hershkowitz and Schwarz (1999) posit that the teacher has the central role of initiating and guiding elaboration in the formation of classroom norms even though the individual student has an active role too. In my study, the teachers' and students' basis of defining classroom norms were founded on their beliefs about what teaching and learning should look like in the science classroom. In redefining the classroom norms, those beliefs had to be confronted. In my various conversations with the teachers, they talked about how they needed to confront their own as well as their students' beliefs about teaching and learning.

Research Findings on Teacher-Student Relationships and the Use of Digital Technology

The findings of this research are consistent with ten of McGrath's (1998) enumeration of twelve ways in which digital technologies affect the teacher-student relationship among K-12 science and math teachers.

My study also confirms Charp's (1998) article on the impact of technology on teachers' practices. Charp's two main arguments were: first, the role of the teacher changed from the deliverer of instruction to that of an academic guide and coach; second, the classroom became more student-centred and student-directed. These two claims are corroborated by my study as I have previously elaborated in the last chapter and earlier in this chapter. My analysis also provides a fuller description of how the teacher-student relationship changed and how the teachers responded to the changes.

In a quantitative study on student-teacher interactions, Swan and Mitrani, (1993) compared student-teacher interactions between secondary school students and teachers involved in computer–based instruction, with interactions between the same students and teachers during traditional classroom instruction. Their findings revealed that student-teacher interactions were more student-centred and individualized during computer-based teaching and learning than during traditional teaching and learning. The results of my study are consistent with Swan and Mitrani's. In fact, my study goes beyond the numerical values that Swan and Mitrani assigned to concepts such as frequency of teacher-student interactions, by providing more details about what such concepts entail, such as the nature of the interactions.

Nissenbaum and Walker (1998) raised three important questions regarding the relationship of technology to teaching practices. They were: "Does the use of computers in schools threaten to undermine the student-teacher relationship? Will computers displace teachers? Can they affect a healthy student-teacher relationship?" (Nissenbaum & Walker, 1998, p. 253). My study shows that using digital technology did not undermine the teacher-student relationships. All three teachers in this study did not talk about or display any traits that might have led me to believe that they felt threatened or displaced by the technology. In fact, when I asked them if they felt threatened by the technology or that students may disrespect them if they are not as technologically competent as the students, they all unequivocally answered no. They all said that despite the Internet and many programs available, their students still regard them as the final arbitrator of science learning in the classroom.

Nissenbaum's & Walker also suggested that:

- To the extent the computer frees the student from dependence on the teacher, the computer diminishes the teacher's importance;
- When the student's learning is controlled by a computer instead of a teacher, the teacher loses influence over students' learning;
- Students' respect for teachers could be undermined if they were to view computers as more competent and trustworthy than teachers. They may view teachers as weak, fallible and idiosyncratic and computers as strong, reliable and unflappable; (p.253)

My study refutes these three suggestions for the following reasons. First, using the technology freed the students from dependence on the teacher for mundane or routine activities only. Thus, there was more time for in-depth conversations about the science concepts. In this study, the students depended less on the teacher for management of learning activities by using the Study Guides in which there were instructions about the various activities and taking more control of their own learning. Having the students take more control of their own learning did not diminish the importance of the teacher. Second, students' learning was aided but not controlled by the technology. The teachers in this study used the technology to aid the curricular requirements and only used the different software to the extent that they felt that it extended students' learning. Thirdly, in this study, the teachers did not perceive that students felt that the technology was more competent or trustworthy than their teachers.

The changing role of the teacher to that of a facilitator gave the students more control of their own learning and this did not imply that the teachers became any less competent. In fact, the opposite took place. The teachers felt more confident in their content and pedagogical teaching knowledge because they were learning how to operate differently in their classroom in addition to what they already knew. My study concurs with the research that shows that, in technology enhanced classrooms, teachers are becoming facilitators of the learning process and higher order students' thinking and not just attendants to mundane educational transactions (Becker, 2000; David, 1994; Means, Penuel & Padilla, 2001). In short, my study shows that *using digital technology as a teaching and learning tool does not pose any credible threat to the teacher-student relationship.*

Nissenbaum and Walker (1998) also listed five key indicators of risk to the teacher-student relationship:

1. reduced exposure of students to teachers;
2. less favourable student perception of teachers;
3. erosion of the importance of the role of the teacher;
4. role conflict between computers and teachers and;
5. lack of teacher control over the use of computers.

My findings did not show that any of these key indicators existed in any of the classrooms. With regards to the first indicator of reduced exposure of students to teachers, this study suggests that there may be the danger of reduced exposure to some of the quieter students as explained by Alex and Bob. Bob said that the kinds of teaching strategies being fostered by the technology led to a reduced exposure to the students as one class group, but his one-on-one interactions with the students were more in-depth. Of import in this case is that the teacher be sensitive to the quieter students and tries to engage them in classroom conversation.

My conversations with the three teachers clearly disagrees with the concern expressed by critics such as Apple (1991), and Bowers (1988), (as cited in Nissenbaum & Walker 1998), who have argued that using computer technology in the classroom would result in less student-student and teacher-student interaction than in a traditional or conventional classroom. The exact opposite occurred in all the classes. The classroom interactions with Alex, Bob and Peter confirm what researchers such as Means, Penuel and Padilla (2001) and Schofield (1995) argue, that there were increased social interactions in digitally enhanced classrooms. They attribute this increase to students tending to work in groups in digitally enhanced classrooms hence there was a lot of peer-peer and teacher-student interactions.

Teacher-Student Power Relationship

Closely related to the issue of the changing role is the teacher-student power relationship. These changing roles and relationships were not always comfortable for either teachers or the students. This lack of comfort is a result of the blurring of the boundaries associated with the traditional perceptions of what teachers and students should do or how they should behave in the classroom. This perception affected the very essence of the classroom. By creating unfamiliar situations and relations, the teachers and students experienced a loss of certainty in their own roles and status. Alex, Bob and Peter experienced constant tension about discovering ways to responsibly empower the students and share authority productively. In some respects, it was simply easier to be an authoritarian.

The power structure in the classroom is inherently asymmetrical (Kaplan, 2000), and teachers can choose to share or retain power over the pedagogical dimensions of classroom practice. For example, Bob articulated this sentiment clearly when he referred to his classroom as "my empire". He was clearly communicating to me that he was the one in charge and that he was willing to use the technology only as far as his authority and the teacher-student power relationship did not shift out of his control. All three teachers told me, and I noticed in their classrooms that not only did they talk about their content, they also frequently explained their actions about various instructional practices such as classroom management, assessment, and choice of classroom activities to the students. This was something they said they rarely did prior to using the technology. This is not unusual according to Erickson and MacKinnon who argue: "the act of making one's knowledge explicit and providing reasons for one's behaviour rarely occurs in the normal activities and routines engaged in by a teacher" (1991, p.18). Educators have argued for the need to promote such teacher talk in the classroom. I posit that technology enhanced learning is one avenue of fostering teacher talk as indicated by my study.

Thus, this study concurs with Cazden (2001), who suggests that in order to ease the transition involved in power sharing, teacher talk is critical for learner consciousness. In this study, *using digital technology enabled the teachers to be able to share power with their students in the production and transmission of knowledge.*

The Pedagogic Contract as a Conceptual Tool

Important conclusions about this study can be made regarding the utility of the conceptual device itself. The conceptual device used in this study is the pedagogic contract. In chapter three, I reviewed studies that showed that the teacher-student relationship involves well-defined and congruent goals, and that these expectations are incorporated into students' and teachers' very definition of *school*. In using the construct of the pedagogic contract, I took the stance that the classroom norms and practices that define the teacher-student relationship constitute a pedagogic contract between the teacher and the students. These norms and practices have been established through years of schooling. Any behaviour that is perceived to violate this norm is viewed as less than legitimate, and in such a case constitutes a breaking of the pedagogic contract. A renegotiation of the contract is then necessary.

In this study, Alex, Bob and Peter introduced new teaching practices that involved the use of digital technology as a teaching and learning tool to students in grades 11 and 12. The introduction of these new practices after the students had been accustomed to other practices from their previous years of schooling, makes the transition more difficult for the students. They promoted strategies such as student centred learning activities and metacognitive learning. From the teachers' perspectives, these strategies promoted student learning and helped the students take more control of their own learning. Unfortunately, the introduction of the technology initially fostered mismatched expectations about the acceptable process of teaching and learning from the teachers' and students' perspectives. The students were not used to some of the different learning practices that were facilitated by the use of the digital technology. These practices include, metacognitive learning, self-pacing, self-assessment and generally assuming more control of their own learning. The students did not necessarily want to take on some of these practices. During the initial stages of this project some of the students' perceptions included concerns such as: the teachers were not fulfilling their part of the contract by teaching the way the students expected them to teach. Students would ask teachers questions such as "How come you don't teach in this class like the other teachers do, and yet we learn?" This suggests that the students have a well defined idea of how teaching should take place in the classroom and any practice that does not conform to this perception is not "proper" teaching and therefore it is unacceptable.

Renegotiating the pedagogic contract involved the challenging process of letting go of some of the old conceptions, familiar practices and comforting routines and establishing a new form of the pedagogic contract-based on selected aspects of the old contract that are acceptable to the teacher and the students. This study suggests then that there is substance to Skinner et al.'s (1998) argument that students are shaped not only by classroom structures and larger social processes, but are also agents who actively co-produce with teachers, ways of acting in the classroom that can lead to the acceptance or non-acceptance of certain classroom norms and practices.

In the case of all three teachers, the students played active roles in the renegotiations. This renegotiation was not an easy process because the students kept referring to the ways they had previously been taught and the ways other teachers were currently teaching them. They often expressed their preference for the teacher centred learning. For example, in Bob's classroom, his decision to revert to some aspects of his teacher-centred practices was due in part to students' protests and the fact that the students were more familiar with and preferred lecture based instruction. In the case of each teacher, there were renegotiations until an acceptable equilibrium was reached. Even in Alex's class, where the most transformative learning took place, he said the process involved constant renegotiation with the students, and because the students preferred more directed learning, he implemented the weekly limits of assignments. Earlier in the project, he tried for a while operating without such a limit and found the results less than satisfactory both from his own point of view and from his students, hence his present operating procedure. Peter also said that his students preferred lecture-oriented teaching to small group learning, so he tried to strike a balance between both ways of teaching.

This result confirms the findings of previous research by Cohen (1988), McNeil (1986), and Sheingold, Hawkins and Char (1990), that teachers may retreat from innovations resisted by their students. Hence, one of the conditions for successful implementation of technology-enhanced learning may be students' perceptions and acceptance of the classroom practices that are facilitated by the technology.

The case of these three teachers also confirms Saye's (1997) study on the students' perceptions of technology and educational empowerment. He found that only a minority of students in his study valued technology as a facilitator of student-centred learning. Most of the students neither appreciated student-centred learning nor did they want to take control of their own learning. He also found that most students valued teacher control more highly than their teachers.

The teachers in this study were committed to having or developing a broad repertoire of teaching strategies. Which strategies they continued to use and how they used those strategies at any time were influenced by their feelings about their students, and their understanding about what would be likely to excite and engage their students' passions, and enthusiasm about the activities. It was important for the teachers that they build and maintain students' excitement and enjoyment of the classes. Hence the results of this study posit that, *the pedagogic contract has to be renegotiated in a meaningful way for any innovative practice to be successful.*

Perhaps the most significant conclusion of this study lies in its support of Hildebrand's (1999) use of the pedagogic contract in examining the teacher-student relationship. The pedagogic contract served as a useful construct for elucidating the complex interplay of classroom interactions, norms and practices. Therefore, *I argue for an extension of the social contract theory to the domain of pedagogy. Hence I posit that the notion of a pedagogic contract is a useful conceptual tool for understanding classroom practices. I propose that there is ample evidence for the use of pedagogic contract to begin to develop a coherent framework for the study of pedagogic relationships.* An appreciation of the pedagogic contract enables a discussion that is focused on process rather than products, beginnings rather than endings, and a continuing process of renegotiation rather than a closure of the teacher-student pedagogic relationship. Hildebrand's study furnishes an important and useful precedent and perspective for this study in terms of its content and methodology. In extending the work of Hildebrand (1999), I propose that *understanding the teacher-student relationship through the lens of the pedagogic contract provides a useful explanation of why educational change may be difficult.*

This study also confirms Hubscher-Younger and Narayanan's (2003) notion of the presence of an implicit classroom contract in which students appear to believe as I discussed in chapter two. My study extends the work of Hubscher-Younger and Narayanan by introducing a language and construct that would have allowed them to describe their observations and conclusions in a more succinct and powerful manner.

The Pedagogic Contract under Scrutiny

Perhaps this study has generated more questions about the pedagogic contract as a conceptual tool than it has provided answers. Some of the questions that I wrestled with were: Is there an endpoint when the pedagogical contract has been successfully renegotiated or is this process always in flux? Is it possible for one pedagogic contract to exist in the classroom or are there mini contracts? When one attempts to use conceptual constructs of this nature to describe reality, there will always be uncertainties and limitations that lead to more questions. For example, based on the criteria of specific aspects of classroom changes that I chose to research, the level of change differed among the three teachers. That difference begs the question of, if and when one can conclude that the pedagogic contract has changed. Furthermore, how does one describe an attribute such as a relationship except in terms of descriptive variables that can be observed? The use of descriptive variables was the approach in this study. While I do admit the use of such variables may be limited, I have not yet come across a more robust alternative.

My conclusion is that, to the extent that the students come to class expecting the classroom to be different from their preconception of the science classroom, then the pedagogic contract has been successfully renegotiated. The three teachers in this study concur that students' expectations of a different kind of pedagogical practice is an integral aspect of their use of digital technology in their classroom. Hence, I can conclude that the pedagogic contract has been renegotiated in the three teacher's classrooms.

Levels of Technology Implementation in TESSI under Scrutiny

As I explained in chapter four, early in the TESSI project the teachers developed a taxonomy to describe the way digital technology was being used in their classrooms and to identify the variety of the teaching styles supported by TESSI. In trying to describe their practices, those teachers differentiated between Levels I, II and III thus describing a teacher's technology implementation practices in terms of the levels became a common language within the TESSI group.

The analysis of the data for this study led me to question this characterization of a teacher's technology implementation in terms of levels. During the initial meetings of TESSI participants, it was constantly emphasized that the notion of levels was only intended to provide a shared language and not meant to imply a hierarchy in teachers' implementation practices. But from my interviews with the teachers, I had a sense that the teachers felt that the ideal or desirable mode of technology integration was the Level III. Thus there was evidence that some teachers felt inadequate or that they were not doing a good job until they could attain the Level III implementation. This feeling may have led Bob to move quickly to a Level III implementation and then subsequently discover that he could not operate comfortably at that level. In his words he then "reverted" to a Level II implementation. Hence the notion of levels seems limited and problematic as it carries an implicit assumption of a developmental stage approach and at the same time does not capture the significant changes taking place in classroom practices as a result of using the technology in different pedagogic contexts. It also does not adequately characterize the different approaches in teachers' application of the technology.

Implications for Practice

This study shows that the teacher-student pedagogic relationships affected the way digital technology was used in the science classrooms. Viewing the teacher-student relationship as a pedagogic contract provided a good understanding of the complexities of the teacher-student relationship, especially during an innovation process. In this section I discuss specific implications of my study for practice under the following headings: scaffolding, assessment of student learning, science teacher educators, and professional development.

Scaffolding

Analysing the teacher-student relationship through the lens of the pedagogic contract afforded the recognition of the agency of the students in the enactment of classroom pedagogy. Brush and Saye (2002) studied the relevance of scaffolds during classroom technology integration. They defined scaffolds as tools, strategies or guides that support students in attaining a higher level of understanding. They proposed two types of scaffolds: soft and hard scaffolds. Soft scaffolds are dynamic, situation specific aids provided by a teacher or peer to help with the learning process. This kind of mediation happens when teachers monitor the progress students are making while engaged in a learning activity and intervene when support or guidance is needed. In other words, the type of assistance was provided *on the fly*. Hard scaffolds are the kind of static support that are anticipated and planned in advance based upon typical student difficulties with a task.

The three participant teachers in my study used both the hard and soft scaffolds. The hard scaffold was in the form of the Study Guides that were given to the students at the beginning of each unit. All three teachers said that the Study Guides helped them in determining where the students were having difficulties understanding the concepts. The Study Guides also assisted the students in focusing on critical information, in order to be able to acquire a deeper contextual framework and see relationships between the concepts. The soft scaffold was in the form of meta-talk that the teachers called "justification" for the unique pedagogy in TESSI classes. This talk occurred almost daily in each classroom, especially at the beginning of the term and at the beginning of each unit. The results of this study shows that *the teachers and students benefited from increased understanding of the complexities of the digitally enhanced classroom through the teachers' scaffolding about the issues of learning rather than just teaching or instructing with the technology.* The implication is that one of the necessary requirements for effective use of digital technology in classroom teaching and learning is for teachers to find time to scaffold issues of learning with the students.

Assessment of Student Learning

Assessment plays a key role in giving flesh to intended pedagogical reform. Assessment reformers have long called for a closer substantive connection between assessment and meaningful instruction (Kulik, 1994; Shaw & PCAT Panel on Educational Technology, 1998; Shepard, 2001). This call is a reaction against the contexts of high stakes accountability testing which has reshaped instructional activities to conform to both the content and format of external examinations. The reshaping of instruction has forced teachers to lower the complexity and demands of curriculum (Shepard, 2001). That is, *what you test is what you get.* The result of this study confirms Shepard's assertion that "for changes to occur at the classroom level, they must be supported and not impeded by external assessments"(2001, p. 1066). One of the difficulties faced by the participant teachers in this study was in the students' expectations that they will only be taught "things" that matter for their grade twelve provincial examinations. This expectation made it difficult to emphasize important strategies that are facilitated by the use of digital technology such as meta-cognition, individual decision-making, cooperative learning and in-depth learning of concepts. These strategies, however, are in conflict with other objectives of the standardized exams that emphasize curricular breadth over depth. Furthermore, the standardized nature of most assessment does not require students to employ many of the analytic strategies that are facilitated by digital technology (Shepard, 2001). Consequently, because the students knew that what they were being taught would not be tested, they were not interested and in some cases actively resisted since it was a "waste of their valuable grade 12 time."

Another role for assessment is for it to become an integral part of classroom learning. Shepard (2001) argues that it is important that a significant role be assigned to assessment as part of the learning process. Alex, Bob and Peter's students used LXR•TEST™ interactive testing program for self-assessment and as an integral aspect of classroom learning. In Bob and Peter's classrooms, because the students' self-assessment was optional, some of the students did not avail themselves of that opportunity. All the teachers reported that students' self assessment was very helpful for students' learning. The results from this study underscore *the need for assessment to be integral to the change process. Consideration should be given to how classroom assessment practices can be transformed to illuminate and enhance the learning process.*

The role of formative assessment within TESSI is consistent with Sheingold and Frederiksen's, (1994) proposition that for assessment to be meaningful it must be grounded in conversations about student work as evidence of learning, accomplishments, and standards. They posit that for an assessment system to productively advance reform goals, the assessment must be a widely shared social system in which students, teachers and community members participate. In the case of TESSI the teachers made efforts to ensure that the formative assessment at least is part of a shared classroom social system by scaffolding the students on the assessment practices. The teacher-student individual and class conversations about assessment in the TESSI classrooms underscore this position

With regard to using technology to support innovative assessment, Sheingold and Frederiksen, (1994) envision that -- though still in its infancy -- digital technology can be a useful tool in the assessment of authentic and complex learning activities that require higher order thinking.

Science Teacher Education

Although most pre-service teacher education programs offer some type of technology course, research continues to show that science teachers do not feel prepared to effectively integrate technology into their instruction (Pedersen & Yerrick, 2000; Schrum, 1999; Strudler & Wetzel, 1999). Future teachers, having spent many years in primarily traditional teaching and learning environments, have the same images that practicing teachers have of science classrooms. Science teacher educators need to find ways to foster beginning teachers' effective use of digital technology in K-12 science classrooms and associated pedagogical skills. Teacher education programs need to include opportunities for beginning teachers to examine their personal epistemologies and beliefs about the roles of the teacher, the students and the nature of the teacher-student relationship. Beginning teachers need to be helped in the examination of an alternative set of beliefs towards their roles as teachers and their relationships with their students in addition to learning new skills for teaching with digital technology. *In short, teacher education programs will have to be developed which help beginning teachers reflect on their own images of the teacher-student relationship and assist them in creating new images. Having a perspective of the teacher-student relationship as a pedagogic contract will help them understand ways in which their roles can be renegotiated.*

Professional Development

Learning to teach differently especially with digital technology is complex and demanding (Putnam & Borko, 2000; Swan, Holmes & Vargas, 2002). Professional development programs have typically focused on training teachers in the technical aspects of how to operate specific software and hardware. Various researchers have since argued against this approach. These researchers note that for professional development programs to be more effective, they need to be in the context of new visions for teaching and learning, made possible with digital technology rather than the training of teachers in using specific computer applications (See Brownwell, 1992; Ertmer, Lehman, Park, Cramer, & Grove 2003; Roblyer, Edwards & Havriluk, 2000; Schrum, 1999; Swan, Holmes & Vargas, 2002).

Barron and Goldman (1994) recommend that pre-service and in-service teacher education programs need to provide teachers with the same kinds of technology integrated learning environment that are advocated for their students, rather than an environment where they just learn about technology. Mitchell (2001) designed and investigated such an environment. In her dissertation, she examined how teacher educators might learn to build technology into their teaching practice in ways that will assist student teachers understanding of educational technology in schools. She found that when technology was integrated into the teacher education program, through both their use and study of educational technology, the students were able to see themselves as users and designers of technology use in schools. She found that over the course of the year, the students spoke with confidence and greater authority about the ways in which they would use technology in their schools. They felt prepared to integrate technology as part of their teaching practice in schools. Her study however did not address the classroom contextual factors that affect the integration of technology.

Analysis of my study suggests that *educating teachers in the processes of integrating technology should include professional development programs that emphasize scaffolding about classroom learning issues such as the teacher-student pedagogic relationship, changes to expect in classroom norms and practices as much as the technical knowledge of digital technology*. Perhaps if teachers are aware that there exists a contract that has to be successfully renegotiated for effective technology integration, there will be more successes with the integration of digital technology. Teachers need to be empowered to be able to discuss these contract changes with students and help students change their own images of how classrooms operate and the respective roles therein.

Researchers have found that expert users of technology in education view the technology as a means rather than an end to learning (Garner & Gillingham, 1996; Meskill, Mossop, DiAngelo & Pasquale, 2002). This was certainly the case with Alex, Bob and Peter who used only the software that they felt extended students' learning. To the extent that they found the technology useful in meeting their curricular goals, they used it, and whenever they did not perceive any added benefits from the technology, they did not use it. Hence, *a view of digital technology as a means rather than an end to learning needs to be emphasized in the design of professional development programs.*

Suggestions for Further Research

Two issues that are worthy of further research emerged from this study. First, the findings of this study highlight the limitations of studies with a narrow view of the implementation of digital technology in classrooms. In the case of the three teachers, even though the introduction of digital technology was entirely dependent on the teacher, the teaching and learning practices were constructed as a result of teacher-student interactions and the renegotiation of the pedagogic contract. Such findings suggest that research on the implementation of digital technology needs to provide a better understanding and a fuller picture of the influence of classroom social practices on the use of digital technology.

Second, although it was not the intention of this study to examine the teacher-student relationship from students' perspectives, it became apparent that students' perceptions and expectations of the teacher-student relationship is very critical in understanding the changing dynamics of classroom norms and practices, and thus the teacher-student relationship. Where the present study has analysed the teachers' perspectives, the students' perspectives of the teacher-student relationship in digitally enhanced classrooms is worthy of further research attention. Future research would produce informative case studies that include the perspectives of both the teachers and the students.

Final comments

This study contributes to the growing number of studies that explore the effects of digital technology on various aspects of classroom teaching and learning. In particular, this research examined the effects of digital technology on the teacher-student pedagogic relationship. In this study, I have shown that when digital technology is introduced into classroom practices, it has a potentially profound effect on the teacher-student pedagogic relationships, such that a renegotiation is required. This renegotiation of relationships is a major factor in determining if and how teachers integrate emerging digital technologies into their classroom teaching and learning practices. Finally, this study makes a case that the pedagogic contract is a powerful conceptual tool in understanding teacher-student pedagogic relationships.

REFERENCES

Akpan, J. P., & Andre, T. (1999). The effect of a prior dissection simulation on middle school's student's dissection performance and understanding of the anatomy and morphology of the frog. *Journal of Science Education and Technology, 8*(2), 107-121.

Altheide, D. L., & Johnson, J. M. (1994). Criteria for assessing interpretive validity in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 485-489). Thousand Oaks, CA: Sage Publications.

Ardac, D., & Sezen, A. H. (2002). Effectiveness of computer-based chemistry instruction in enhancing the learning of content and variable control under guided versus unguided conditions. *Journal of Science Education and Technology, 11*(1), 39-48.

Aspy, D. N. (1986). *This is school! : sit down and listen!* Massachusetts: Human Resource Development Press.

Baker, E. L., Herman, J. L., & Gearhart, M. (1996). Does technology work in schools? Why evaluation cannot tell the full story. In C. Fisher, Dwyer, D. C. & Yocam, K., (Ed.), *Education & Technology: Reflections on computing in classrooms,* (pp. 185-202). San Francisco, CA: Jossey-Bass.

Barnea, N., & Dori, Y. (1999). High school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *Journal of Science Education and Technology, 8*(4), 257-271.

Barron, L. C., & Goldman, E. S. (1994). Integrating technology with teacher preparation. In B. Means (Ed.), *Technology and education reform: The reality behind the promise* (pp. 81-110). San Francisco, CA: Jossey-Bass.

Barton, R. (1997). Does data logging change the nature of children's thinking in experimental work in science? In B. Somekh & N. Davis (Eds.), *Using information technology effectively in teaching and learning.* London: Routledge.

Becker, H. J. (2000). Findings from the teaching, learning, and computing survey: Is Larry Cuban right? [Electronic version]. *Education Policy Analysis Archives, 8*(51), 1-31.

Beichner, R. J. (1994). Multimedia editing to promote science learning. *Journal of Computers in Mathematics and Science Teaching, 13*(2), 147-162.

Black, A. (1993). The juristic origins of social contract theory. *History of Political Thought, XIV*(1), 57-67.

Blumenfeld, P. C., & Meece, J. L. (2001). Life in the classrooms revisited. *Theory into Practice, 24*(1), 50-56.

Bork, A. (2003). Interactive learning: Twenty years later. *Contemporary Issues in Technology and Teacher Education, 2*(4), Retrieved September 20, 2003, from http://www.citejournal.org/vol2002/iss2004/seminal/article2002.cfm.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience and school.* Washington, D.C: National Research Council.

Brassell, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching, 24*, 343-367.

Breuleux, A., Laferriere, T., & Bracewell, R. (1998). *Networked learning communities in teacher educatio.*: Retrieved February 16, 2003, from http://www.coe.uh.edu/insite/elec_pub/HTML1998/ts_breu.htm.

Briano, R., & Midoro, V. (1998). Teaching environmental science via cooperative production of a hypermedia. *Journal of Computers in Mathematics and Science Teaching, 17*(2/3), 223-237.

Briscoe, C. (1991). The dynamic interactions among beliefs, role metaphors and teaching practices: A Case Study of teacher change. *Science Education, 75*(2), 185-199.

British Columbia Teachers Federation. (1986). *Task force on microtechnology in the schools.*Unpublished manuscript, Vancouver, B.C, Canada.

Brophy, J. (1996). Enhancing students' socialization: Key elements. *ERIC Digest*(ED 395713), Retrieved September 20, 2003 from http://www.ericfacility.net/databases/ERIC_Digests/ed395713.html.

Brophy, J., & Good, T. (1974). *Teacher-Student relationships: Causes and consequences.* New York: Holt, Rinehart & Winston.

Brousseau, G. (1984). The crucial role of the didactical contract in the analysis and construction of situations in teaching and learning mathematics. In H. G. Steiner (Ed.), *Theory of mathematics education.* Bielefeld, Germany: University of Bielefeld Institut fur Didaktik der Mathematik.

Brousseau, G. (1997). *Theory of didactical situations in mathematics.* Dordrecht: Kluwer Academic Publishers.

Brownwell, G. (1992). *Computers and teaching* (2nd ed.). New York: West Publishing Company.

Brush, T., & Saye, J. (2002). *A summary of research exploring hard and soft scaffolding for teachers and students using a multimedia supported learning environment.* Paper presented at the annual meeting of the American Educational Research Association (AERA), New Orleans.

Buchmann, M. (1990). Beyond the lonely, choosing will: Professional development in teacher thinking. *Teachers College Record, 91*(4), 481-508.

Buck, G. (2001). Factors affecting the adoption and use of instructional devices. In B. Barrell (Ed.), *Technology teaching and learning* (pp. 61-82). Calgary, AB, Canada: Detselig Enterprises.

Burbules, N. C., & Callister, T. A. (2000). *Watch IT: The risks and promises of Information Technologies for education*. Boulder, CO: Westview Press.

Cadiero-Kaplan, K. (1999). Integrating technology: Issues for traditional and constructivist pedagogies. *Journal of Computing in Teacher Education, 15*(2), 14-18.

Canadian Education Statistics Council. (2003). *Education indicators in Canada*. Available: http://www.cesc-csce.ca/pceip/PCEIP2003-C.pdf [2004, May 30].

Cazden, C. (2001). *Classroom discourse: The language of teaching and learning*. Portsmouth: Heinemann.

Charp, S. (1998). The changing teacher/student relationship. *Technological Horizons in Education*, Retrieved June 28, 2003, from http://www.thejournal.com/magazine/vault/articleprintversioncfm?aid=1978.

Clandinin, D. J., & Connelly, F. M. (1996). Teachers' professional knowledge landscapes: Teacher stories-Stories of teachers-School stories-Stories of schools. *Educational Researcher, 25*(3), 24-30.

Clarke, A. (2001). The landscape of teacher education: Critical points and possible conjectures. *Teaching and Teacher Education, 17*(5), 599-611.

Clarke, A., & Erickson, G. (2003). Teacher Inquiry: A defining feature of professional practice. In A. Clarke & G. Erickson (Eds.), *Teacher Inquiry: Living the research in everyday practice*. New York: RoutledgeFalmer.

Cobb, P., Yackel, E., & Wood, T. (1992). A constructivist alternative to the representational view of mind. *Journal of Research in Mathematics Education, 23*(2-33).

Coburn, C. E. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. *Educational Researcher, 32*(6), 3-12.

Cohen, D. K. (1988). Educational technology and school organization. In R. Nikerson & P. Zodhiates (Eds.), *Technology in education: Looking toward 2020* (pp. 231-264). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cuban, L. (1993). Computers meet classroom: Classroom wins. *Teachers College Record, 95*(2), 185-209.

Cuban, L. (1999). High-tech schools, Low-tech teaching. *Education Digest, 64*(5), 53-55.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Havard University Press.

Cuban, L., & Kirkpatrick, H. (1998). Computers make kids smarter-Right? *Technos, 7*(2), 26-31.

da Silva, B., Manrique, A., Bianchini, B., Dubus, G., & de Souza, V. (2002). *Analyzing functions' behaviour in a computational environment.* Paper presented at the 2nd International Conference on the Teaching of Mathematics, University of Crete, Greece. Retrieved January 10, 2003 from http://www.math.uoc.gr/~ictm2/Proceedings/ICTM2_Presentations_by_Theme.html.

D'Agostino, F. (1996). *Contemporary approaches to the social contract.* Standard Encyclopedia of Philosophy. Retrieved May 20, 2003, from http://www.science.uva.nl/~seop/entries/contractarianism-contemporary.

Darling-Hammond, L., & Berry, B. (1998). Investing in teaching. *Education Week on the Web*, Retrieved June 28, 2002, from http://www.edweek.org/ew/vol-2017/2037darlin.h2017.

Datnow, A., & Castellano, M. (2000). Teachers' responses to success for all: How beliefs, experiences and adaptations shape implementation. *American Educational Research Journal, 37*(3), 775-779.

David, J. L. (1994). Realizing the promise of technology: A policy perspective. In B. Means (Ed.), *Technology and education reform* (pp. 169-189). San Francisco: Jossey-Bass.

Dede, C. (2000). Emerging influences of information technology on school curriculum. *Journal of Curriculum Studies, 32*(2), 281-303.

Denzin, N. K. (1989). *The research act: A theoretical introduction to sociological methods* (3rd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Denzin, N. K., & Lincoln, Y. S. (1994). *Handbook of qualitative research.* Thousand Oaks: Sage Publications.

Denzin, N. K., & Lincoln, Y. S. (2000). Introduction: The discipline and practice of qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Dobuzinskis, L. (2000). Serge Kolm on Social Justice and the Social Contract: A contextual analysis and a critique. *The European Legacy, 5*(5), 687-702.

Duffy, M. (1995). Sensemaking: A Collaborative inquiry approach to "doing" learning. *The Qualitative Report*, Retrieved June 28, 2003, from http://www.nova.edu/ssss/QR/QR2002-2002/duffy.html.

Duhaney, D. C., & Zemel, P. C. (2000). Technology and the educational process: Transforming classroom activities. *International Journal of Instructional Media, 27*(1), 67-71.

Dwyer, D. (1994). Apple classrooms of tomorrow: What we've learned. *Educational Leadership, 51*(7), 4-11.

Dwyer, D., Ringstaff, C., & Sandholtz, J. H. (1990). *Teacher beliefs and practices part I: Patterns of change - The evolution of teacher's instructional beliefs and practices in high-access-to technology classrooms* (8). Cupertino, CA.: Apple Classrooms of

Tomorrow Research Report Apple Computer, Inc. Retrieved January 20, 2004, from http://www.apple.com/education/k12/leadership/acot/library.html.

Dwyer, D. C. (1996). The imperative to change our schools. In C. Fisher, & Yocam, K., (Ed.), *Education and technology: Reflections on computing in classrooms* (pp. 15-34). San Francisco: Jossey-Bass.

Edelson, D., & Lento, E. (1996). *Teachers as seekers of understanding: Technological support for a partnership between teachers and students.* Paper presented at the annual meeting of the American Educational Research Association (AERA), New York.

Edelson, D., Pea, R., & Gomez, L. (1996). Constructivism in the collaboratory. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design*. Engelwood Cliffs, NJ: Educational Technology Publications.

Eichorn, D. (1997). *A study of the application of the TESSI model in Biology 12.* Unpublished master's thesis, University of British Columbia, Vancouver, Canada.

Eisner, E. W., & Peshkin, A. (Eds.). (1990). *Qualitative inquiry in education: The continuing debate*. New York: Teachers College Press.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (Vol. 3, pp. 119-161). New York: Macmillan.

Erickson, G., & MacKinnon, A. M. (1991). Seeing classrooms in new ways: On becoming a science teacher. In D. Schon (Ed.), *The reflective turn*. New York, NY: Teacher's College.

Ertmer, P. A., Lehman, J., Park, S. H., Cramer, J., & Grove, K. (2003). *Barriers to teachers' adoption and use of technology -supported learner-centred pedagogies.* Paper presented at the 14th Annual Conference of The Society for Information Technology and Teacher Education (SITE), Albuquerque, NM. Retrieved on January 20, 2004 from http://www.edci.purdue.edu/ertmer/docs/SITE03-TKB-paper.pdf.

Farenholtz, A. (1999). *The quest for the most effective technology-based instructional model: The operational definition of technology enhanced instruction.* Unpublished master's thesis, University of British Columbia, Vancouver, Canada.

Featherstone, H. (1993). Learning from the first years of classroom teaching: The journey in, the journey out. *Teachers College Record, 95*(1), 93-112.

Finarelli, M. G. (1998). GLOBE: A worldwide environmental science and education partnership. *Journal of Science Education and Technology, 7*(1), 77-84.

Firestone, W. A. (1993). Alternative arguments for generalizing from data as applied to qualitative research. *Educational Researcher, 22*(4), 16-23.

Fisher, B. (1997). Computer modelling for thinking about and controlling variables. *School Science Review, 79*(287), 87-90.

Fisher, C., Dwyer, D., & Yocam, K. (1996). *Education and technology: Reflections on computing in classrooms*. San Francisco, CA: Jossey-Bass.

Flick, L., & Bell, R. (2000). Preparing tomorrow's science teachers to use technology: Guidelines for science educators. *Contemporary Issues in Technology and Teacher Education, 1*(1), 39-60.

Fulghum, R. (Ed.). (1989). *All I really need to know I learned in kindergarten*. New York: Villard Books.

Fullan, M., & Hargreaves, A. (1992). *Teacher development and educational change*. New York: Falmer Press.

Garner, R., & Gillingham, M. (1996). *Internet communication in six classrooms: Conversations across time, space, and culture*. Mahwah, NJ: Lawrence Erlbaum Associates.

Geertz, C. (1973). *The interpretation of cultures*. New York: Basic Books.

Geiselhart, K. (2001). Teaching technology to share. *Ultibase*, Retrieved May 28, 2001, from http://ultibase.rmit.edu.au/Articles/may2001/geiselhart2001.htm.

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine Publications.

Good, R., & Berger, C. (1998). The computer as a powerful tool for understanding science. In J. Mintzes & J. H. Wandersee & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view*. New York: Academic Press.

Goode, F. (2000). *A phenomenological study of the influence of the pedagogic relationship between a beginning teacher and her students on the teacher's development of practical teaching knowledge*. Unpublished doctoral dissertation, Texas Technology University, Lubbock, Texas.

Gordin, D. N., Polman, J. L., & Pea, R. D. (1994). The climate visualizer: Sense-making through scientific visualization. *Journal of Science Education and Technology, 3*, 203-226.

Greenberg, R., Raphael, J., Keller, J. L., & Tobias, S. (1998). Teaching high school science using image processing: A case study of implementation of computer technology. *Journal of Research in Science Teaching, 35*(3), 297-327.

Guba, E. G., & Lincoln, Y. S. (1981). *Effective evaluation*. San Francisco, CA: Jossey-Bass.

Guba, E. G., & Lincoln, Y. S. (1982). Epistemological and methodological bases of naturalistic inquiry. *Educational Communication and Technology Journal, 30*, 233-252.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 105-117). Thousand Oaks, CA: Sage Publications.

Hammersley, M., & Atkinson, P. (1983). *Ethnography: Principles in practice*. London: Routledge.

Hargreaves, A. (1994). *Changing teachers, changing times: Teachers' work and culture in the postmodern age*. London: Cassell.

Hargreaves, A. (1998). The emotional practice of teaching. *Teaching and Teacher Education, 14*(8), 835-854.

Hargreaves, A., Earl, L. M., Moore, S., & Manning, S. (2001). *Learning to change: Teaching beyond subjects and standards*. San Francisco: Jossey-Bass.

Harrington, H. L. (1993). The essence of technology and the education of teachers. *Journal of Teacher Education, 44*(1), 5-16.

Haughey, M. (2002). *Canadian research on information and communications technologies: A state of the field*. Montreal, Quebec, Canada: Report prepared for 2002 Pan-Canadian Education Research Agenda Symposium "InformationTechnology and Learning". Retrieved January 10, 2003, from http://www.cmec.ca/stats/pcera/RSEvents02/MHaughey_OEN.pdf.

Hershkowitz, R., & Schwarz, B. (1999). The emergent perspective in rich learning environments: Some roles of tools and activities in the construction of sociomathematical norms. *Educational Studies in Mathematics, 39*, 149-166.

Hess, R. D. (1970). *The computer as a socializing agent: Some socio-affective outcomes of CAI*. ERIC Clearing House, No. ED044942.

Hildebrand, G. M. (1999). *Breaking the pedagogic contract: Teachers' and students' voices*. Paper presented at the National Association for Research in Science Teaching (NARST), Boston, MA. Retrieved September 25, 2001 from http://www.educ.sfu.ca/narstsite/conference/hildebrand/hildebrand.html.

Hodas, S. (1993). Technology refusal and the organizational culture of schools. *Education Policy Analysis Archives*, Retrieved January 12, 2004, from http://olam.ed.asu.edu/epaa/v2001n2010.html.

Hodson, D. (1993). Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: Some preliminary findings. *Interchange, 24*(1&2), 41-52.

Hubscher-Younger, T., & Narayanan, N. H. (2003). Authority and convergence in collaborative learning. *Computers and Education, 41*(4), 313-334.

Hutchinson, B. W. (1998). *Innovation in teacher practice: Issues that arise as a teacher introduces technology enhanced instruction*. Unpublished master's thesis, University of British Columbia, Vancouver, Canada.

Jacobsen, M. (2001). *Building different bridges: Technology integration, engaged student learning, and new approaches to professional development*. Paper presented at the

American Educational Research Association (AERA), Seattle, Wa. Retrieved January 20, 2003, from http://www.ucalgary.ca/~dmjacobs/aera/building_bridges.html.

Janesick, V. J. (2000). The choreography of qualitative research design: Minuets, improvisations and crystallization. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Jonassen, D. (1995). Communities of learners with technology: A vision for integrating technology with learning in schools. *Educational Technology, 35*(4), 60-63.

Jonassen, D., Peck, K., & Wilson, B. (1999). *Learning with technology: A constructivist pespective.* Upper Saddle River, NJ: Prentice Hall.

Jonassen, D. H., Howland, J., Moore, J., & Marra, R. M. (2003). *Learning to solve problems with technology: A constructivist perspective* (2nd ed.). Columbus, OH: Merrill/Prentice-Hall.

Jones, G. M., & Carter, D. (1998). Small groups and shared constructions. In J. Mintzes & J. H. Wandersee & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view* (pp. 261-279). New York: Academic Press.

Kaplan, A. (2000). Teacher and student: Designing a democratic relationship. *Journal of Curriculum Studies, 32*(3), 377-402.

Knapp, L. R., & Glenn, A. D. (1996). *Restructuring schools with technology*. Needham Heights, MA: Allyn & Bacon.

Kolm, S. (1996). *Modern theories of justice.* Cambridge, MA: MIT Press.

Kulik, J. A. (1994). Meta-Analytic Studies of Findings on Computer-Based Instruction. In E. L. Baker & H. F. O'Neil (Eds.), *Technology Assessment in Education and training.* Hillsdale, NJ: Lawrence Erlbaum.

Kumar, D. D., & Helgeson, S. L. (1995). Trends in computer applications in science assessment. *Journal of Science Education and Technology, 4*(1), 29-36.

Laferriere, T., Bracewell, R., Breuleux, A., Erickson, G., Lamon, M., & Owston, R. (2001). *Teacher education in the networked classroom.* Paper presented at the annual meeting of the 2001 Pan-Canadian Education Research Agenda, Quebec City, Canada. Retrieved January 20, 2004, from http://www.cmec.ca/stats/pcera/symposium2001/LAFERRIERE.O.EN.pdf.

Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Educational Research Journal, 27*(1), 29-63.

Lawson, A. E. (1995). *Science teaching and the development of thinking*. California: Wardsworth.

Lederman, N. G., & Zeidler, D. L. (1987). Science teachers' conceptions of the nature of science: Do they really influence teaching behaviour? *Science Education, 71*(5), 721-734.

Lewis, E. L., Stern, J. L., & Linn, M. C. (1993). The effect of computer simulations on introductory thermodynamics understanding. *Educational Technology, 33*, 45-58.

Limerick, B., Burgess-Limerick, T., & Grace, M. (1996). The politics of interviewing: Power relations and accepting the gift. *Qualitative Studies in Education, 9*(4), 449-460.

Lincoln, V., & Guba, E. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Linn, M. C., diSessa, A., Pea, R. D., & Songer, N. B. (1994). Can research on science learning and instruction inform standards for science education? *Journal of Science Education and Technology, 3*(1), 7-15.

Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers: Science learning partners*. Mahwah, NJ: Lawrence Erlbaum Associates.

Lynch, M., & Cicchetti, D. (1997). Children's relationships with adults and peers: An examination of elementary and junior high school students. *Journal of School Psychology, 35*(1), 81-100.

Maor, D., & Taylor, P. (1995). Teacher epistemology and scientific inquiry in computerized classroom environments. *Journal of Research in Science Teaching, 32*, 839-854.

Martinez, M. E. (1993). Item formats and mental abilities in biology assessment. *Journal of Computers in Mathematics and Science Teaching, 12*(3/4), 289-301.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1998). New technologies for teacher professional development. *Teaching and Teacher Education, 14*, 33-52.

Mayer-Smith, J. (2003). The Experience and Challenges of teacher leadership in learning technology reform for science education: A tale of TESSI. In J. Wallace & J. Loughran (Eds.), *Leadership and professional development in science education: New possibilities for enhancing teacher learning* (pp. 81-98): Routledge Falmer.

Mayer-Smith, J., Pedretti, E., & Woodrow, J. (1998a). Embracing technology to transform science teaching and learning. *Journal of Staff Development, 19*(1), 26-30.

Mayer-Smith, J., Pedretti, E., & Woodrow, J. (1998b). An examination of how science teachers experiences in a culture of collaboration inform technology implementation. *Journal of Science Education and Technology, 7*(2), 127-134.

Mayer-Smith, J., Pedretti, E., & Woodrow, J. (2000). Closing of the gender gap in technology enriched science education: A case study in secondary science. *Computers and Education, 35*(1).

McGrath, B. (1998). Partners in Learning: Twelve ways technology changes the teacher-student relationship. *T H E Journal, 25*(9), 58-62.

McMillan, J. H., & Schumacher, S. (1993). *Research in education: A conceptual introduction* (3rd ed.). New York: Harper Collins College.

McNeil, S. (1986). *Contradictions of control: School structure and school knowledge.* New York: Routledge.

Means, B. (1994a). Using technology to advance educational goals. In B. Means (Ed.), *Technology and educational reform: The reality behind the promise* (pp. 1-21). San Francisco, Ca: Jossey-Bass.

Means, B. (1994b). The link between technology and authentic learning. *Educational Leadership, 51*(7).

Means, B., Penuel, W., & Padilla, C. (2001). *The connected school: Technology and learning in high school.* San Francisco, CA: Jossey-Bass.

Mercer, N. (1992). Culture, context and the construction of knowledge in the classroom. In P. Light & G. Butterworth (Eds.), *Context and cognition: Ways of learning and knowing* (pp. 28-46). Hillsdale, NJ: Erlbaum.

Mercier, A., Sensevy, G., & Schubauer-Leoni, M. (1999). *How social interactions within a class depend on the teachers' assessment of the pupils various mathematical capabilities: A Case study.* Retrieved January 20, 2003, from http://www.fmd.uni-osnabrueck.de/ebooks/erme/cerme1-proceedings/cerme1-proceedings.htm.

Mergendoller, J. R. (1996). Moving from technological possibility to richer student learning: Revitalized infrastructure and reconstructed pedagogy. *Educational Researcher, 25*(8), 43-46.

Merriam, S. B. (1998). *Qualitative research and case study applications in education.* San Francisco: Jossey-Bass.

Meskill, C., Mossop, J., DiAngelo, S., & Pasquale, R. (2002). Expert and novice teachers talking technology: Precepts, concepts, and misconcepts. *Language Learning Technology, 6*(3), 46-57.

Mitchell, J. (2001). *Computer technology in teacher education: Tool for communication, medium for inquiry, object of critique.* Unpublished doctoral dissertation, University of British Columbia, Vancouver, Canada.

Moje, E. B. (1996). I teach students, not subjects: Teacher-student relationships as contexts for secondary literacy. *Reading Research Quarterly, 31*(2), 172-195.

Mokros, J., & Tinker, R. (1987). The Impact of microcomputer-based labs on children's ability to interpret graphs. *Journal of Research in Science Teaching, 24 (4): 369-383.*

Muller, C., Katz, S. R., & Dance, J. L. (1999). The mismatch of teacher and student expectations: Circumstances and consequences. *Urban Education, 34*(3), 292-337.

Mumtaz, S. (2000). Factors affecting teachers' use of information and communications technology: a review of the literature. *Journal of Information Technology for Teacher Education, 9*(3), 319-340.

Munns, G., McFadden, M., & Koletti, J. (2002). *The messy space: Research into student engagement and the social relations of pedagogy.* Paper presented at the Australian Association for Research in Education (AARE), Brisbane, Australia. Retrieved January 20, 2003, from www.aare.edu.au/02/pap/mun02359.htm.

Nakhleh, M. B. (1994). A review of microcomputer-based labs: How they affected learning. *Journal of Computers in Mathematics & Science teaching, 13*(4), 367-381.

Nakhleh, M. B., & Krajcik, J. S. (1994). Influence of levels of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching, 31*(10), 1077-1096.

Nissenbaum, H., & Walker, D. (1998). Will computers dehumanize education? A grounded approach to values at risk. *Technology in Society, 20*, 237-273.

Noddings, N. (1992). *The challenge to care in schools: An alternative approach to education.* New York: Teachers College Press.

Osbourne, R. J., & Wittrock, M. C. (1983). Learning in science: A generative process. *Science Education, 67*, 489-508.

Owston, R. (2000). *A Meta-evaluation of six case studies of web-based learning.* Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans. Retrieved December 15, 2003, from http://www.edu.yorku.ca:8080/~rowston/aera2000.html.

Oyler, C. (1996). *Making room for students.* New York: Teachers' College Press.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York: Basic Books.

Peck, C., Cuban, L., & Kirkpatrick, H. (2002). Techno-Promoter dreams, student realities. *Phi Delta Kappan, 83*(6), 472-480.

Pedersen, J., & Yerrick, R. (2000). Technology in science teacher education: Survey of current uses and desired knowledge among science educators. *Journal of Science Teacher Education, 11*(2), 131-153.

Pedretti, E., Mayer-Smith, J., & Woodrow, J. (1998). Technology, text and talk: Students' perspectives on teaching and learning in a technology-enhanced secondary science classroom. *Science Education, 82*(5), 569-589.

Pianta, R. C. (1999). *Enhancing relationships between children and teachers.* Washington, DC: American Psychological Association.

Pianta, R. C. (Ed.). (1992). *Beyond the parent: The role of other adults in children's lives.* San Francisco: Jossey-Bass.

Pianta, R. C., Cox, M. J., & National Center for Early Development & Learning (U.S.). (1999). *The transition to kindergarten*. Baltimore: P.H. Brookes Publications.

Pianta, R. C., & Kraft-Sayre, M. (2003). *Successful kindergarten transition: Your guide to connecting children, families and schools*. Baltimore: P.H. Brookes.

Pianta, R. C., & Steinberg, M. (1992). Teacher-child relationships and the process of adjusting to school. In R. C. Pianta (Ed.), *Beyond the parent: The role of other adults in children's lives* (pp. 61-80). San Francisco: Jossey-Bass.

Pianta, R. C., & Walsh, D. J. (1996). *High-risk children in schools: Constructing sustaining relationships*. New York: Routledge.

Pigford, T. (2001). *Improving teacher-student relationships: What's up with that?*: ERIC Clearing House, No. EJ630698.

Provenzo, E., Brett, A., & McCloskey, G. N. (1999). *Computers, curriculum and cultural change: An introduction for teachers*. New Jersey: Lawrence Erlbaum Associates.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning. *Educational Researcher, 29*(1), 4-15.

Raizen, S. (1998). Standards for science education. *Teachers College Record, 100*(1), 66-112.

Ravitz, J., Becker, H. J., & Wong, Y. (2000). *Constructivist compatible beliefs and practices among U.S. teachers*. Retrieved March 13, 2003, from http://www.crito.uci.edu/tlc/findings.html.

Reeves, B., & Nass, C. (1996). *The media equation: How people treat computers, television and new media like real people and places*. Cambridge: Cambridge University Press.

Resnick, L. B., & Resnick, D. P. (Eds.). (1991). *Assessing the thinking curriculum: New tools for educational reform*. Boston: Kluwer.

Roblyer, M. D., Edwards, J., & Havriluk, M. A. (2000). *Integrating educational technology into teaching* (2nd ed.). Columbus, OH: Merrill.

Rogers, L. (1997). New data-logging tools -- New investigations. *School Science Review, 79*, 61-68.

Rosenfeld, M. (1998). A pluralist critique of contractarian proceduralism. *Ratio Juris, 11*(4), 291-319.

Roth, W. M. (1995). Affordances of computers in teacher-student interactions: The case of Interactive Physics. *Journal of Research in Science Teaching, 32*(329-347).

Rouchier, A. (1999). *Recent trends in the theory of didactical situations.* Paper presented at the first conference of the European Society for Research in Mathematics Education, Universitat Osnabruck. Retrieved May 20, 2003, from http://www.fmd.uni-osnabrueck.de/ebooks/erme/cerme1-proceedings/cerme1-proceedings.html.

Salomon, G. (1992). New challenges for educational research: Studying the individual within learning environments. *Scandinavian Journal of Education, 36*(3), 167-182.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. (1992). Teaching in high-tech environments: Classroom management revisited. *Journal of Educational Computing Research, 8*(4), 479-505.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student centered classrooms*. New York: Teachers College Press.

Saye, J. (1997). Technology and educational empowerment: Students' perspectives. *Educational Technology Research and Development, 45*(2), 2-25.

Scardamalia, M., & Bereiter, C. (1996). Engaging students in a knowledge society. *Educational Leadership, 54*(3), 6-10.

Scardamalia, M., & Bereiter, C. (2000). Schools as knowledge building organizations. Retrieved January 11, 2003, from http://csile.oise.utoronto.ca/abstracts/ciar-understanding.html.

Schofield, J. W. (1995). *Computers and classroom culture*. Cambridge, NY: Cambridge University Press.

Schon, D. A. (1991). *The reflective turn*. New York: Teachers College Press.

Schrum, L. (1999). Technology professional development for teachers. *Educational Technology Research and Development, 47*(4), 83-90.

Selwyn, N. (2000). Researching computers and education-glimpses of the wider picture. *Computers and Education, 34*(2), 93-101.

Shaw, D., & PCAST Panel on Educational Technology. (1998). Report to the president on the use of technology to strengthen K-12 Education in the United States: Findings related to research and evaluation. *Journal of Science Education and Technology, 7*(2), 115-126.

Sheingold, K., & Frederiksen, J. (1994). Using technology to support innovative assessment. In B. Means (Ed.), *Technology and education reform*. San Francisco: Jossey-Bass.

Sheingold, K., Hawkins, J., & Char, C. (1990). I'm the thinkist, you're the typist. In O. Boyd-Barret & S. E. (Eds.), *Computers and learning* (pp. 174-185). Workingham, England: Addison-Wesley.

Shepard, L. A. (2001). The role of classroom assessment in teaching and learning. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 1066-1101). Washington, D.C: American Educational Research Association.

Shim, J. S. (1999). *Technology implementation and integration from the experience of TESSI science teachers*. Unpublished master's thesis, University of British Columbia, Vancouver, Canada.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-21.

Sierpinska, A. (1999). The notion of didactic contract. Retrieved July 29, 2003, http://alcor.concordia.ca/~sierp/3.DidCon.pdf.

Sinclaire, C. (1994). *Looking for home: A phenomenological study of home in the classroom*. Albany: State University of New York Press.

Singley, M. K., & Taft, H. L. (1995). Open-ended approaches to science assessment using computers. *Journal of Science Education and Technology, 4*(1), 7-20.

Skinner, D., Bryant, D., Coffman, J., & Campbell, F. (1998). Creating risk and promise: Children's and teachers' co-constructions in the cultural world of kindergarten. *The Elementary School Journal, 98*(4), 297-310.

Somekh, B., & Davies, R. (1991). Towards a pedagogy for information technology. *The Curriculum Journal, 2*(2), 153-170.

Spitulnik, M. W., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1998). Using technology to support students' artifact construction in science. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 363-381). London: Kluwer Academic Publishers.

Stake, R. (2000). Case studies. In N. K. Denzin & Y. Lincoln (Eds.), *Handbook of qualitative research*. Thousand Oaks: Sage Publications.

Stratford, S. J., & Finkel, E. A. (1996). The impact of ScienceWare and foundations on student attitudes towards science and science classes. *Journal of Science Education and Technology, 5*(1), 59-67.

Strudler, N., & Wetzel, K. (1999). Lesson from exemplary colleges of education: Factors affecting technology integration in preservice programs. *Educational Technology Research and Development, 47*(4), 63-81.

Swan, K., Holmes, A., & Vargas, J. (2002). Situated professional development and technology integration: The capital area technology and inquiry in education (CATIE) mentoring program. *Journal of Technology and Teacher Education, 10*(2), 169-190.

Swan, K., & Mitrani, M. (1993). The changing nature of teaching and learning in computer-based classrooms. *Journal of Research on Computing in education, 26*(1), 40-54.

Tapscott, D. (1998). *Growing up digital: The rise of the net generation*. New York: McGraw-Hill.

Thornton, R. K., & Sokoloff, D. R. (1990). Learning motion concepts using real time microcomputer-based laboratory tools. *American Journal of Physics, 58*(858-867).

Tiene, D., & Luft, P. (2001). Teaching in a technology-rich classroom. *Educational Technology, 41*(4), 23-31.

Tobin, K., Kahle, J. B., & Fraser, B. J. (1990). *Windows into science classrooms: Problems associated with higher-level cognitive learning.* London: Falmer Press.

Too, Y. L. (2000). *The pedagogical contract: the economies of teaching and learning in the ancient world.* Ann Arbor, MI: University of Michigan Press.

Turkle, S. (1984). *The second self: Computers and the human spirit.* New York: Simon and Schuster.

van Manen, M. (1986). *The tone of teaching.* Richmond Hill, Ont: Scholastic.

van Manen, M. (1991). *The tact of teaching: The meaning of pedagogic thoughtfulness.* Albany, New York: State University of New York Press.

van Manen, M. (1994). Pedagogy, virtue, and narrative identity in teaching. *Curriculum Inquiry, 24*(2), 135-170.

van Manen, M. (2002). *The tone of teaching: The language of pedagogy* (2nd ed.). London, Ont: Althouse Press.

Wallat, C., & Green, J. (1979). Social rules and communicative contexts in kindergarten. *Theory into Practice, 18*(4), 275-284.

Watson, G., Shepard, J., & Stephens, C. (1999). Fairness and ideology. *Business and Society, 38*(1), 83-108.

Weller, H. (1996). Assessing the impact of computer-based learning in science. *Journal of Research on Computing in Education, 28*(4), 461-485.

Wellington, J. (2000). Using ICT in teaching and learning science, *Teaching and Learning Secondary Science* (1st ed.). New York: Routledge.

White, R. T. (1988). *Learning Science*. Oxford: Blackwell.

Wiesenmayer, R. L., & Koul, R. (1998). Integrating Internet resources into the science classroom: Teachers' Perspectives. *Journal of Science Education and Technology, 7*(3), 271-277.

Williamson, V., & Abraham, M. (1995). The effects of computer animation on the particulate mental models of college chemistry students. *Journal of Research in Science Teaching, 32*(521-534).

Wilson, S. (1976). You can talk to teachers: Student-teacher relations in an alternative high school. *Teachers College Record, 78*(1), 77-100.

Wisnudel, M. (1994). Constructing hypermedia artifacts in math and science classrooms. *Journal of Computers in Mathematics and Science Teaching, 13*(1), 5-15.

Woodrow, J. (1998). Technology enhanced instruction: A perspective from experience. *Journal of Technology and Teacher Education, 6*(1), 3-9.

Woodrow, J. (1999). *Technology enhanced secondary science instruction: Seven years of success in core curriculum.* Retrieved April 24, 1999, from http://iccel.wfu.edu/publications/journals/jcel/jcel990305/jwoodrow.htm.

Woodrow, J., Farenholtz, A., & Spann, G. (1998). *Teaching and learning strategies for technology enhanced science classrooms: Teachers' perspectives.* Paper presented at the National Association for Research in Science Teaching (NARST), San Diego, CA.

Woodrow, J., Mayer-Smith, J., & Pedretti, E. (1998). *Self-monitoring: A study of student interactive assessment.* Paper presented at the American Educational Research Association Conference (AERA), San Diego, CA.

Woodrow, J., Mayer-Smith, J. A., & Pedretti, E. G. (1996). The impact of technology enhanced science instruction on pedagogical beliefs and practices. *Journal of Science Education and Technology, 5*(3), 241-252.

Woodrow, J., Mayer-Smith, J. & Pedretti, E. (2000). Assessing technology enhanced instruction: A case study in secondary science. *Journal of Educational Computing Research, 23*(1), 15-39.

Woodrow, J., & Spann, G. (1997). *A Multimedia, professional development program in technology enhanced instruction.* Paper presented at the Conference on Educational Multimedia and Hypermedia(ED-MEDIA), Calgary, AB.

Yerrick, R., & Hoving, T. (1999). Obstacles confronting technology initiatives as seen through the experience of science teachers: A comparative study of science teachers' beliefs, planning, and practice. *Journal of Science Education and Technology, 8*(4), 291-306.

Yin, R. K. (1994). *Case study research: Design and methods.* Thousand Oaks: Sage Publications.

Zhao, Y. (1998). Design for adoption: The development of an integrated Web-based education environment. *Journal of Research on Computing in Education, 30*(3), 307-329.

Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for classroom technology innovations. *Teachers College Record, 104*(3), 482-515.

APPENDIX A: SELECTED PAGES FROM THE CHEMISTRY 12 STUDY GUIDES

ELECTROCHEMISTRY PART 2 –
ELECTROCHEMICAL & ELECTROLYTIC CELLS

Key Question / Objectives: How are electrochemical principles applied in electrochemical and electrolytic cells?

Chemistry Text Reference

- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p. 652–697**
- **Heath Chemistry: Chapter 21 Electrochemistry, p. 633-654**

ELECTROCHEMICAL CELLS

Chemistry Text Reference

- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p. 653-668;**
- **Heath Chemistry: Chapter 21 Electrochemistry, p. 633-634**

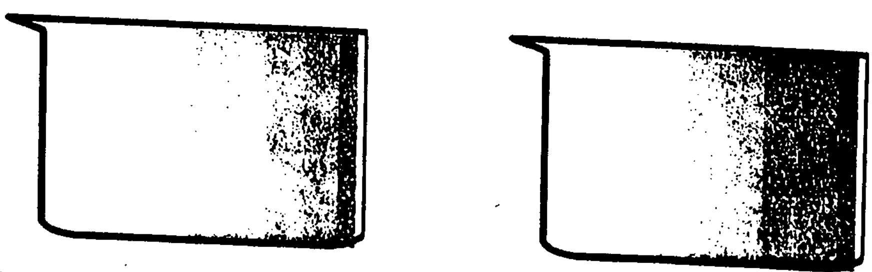
1. Electrochemical cells consist of two spontaneous half reactions.

1. A reduction half-reaction (usually of an ion) at the **CATHODE** that consumes electrons arriving through a circuit at an electrode immersed in the solution. Since electrons flow towards this electrode, the electrode is ___________ charged.
2. An oxidation half-reaction (usually of a metal) at the **ANODE** that produces electrons at an electrode immersed in a solution. This process tends to make the electrode ___________ charged since the electrons are in excess at this electrode.

Teacher Demonstration: Electrochemical Cells (Fruits & Voltaic Cells)
Your teacher may demonstrate more examples of electrochemical cells.

2. Diagramming Electrochemical Cells

Draw a standard electrochemical cell using Zn and Cu half-cells. Indicate electron flow, electrolytes, half reactions, overall reaction, cell voltage, the anode, the cathode, the positive and negative electrode:



2. Reactions and Parts for the Zn Cu Cell (above):

The Zinc Half-Cell: Zn → Zn^{2+} + 2e-

The zinc metal electrode oxidizes into + ions which go into solution and leave 2 electrons behind on the electrode (which decreases in mass since Zn(s) is converted to Zn^{2+}(aq)). Since the electrode tends to accumulate electrons, the electrode becomes NEGATIVE. The electrons will then flow through an external circuit to the other electrode.

The excess positive ions near the electrode draw negative ions that are present in the solution towards this electrode. The negative ions, anions, are said to attract towards the ANODE. It then follows that:

1. the negative electrode is the ANODE.
2. oxidation occurs at the anode.

The Copper Half-Cell: Cu^{2+} + 2e- → Cu

As the electrons flow through the external circuit and accumulate at the copper electrode, the copper ions in solution attract to the Cu electrode and are reduced into elemental copper which attaches to the electrode (and increases the mass of Cu at this electrode). Since this electrode tends to draw electrons to itself from the circuit, the electrode is POSITIVE.

The drop in [+ ion] near this electrode due to the reduction process draws additional +ions , cations, towards this electrode. Since this electrode attracts cations, it is said to be a CATHODE.

The Salt Bridge

When the Zn oxidizes in the zinc half-cell, the [Zn^{2+}] increase. Similarly, as the copper ions reduce into elemental copper, the [Cu^{2+}] decreases. This upsets the equilibrium and produces a drift of (+) ions from the ANODE (Zn half-cell) to the CATHODE (Cu half-cell) through a conducting tube, the salt bridge

3. Cell Notation

We can abbreviate the parts of a cell using cell notation:

anode | anode ion || cathode ion | cathode

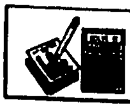
In our example: Zn | Zn^{2+} || Cu^{2+} | Cu

4. Summary:

- REDUCTION occurs at the ___________ and it is ___________ charged.
- OXIDATION occurs at the ___________ and it is ___________ charged.
- Electrons travel in the external circuit towards the ___________.
- ___________ travel towards the cathode and ___________ travel towards the anode.

Note from the Teacher: **Memory Tip for Electrochemical Cells:**

- **Anions to Anode, Anode is Oxidation** (Vowel / Vowel)
- **Cations to Cathode, Cathode is Reduction** (Consonant / Consonant)



Problem Set #1: Voltaic Cells & Batteries

- **Nelson Chemistry: Exercise p. 656 #1-5; p. 660 #9-12, (13); p. 669 #14-21, (22)**
- Worksheet:

STANDARD REDUCTION POTENTIALS

Text Reference

- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p. 669-676**
- **Heath Chemistry:** Chapter 21 Electrochemistry, p. 635-642

1. Half-Cell Potentials

Electrons in electrochemical cells move through external wires from the site of OXIDATION (ANODE, -electrode), to the site of REDUCTION (CATHODE, +electrode).

The strength with which each oxidizing agent in each half-cell attracts electrons and undergoes reduction is its **half-cell reduction potential, E°**. The higher the species lies on the reduction potential table, the greater its attraction or **affinity** for electrons, the greater its reduction potential and the stronger it acts as an oxidizing agent.

If one of the two half-cells in an electrochemical cell is a reference half-cell of known electric reduction potential, then the measured electrochemical cell voltage will allow calculation of the other half-cells' reduction potential. The standard **reference half-cell** is DEFINED by the hydrogen half-cell:

$2H^+ + 2e^- \leftrightarrow H_2$ at 25°C, 1 M [H^{+1}], 1 atm pressure

It has been defined as having a reduction/oxidation potential of **0.00 V**. Thus all other half-cells are defined by comparing to this half-cell.

Sample Problems: Half-Cell Potentials Based on the Standard Reference Half –Cell

Example 1:	An electrochemical cell consisting of a copper half-cell and a hydrogen half-cell has a measured cell potential of 0.34 V. What is the reduction potential for the copper half-cell?V)
Steps	*Solution:*
1. Determine preferred reactants:	The Cu^{2+} in the Cu half-cell is SOA than the H+ in the hydrogen (reference) half-cell. The Cu^{2+} then reduces and the H_2 must oxidize:
2. Write the half equations:	(*Notice that you reverse a reduction half-reaction to form the oxidation half-reaction) Reduction: $Cu^{2+} + 2e^- \rightarrow Cu$ E° = x Oxidation: $H_2 \rightarrow 2H^+ + 2e^-$ E° = 0.00V
3. Write the full reaction and solve for the voltages:	$Cu^{2+} + H_2 \leftrightarrow Cu + 2H^+$ E° = 0.34 V (measured) Then: x + 0.00 = 0.34 x = _______ V Since the measured potential is 0.34V, and the copper half-cell has a higher reduction potential than the hydrogen half cell, then: reduction potential for Cu^{2+} = 0.34V

Example 2:	An electrochemical cell consisting of a zinc half-cell and a hydrogen half-cell has a measured potential of 0.76 V. What is the reduction potential for the zinc half-cell?
Steps	*Solution:*
1. Determine preferred reactants	The H^{+1} is a stronger oxidizing agent than the Zn^{2+}; the H^{+1} then reduces and the Zn must oxidize.
2. Write the half equations:	Reduction: E° = Oxidation: E° =
3. Write full reaction and solve for the voltages	Overall: E° = Then: 0.00 + x = 0.76 V x = 0.76 V
4. CHECK!!	BUT we have written the oxidation half-reaction, hence **this is an oxidation potential.** The reduction half-reaction is the ____________ of the oxidation half-reaction and its reduction potential is the NEGATIVE of the oxidation potential. Therefore: Reduction potential for Zn^{2+} = - 0.76 V

Note from the Teacher: **Reduction Potential and Voltages**

- You can also calculate cell voltage as: $E^\circ_{cell} = E^\circ_{ox} + E^\circ_{red}$
- When switching the reduction to an oxidation from the table, switch the SIGN of the reduction potential.
- Voltages are NOT multiplied. The cell voltage is a measure of (the work done or potential of) how readily electrons move from one half-cell through wires to another half-cell. Multiplying a half-cell equation by a numerical factor to balance electrons does NOT affect the half-cell potential.

2. Electrochemical Cell Potential

The difference in reduction potential between the two half-cells is the ELECTROCHEMICAL CELL POTENTIAL and is measured in volts, V. It is this difference in reduction potentials that drives the electrons towards the half-cell with the greater reduction potential.

Sample Problems: Electrochemical Cell Potentials

Example 1:	What is the voltage when Br_2 reacts with I^{-1}? (Answer: 0.55 V)
Steps	*Solution:*
1. Determine preferred reactants	

2. Write the half equations:	$Br_2 + 2e^- \rightarrow 2\,Br^-$ 1.09 V $2I^{-1} \rightarrow I_2 + 2e^-$ -0.54 V
3. Write the full reaction and ADD the voltages	

Example 2:	Find the cell potential when Cu^{2+}, Cu, Zn and Zn^{2+} are in placed in solution. (Answer: 1.10 V)
Steps	*Solution:*
1. Determine preferred reactants	
2. Write the half equations:	
3. Write full reaction and ADD the voltages	

Example 3:	What voltage would be produced by an electrochemical cell consisting of a silver half-cell and an aluminum half-cell? (Answer: 2.46 V)
Steps	*Solution:*
1. Determine preferred reactants	
2. Write the half equations:	reduction: $Ag^+ + e^- \rightarrow Ag$ $E° = 0.80$ V oxidation: $Al \rightarrow Al^{3+} + 3e^-$ $E° = 1.66$ V
3. Write full reaction and ADD the voltages	Overall:

3. Predicting Spontaneity of Reaction Using Cell Potentials

- Redox reactions with a **POSITIVE cell potential** will processed SPONTANEOUSLY as written.
- A NEGATIVE cell potential means that the REVERSE reaction could proceed or that the forward reaction is NON-SPONTANEOUS.

Sample Problems: Predicting Spontaneity of Reaction Using Cell Potentials Cell Potentials

Write balanced equations and calculate E° for the following reactions. State whether the combination will be spontaneous or non-spontaneous.

Example 1:	Will the <u>salt</u> in seawater (i.e. ignore water) react with an iron pail that it is stored in?
Steps	*Solution:*
1. Determine preferred reactants*	The salt in sea water is mainly Na+(aq), Cl^- (aq). Assume that the iron pail is Fe(s). SOA RA SRA The strongest oxidizing agent (SOA) and strongest reducing agent (SRA) will react.
2. Write the half equations:	$Na^+ + e^- \rightarrow Na$ - 2.71 V $Fe \rightarrow Fe^{2+} + 2e^-$ +0.45 V ------------------------------------
3. Write full reaction and ADD the voltages	
4. State spontaneity:	Since the cell potential is -2.26 V and is NEGATIVE the reaction is ________________. The salt water can be stored in the iron pail since it will not react with the pail.

***Recall:** Determing preferred reactants is based on considering the SOA and SRA out of the possible reactions that can occur.

Example 2:	Can chlorinated water be stored in a galvanized (Zn-coated) container? Prove.
Steps	*Solution:*
1. Determine preferred reactants	Chlorinated water is Cl_2(aq) AND H_2O. The galvanized containter is Zn(s). SOA OA/RA SRA The SOA and SRA will react.
2. Write the half equations:	
3. Write full reaction and ADD the voltages	
4. State spontaneity:	The cell potential is 2.12 V and is POSITIVE, which indicates a spontaneous reaction. Therefore the chlorinated water cannot be stored in a galvanized container.

Example 3:	Show that gold jewellery is resistant reacting with nitric acid ? (Final voltage = -0.54V)
Steps	*Solution:*
1. Determine preferred reactants	
2. Write the half equations:	
3. Write the full reaction and ADD the voltages	

Example 4:	Will $KMnO_4$ and Ca react under neutral aqueous conditions? (Final voltage = 3.47V)
Steps	*Solution:*
1. Determine preferred reactants	
2. Write the half equations:	
3. Write the full reaction and ADD the voltages	

Example 5:	How will $KMnO_4$ (in acid) and H_2S react? (Final voltage = 1.37V)
Steps	*Solution:*
1. Determine preferred reactants	
2. Write the half equations:	

3. Write the full reaction and ADD the voltages	

Problem Set #2: Electrochemical Cell Potentials
- **Nelson Chemistry: Exercise p. 674 #23-28**
- Heath Chemistry: Review & Practice p.642#1-9
- Worksheet:

MBL

Micro-Computer Based Lab (MBL): Establishing a Table of Reduction Potentials: Micro-Voltaic Cells (CWC 28.1)

Science Workshop
Logger-Pro

OPTIONAL Simulation: 8B – Electrochemical Cells [CheMedia]
(Recommended time = 45 min.)

Simulation

Logal Explorer

M

OPTIONAL **Micro-Computer Based Lab (MBL): Pop Can Cell Challenge** *(a.k.a. The McGyver Challenge)*

"You are a top secret agent stuck in a dark mine shaft. In order to get out, you must make yourself a source of electricity. You just happen to realize that you have all the ingredients required to make an electrochemical cell, and an excellent container to put in all in ..."

Science Workshop
Logger-Pro

CORROSION

Text Reference

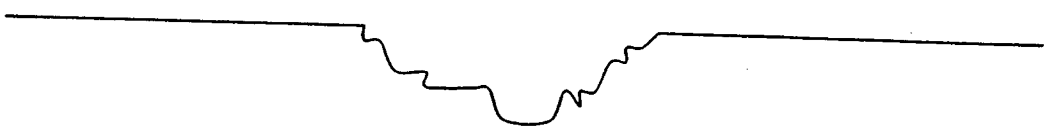
- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p. 676-681**
- Heath Chemistry: Chapter 21 Electrochemistry, p. 653-654

Corrosion is a spontaneous electrochemical process where a metal oxdizes in the presence of an oxidizing agent. The oxidation of a metal is usually unwanted, and the oxidizing agent is usually oxygen gas in water or an ion with a higher reduction potential then the metal's ion.

Group Synthesis / Review: Corrosion
With a partner or group, use the text resources for this section to **summarize the information** to obtain the following learning objectives:

a) Describe the conditions necessary for corrosion to occur:

b) Analyse the process of metal corrosion in electrochemical terms (DRAW a diagram outlining the processes and location of reactions on a section of an iron nail):



Cathode:

Anode:

c) Suggest several (four) methods of preventing or inhibiting corrosion of a metal:

1)

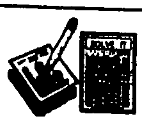
2)

3)

4)

d) Describe and explain the principle of cathodic protection (in detail):

NOTE: For cathodic protection to occur, it's not necessary to cover the entire surface of the metal with a second metal, as in galvanizing iron. All that's required is electrical contact with the second metal. An underground steel pipeline, for example, is protected by connecting it through an insulating wire to a stake of magnesium, which acts as a **sacrificial anode** and corrodes itself instead of iron. For large steel structures such as pipelines, storage tanks, bridges, and ships, cathodic protection is the best defense against premature rusting.



Problem Set #3: Corrosion

- **Nelson Chemistry: Exercise p.680 #29-36**
- **Heath Chemistry: Review & Practice p.654 #5; Interpret & Apply p.656 #10**
- **Worksheet:**

Teacher Demonstration: Corrosion of Iron

Your teacher may demonstrate examples of corrosion.

ELECTROLYSIS AND ELECTROLYTIC CELLS

Chemistry
Text Reference

- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p.681-691**
- **Heath Chemistry: Chapter 21 Electrochemistry, p. 647-653**

1. Similarities and Differences between Electrochemical and Electrolytic Cells
Electrolysis occurs when an external electrical potential (e.g. electrical energy from a battery or power supply) is used to force a non-spontaneous redox reaction to occur. This process occurs in electrolytic cells. A basic electrolytic cell consists of two electrodes, an electrolyte and an external power source. The power source acts an "electron pump" forcing electrons to transfer inside the electrolytic cell.

Electrochemical	**Electrolytic**
• Oxidation occurs at Anode, Reduction at Cathode	• Oxidation occurs at Anode, Reduction at Cathode
• Anode is Negative	• Anode is Positive
• Cathode is Positive	• Cathode is Negative
• Spontaneous	• Non-spontaneous
• Exothermic/ produces energy	• Endothermic / consume energy
• Positive E°	• Negative E°

Note: "Cations move towards the Cathode and Anions move towards the Anode."

2. Three Major Types of Electrolytic Cells:
Despite the different reactivity in each of the major classes of electrolytic cells, the reaction will still occur between the SOA and SRA (OR: between the two half-reactions with the lowest absolute E°).

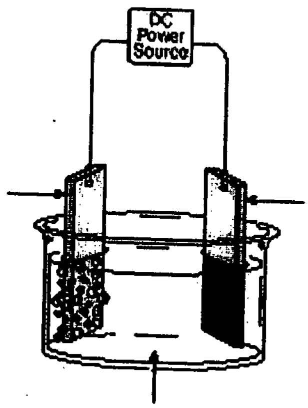
<u>Type 1: Molten (Melted) Binary Salt</u>
- Contains inert electrodes (usually Pt or carbon-graphite)
- Requires high temperatures to melt salts (therefore may be difficult to perform)
- Relatively simple to analyze since only one OA and one RA (from the binary salt)

Example: NaCl (l) (molten!) → $Na^+(l) + Cl^-(l)$
OA RA

Type 2: Aqueous Solution (Dissolved Salt)

- Contains inert electrodes
- **Main difference: H_2O can react as OA OR RA** along with salt. (Therefore H_2O must be included in the analysis of preferred reactants—twice!)
- Examples: **Electrolysis** of H_2O, KI(aq) in Part 1 of Heath Lab 21E, $ZnSO_4$(aq) in Part 2 of Heath Lab 21E.

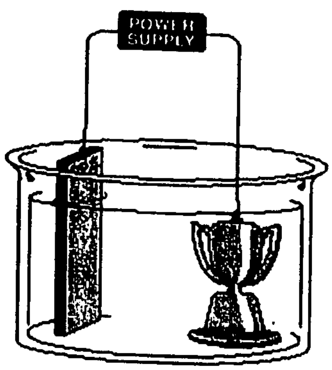
Example:



Type 3: Active Electrodes (Electroplating, Electro-refining and Others)

- Electrodes may also react, therefore everything in the solution and each electrode needs to be considered for potential reactivity
- Examples: **Electroplating,** Part 3 of Heath Lab 21E (Copper sulfate solution is placed in a electrolytic cell. At the anode is solid copper and at the cathode is a metal to be plated.)

Example:



- **Electroplating** is the process of depositing a metal at the cathode of a cell. As a result of this process, one metal is deposited onto the surface of another metal to provide a protective and/or decorative coating. Silver, gold, chromium and zinc are used most often since they are resistant to corrosion or considered to be attractive.

- Examples of electroplating can be found in the silver or gold plating of table utensils or jewellery, chrome plating of car bumpers, and tin plating of a steel can (for foods). In each case, an inexpensive metal object like an iron spoon (see diagram) is used as a cathode and a thin coat of the metal is deposited on its surface to provide a shiny, corrosion resistant finish.

Note from the Teacher: **Battery/Electrochemical Cell Symbols**

- The end with the short line indicates negative end.
- It is easier to consider that the battery or electrochemical cell in an electrolytic cell determines which electrode will be the cathode and anode. The electron comes out of negative end of the battery and determines the cathode.

Extension: **The Overpotential Effect**

Did you know that … in practice, more than the theoretical voltage is required. For water this effect is very profound. Water reactions must be considered to be ranked at the position of the overpotential arrow.

Problem Set #4: Electrolysis & Electrolytic Cells

- **Nelson Chemistry: Exercise p.684 #39-39; p.688 #40-41, (42), 43**
- Heath Chemistry: Review & Practice p.649 #1-3; p.654 #1-4; Interpret & Apply p.656 #9
- Worksheet:

Hands-on Lab

Hands-on Lab: Lab 21E: Electrolytic Cells (adapted from Heath)

- This lab requires 1 hour if have prepared by completing your theory for Electrolytic Cells. You will need to bring something to plate for Part 3.
- Complete 3 FULL PAGE DIAGRAMS illustrating the three different cells you construct in this lab.
  - Part 1: Electrolysis of 1.0 KI
  - Part 2: Electrolysis of 1.0 M $ZnSO_4$
  - Part 3: Copper Plating
- NOTE: Recycle Materials from Part 2 and 3. Assume the carbon electrodes are inert in all of the reactions.

Simulation

OPTIONAL Simulation: 8C – Electrolytic Cells [CheMedia]
(Recommended time = 50 min.)

Logal Explorer

MBL

BONOUS Micro-Computer Based Lab (MBL): Faraday's Law of Electrolysis

In this experiment you will measure the amount of material produced during an electrolysis experiment using ScienceWorkshop file C29 Electroplating. Collect the lab guide from your teacher

Science Workshop

Logger-Pro

Group Synthesis: Electrolysis and Electrolytic Cells

Review your own notes, diagrams & tables to ensure that the minimum required Learning Outcomes (listed below) in the **Electrolytic Cells** sections are met..

1. define **electrolysis and electrolytic cell**
2. **design and label the parts of an electrolytic cell** capable of electrolyzing an aqueous salt (use of overpotential effect not required)
3. predict the direction of flow of all **ions** in the cell
4. write the **half-reaction** occurring at each electrode
5. demonstrate the principles involved in simple **electroplating**
6. **construct an electrolytic cell capable of electroplating** an object
7. describe the electrolytic aspects of **metal refining** processes
8. draw and label the parts of an electrolytic cell used for **electrolysis of a molten binary salt**

ELECTROCHEMICAL CELL APPLICATIONS

Chemistry

Text Reference

- **Nelson Chemistry: Chapter 16 Voltaic and Electrolytic Cells, p. 653-668; 657-661**
- **Heath Chemistry: Chapter 21 Electrochemistry, p. 643-647**

Group Synthesis: Electrochemical Cell Applications

- Make your own notes, diagrams & tables on **Applied Electrochemistry / Batteries / Voltaic Cells.**
- Examples: Make your own notes on the **Leclanche cell, alkaline cell, lead/acid battery and different fuel cells.** For each cell make note of the anode and cathode, electrolyte, and oxidation and reduction half reactions.

ELECTROCHEMISTRY UNIT REVIEW

Problem Set #5: Electrochemistry Unit Review

- **Nelson Chemistry: Chapter 15 Overview Questions, p.648 #1-22, (23,24), 25-28, (Problem 15K, 15L); Chapter 16 Overview, p.694 #1-26, (27-36), 37-38**
-

Interactive Quiz

Interactive Quiz #2: Electrochemistry

Test your understanding on the computer. Take the test **Quiz #2** on **Electrochemistry #2.** Your test will be marked automatically.

LXR Interactive

Evaluation

Evaluation:

1. **Review** your study guide to this point; refer to the "Prescribed Learning Outcomes" in this study guide and your assignments to direct your studies.
2. Do the **LXR Practice Quiz** on Electrochemistry #2
3. Unit Exam: Electrochemistry Test #2

APPENDIX B: SAMPLE PHYSICS 12 UNIT ASSIGNMENT CHECKLIST

Equilibrium 12 Assignment Checklist

Name:__________________________________

Goal:_____

Description	Guide Reference	Done?	Mark
• COMPLETE *ONE OF* THE FOLLOWING: • LAB: Experiment #3 'Equilibrium of Forces' - Physics 12 Lab manual • Computer Simulation: Equilibrium of Forces	Pg. #5		
• Problem Set #1 - Translational Equilibrium Hand Out: Translational Equilibrium 3rd Edition: Pg. 229 - 235 Q: #2, 11, 13 4th Edition: Pg. 249 - 256 Q: #2, 11, 13 5th Edition: Pg. 265 - 273 Q: #5, 14, 16	Pg. #5		
• Interactive Quiz: Quiz #1	Pg. #6		
• *OPTIONAL* ASSIGNMENTS - Corrective Problem Set: 3rd Edition: Pg. 229 Q#9, 12 P#1, 4, 7, 62 4th Edition: Pg. 250 Q#9, 12 P#1, 6, 13, 65 5th Edition: Pg. 265 Q#2, 13, 15 P#1, 5, 12, 13, 66 - Interactive Quiz: Re-Quiz #1	Pg. #6		
• COMPLETE *ONE OF* THE FOLLOWING: • LAB: Experiment #4 'Loaded Beam' - Physics 12 Lab manual • Computer Simulation: Loaded Beam	Pg. #10		
• Problem Set #2 - Rotational Equilibrium 3rd Edition: Pg. 229 Q: #1, 3, 5 Pg. 230 P: #2, 3, 12, 15, 16, 18, 21, 68 4th Edition: Pg. 250 Q: #1, 3, 5 Pg. 251 P: #3, 5, 22, 23, 25, 26, 30, 71 5th Edition: Pg. 266 Q: #4, 6, 8 Pg. 267 P: #3, 6, 11, 25 - 27, 31, 82	Pg. #10		
• Interactive Quiz: Quiz #2	Pg. #11		
• *OPTIONAL* ASSIGNMENTS - Computer Simulation: Sliding Board - Corrective Problem Set: 3rd Edition: Pg. 230 P: #5, 8, 11, 14, 17, 64, 72 4th Edition: Pg. 250 P: #4, 7, 10, 18, 24, 66, 75 5th Edition: Pg. 265 P: #1, 4, 10, 18, 22, 23, 67 - Interactive Quiz: Re-quiz #2	Pg. #12		
• Equilibrium Unit Exam	Pg. #12		
• Equilibrium Study Guide			

APPENDIX C: SAMPLE PHYSICS 12 INDIVIDUAL MASTERY REPORT ON A UNIT EXAMINATION

Date: Thu,
Test Name: Circular Motion Unit Exam
Instructor.
Score: 44 of 53 (83%)
Student:

Mastery [Individual]
Test Date: Mon,

School/Class: Physics 12 AP

Page: 2

# of Objectives: 4

	# of Items	Maximum Score	Mastery % Req	Points Received	% Received	Mastery
Centripetal Force	6	16	80	11	69	Ø
Centripetal Acceleration	6	6	80	6	100	●
Universal Law of Gravitation	6	19	75	17	89	●
Gravitational Potential Energy	4	12	75	10	83	●
OVERALL	22	53		44	83	3

Key: ● Mastery Achieved Ø Partial Mastery Achieved O None correct

APPENDIX D: SAMPLE PHYSICS 12 WHOLE CLASS OBJECTIVES SUMMARY ON A UNIT EXAM

Objective [Summary]

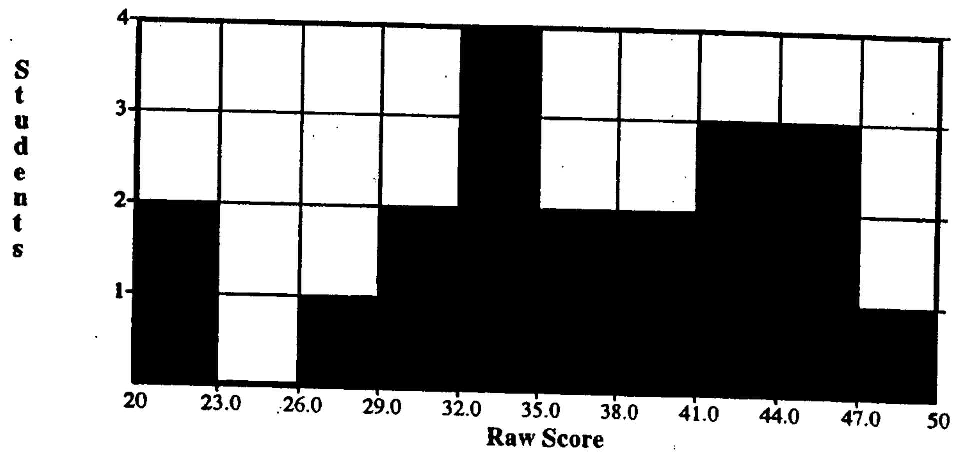
Date: Thu, Jun 3,
Test Name: Circular Motion Unit Exam
Test Date: Mon,
School/Class: Physics 12 AP
Instructor:

# of Examinees: 20
# of Objectives: 4

	Maximum Score	Average Score	% Average Raw Score	Highest Score	Lowest Score
Centripetal Force	16	11	66	16	4
Centripetal Acceleration	6	5	83	6	2
Universal Law of Gravitation	19	15	79	19	9
Gravitational Potential Energy	12	6	53	11	0
OVERALL	53	37	70	50	20

APPENDIX E: SAMPLE PHYSICS 12 WHOLE CLASS STATISTICS SUMMARY ON A UNIT EXAM

Thu, . Statistics [Test] Page: 1



Test Name:Circular Motion Unit Exam		
Test Date:	Mon, .	
Number of Students:	20	
Number of Items:	22	
Maximum Point Value:	53	
Highest Score:	50	(94.3 %)
Lowest Score:	20	(37.7 %)
Median:	37	(69.8 %)
Mean:	36.900	(69.6 %)
Standard Deviation:	8.006	
Test Reliability:	0.674	
Standard Error of Measurement:	4.571	