PAPER FOLIO ONE: CONSTRUCTIVISM DEFINED AND IMPLICATIONS FOR THE CLASSROOM

PAPER FOLIO TWO: CONSTRUCTIVISM IN MATHEMATICS EDUCATION AS EXEMPLIFIED BY THE NCTM STANDARDS

PAPER FOLIO THREE: PROBLEM-SOLVING IN TECHNOLOGY EDUCATION AS A MODEL OF CONSTRUCTIVISM

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Paper Folio One:	Constructivism Defined and Implications for the Classroom
Paper Folio Two:	Constructivism in Mathematics Education as Exemplified by the NCTM Standards
Paper Folio Three:	Problem-Solving in Technology Education as a Model of Constructivism

by

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A Paper Folio submitted to the School of Graduate Studies
in partial fulfillment of the requirements for the
Degree of Master of Education

Faculty of Education
Memorial University of Newfoundland

August 1997

St. John's Newfoundland

ABSTRACT

Paper Folio One: Constructivism Defined and Implications for the Classroom

Paper folio one deals with the notions of constructivism as a theory of teaching and learning in education. The focus for the paper was to establish an historical perspective on the theory of constructivism, and several prominent constructivist authors are highlighted in that regard. Constructivism was a radical shift away from the older theories of behaviorism and positivism, and this shift was also explored. As well, constructivism was defined, and the implications that a theory such as constructivism has had and will have on practice are discussed. The implications that constructivism has on the classroom, including the teacher, student, and curriculum are explained. Also, as with any theory of education, their exists some criticisms of constructivism, which have to be considered as legitimate in light of the relative importance such a theory has been getting in the research literature over the past number of years. These criticisms have put added responsibility on our education system. Throughout the discussion of constructivism in this paper, a major focus will be to look at what this means for a classroom filled with children and a teacher, for the real significance of any theory lies in how it gets lived out in practice.

ABSTRACT

Paper Folio Two: Constructivism in Mathematics Education as Exemplified by the NCTM Standards

Paper folio two deals with the notions of constructivism as they apply to mathematics education. A brief history of the mathematical reform movements is given, culminating with the most recent Standards movement. Constructivism has emerged as the underlying theoretical basis of the Standards documents. The theory of constructivism from a mathematical perspective will be explored, but more importantly the implications that such a theory will have on the mathematics classroom will be highlighted. The impact of the standards have been dramatic, in particular on teacher education programs and research endeavours in the field of mathematics education. These impacts will be explored in this paper. Throughout the paper, the argument will be brought forward that amidst this ever-changing society we live in, mathematics education needs to be reformed, and the theory of constructivism can form the basis of that reform. The National Council of Teachers of Mathematics (NCTM) have recognized that need for reform and are well on the way to making it a reality in our mathematics education community.

ABSTRACT

Paper Folio Three: Problem-Solving in Technology Education as a Model of Constructivism

Probably the most dynamic field with our education system today is technology education. This is partly a reflection of the society we live in today, and partly because the field as it exists today is relatively new. The field does have a great deal to offer us, however, in our constant quest to improve the quality of education in our society. Paper folio three looks at technology education as a model for other reform efforts. The key ingredient in all these reform efforts is constructivism. The technology education field will be explored in general terms, but more specifically notions such as technological literacy, technological integration, technological standards, curriculum focus for technology education, and technology's support for reform efforts will be discussed. As well, the problem solving approaches used in technology education will form the basis of our discussion providing the link to constructivism. Constructivists practices, while not preached within the technology education field, certainly exist there, and the technological problem solving approaches are an example of those practices. While few would disagree that technology will play an important role in the future of our education system, the discipline of technology education itself has an uncertain future. The future of technology education as a distinct discipline lies in its ability to establish a strong theoretical basis for its practices. Constructivism could be that basis.

ACKNOWLEDGEMENTS

Completion of this paper folio would not have been possible without the guidance and support of a number of people. Dr. George Hache, who acted as my supervisor, was very helpful in directing me towards sources of information and in the final editing and preparation of this paper folio. I am deeply indebted to Dr. Hache for his advice and assistance. His help, both online and offline, was very important, and his encouragements were timely as I proceeded through the researching and writing of this paper folio. Also, to Dr. Walter Ryan, who first turned me on to constructivism, when he introduced a graduate course with the topic. I want to also acknowledge my family, whose continuous support over these past four years have helped me reach this stage in my graduate work. Their summer vacations have been put on hold for four years because of my commitments to summer school classes and the researching and writing of this paper folio. Lastly, I acknowledge the support and assistance of my employer, Churchill Falls Labrador Corporation (CFLCo), whose financial support has helped me complete courses toward the achievement of this graduate degree.

TABLE OF CONTENTS

Page

ABSTRACTS

PAPER FOLIO ONE ii

PAPER FOLIO TWO iii

PAPER FOLIO THREE iv

ACKNOWLEDGEMENTS v

LIST OF FIGURES viii

CHAPTER

1 FOLIO ONE: CONSTRUCTIVISM DEFINED AND IMPLICATIONS FOR THE CLASSROOM 1

INTRODUCTION 2

HISTORICAL PERSPECTIVE ON CONSTRUCTIVISM 3

THEORIES OF EDUCATION: SHIFTING PARADIGMS 11

A CONSTRUCTIVIST PERSPECTIVE 17

IMPLICATIONS FOR THE CLASSROOM 21

RESPONDING TO CRITICISMS OF CONSTRUCTIVISM 24

DISCUSSION 28

CONCLUSION 30

2 FOLIO TWO: CONSTRUCTIVISM IN MATHEMATICS EDUCATION AS EXEMPLIFIED BY THE NCTM STANDARDS 31
INTRODUCTION 32
MATHEMATICAL REFORM 33
CONSTRUCTIVISM: A MATHEMATICAL PERSPECTIVE 37
THE STANDARDS DOCUMENTS 39
IMPLICATIONS FOR TEACHING AND LEARNING 42
TEACHER EDUCATION PROGRAMS 56
FUTURE RESEARCH ISSUES 58
CONCLUSION 59
3 FOLIO THREE: PROBLEM-SOLVING IN TECHNOLOGY EDUCATION AS A MODEL OF CONSTRUCTIVISM 62
INTRODUCTION 63
THE TECHNOLOGY EDUCATION DISCIPLINE 65
A CASE FOR CONSTRUCTIVISM 79
A PROBLEM SOLVING APPROACH 83
CONCLUSION 92
4 SUMMARY AND IMPLICATIONS 94
REFERENCES 98

List of Figures

Page

Figure 1.1: A Theory of Education 12

Figure 2.1: The Investigative Process 41

Figure 2.2: A Constructivist Model of Teacher Change Based on Beliefs and Monitoring by Metacognition 47

Figure 2.3: Problem Centered Learning 49

Figure 2.4: The Teaching Triad 55

Figure 3.1: All Technologies can be Studied Using the Systems Model 85

Figure 3.2: Top-Down Problem Solving Method 88

Figure 3.3: Cyclical Design Model 89

Folio One: Constructivism Defined and Implications for the Classroom

Introduction

The word constructivism dominates the current education literature. Anderson (1996) tells us that it "continues to appear in educational journals, position papers, conference sessions, and professional development workshops across the country" (p. 49). The Southwest Educational Development Laboratory (SEDL) (1996a) tells us that the word "appears in 28 files archived at the US Department of Education's World Wide Web site [and it] summoned 240 journal article abstracts at the ERIC Gopher site - and that was a partial list only" (p. 1). It has assumed a dominance in education (Zevenbergen, 1996) that seems to be unparalleled throughout history. Schulte (1996) adds that "the philosophy of constructivism is a popular topic for graduate school lectures and research articles" (p. 25).

This report will explore the concept of constructivism in an attempt to ascertain the implications such a notion has had and will have on the education that goes on in a typical classroom every day. Firstly, the historical perspective will be explored, and the originators, if we may call them that, will be identified and discussed as to their contributions to the theoretical foundations of constructivism. People such as the Neapolitan philosopher Giambattista Vico, John Dewey, Jean Piaget, Lev S. Vygotsky, and Ernst von Glasersfeld will be a sample of those who have contributed a great deal to this theory. In addition to looking at the historical foundations of this theory, we will also examine how there has been a shift in the theory of education from traditional behaviorism and positivism to constructivism. This constructivist perspective will be defined and the implications that constructivism has for the teaching and learning environments will be explored. As well, some attempt will be made to distinguish between the different forms of constructivism that have emerged as somewhat different from what we may call "true" constructivism.

Constructivism is not without its critics, however, and these will be explained in some detail later in this report. As well, a major focus for this report will be to look at the implications this philosophy has for the classroom, including students, teachers, and the curriculum. Much research literature these days is concentrated in this area. This will be the major focus of this report, for what happens within the classroom is crucial to any educational theory about teaching and learning. Once the theoretical foundations have been set forth, the real significance of constructivism becomes what it means for a classroom filled with children and a teacher. What role does each of these individuals take in order to adopt constructivism as the means for improving education?

Historical Perspective on Constructivism

The roots of constructivism can be traced back at least to the eighteenth century and the work of the Neapolitan philosopher Giambattista Vico (SEDL, 1995a; von Glasersfeld, 1989; Yager, 1995). Vico claimed that humans can only clearly understand what they have themselves constructed. Von Glasersfeld (1989) says that "over and over [Vico] stresses that 'to know' means to know how to make [and] one knows a thing only when one can tell what components it consists of" (p. 123). Hence only God can truly know the real world, whereas the human knower can know only what the human knower has constructed (von Glasersfeld, 1989). This interpretation has put a different connotation on the word knowledge. Wilson (1995) tells us that if we have different assumptions about knowledge, then that can influence our views of instruction itself. We will discuss the implications on the teaching-learning process later in this report. For now, we consider von Glasersfeld's (1989) description:

> For constructivists, therefore, the word knowledge refers to a commodity that is radically different from the objective representation of an observer-independent world which the mainstream of the Western philosophical tradition has been looking for. Instead knowledge refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable (p. 124).

Wheatley (1991) adds that "knowledge originates in the learner's activity performed on objects" (p. 10). He goes on to tell us that contrasted with "a realist's perspective, a constructivist believes that knowledge is not disembodied but is intimately related to the action and experience of a learner - it is always contextual and never separated from the knower" (p. 10). This view of knowledge is much different from our traditional view that knowledge and the knower are two separate entities and the goals of education are to bring both of those entities together as one within the mind of the knower.

Many others have worked with the ideas of Vico, "but the first major contemporaries to develop a clear idea of constructivism as applied to classrooms and childhood development were Jean Piaget and John Dewey" (SEDL, 1995a, p. 1). Phillips (1995) lists John Dewey among six of the major constructivist authors. He quotes Dewey as saying that:

> the true and valid object of knowledge is that which has being prior to and independent of the operations of knowing. They spring from the doctrine that

> knowledge is a grasp or beholding of reality without anything being done to modify its antecedent state - the doctrine which is the source of the separation of knowledge from practical activity. If we see that knowing is not the act of an outside spectator but of a participator inside the natural and social scene, then the true object of knowledge resides in the consequences of directed action. (p. 6)

For Dewey then, education depended on action. Individuals gained knowledge and ideas from situations in which they could find some meaning and importance to them. "These situations had to occur in a social context, such as a classroom, where students joined in manipulating materials and, thus, created a community of learners who built their knowledge together" (SEDL, 1995a, p.1).

Dewey consistently expounded his own constructivist view of knowledge which was in contrast to what others had called the 'spectator theory of knowledge' (Phillips, 1995). An interpretation of Dewey's philosophy on this matter is provided by Phillips (1995) when he says:

> The spectator theory, as Dewey interpreted it, can be explained by means of an analogy with football. According to the spectator theory, the way a knower obtains knowledge is analogous to the way a person can learn about football. He or she can learn by watching, by being a spectator; while learning, the spectator remains passive, and does not affect the course of the game. In contrast, in the theory held by James and Dewey the knower is an organic part of the same situation as the material to be known. To return to the football analogy, the person learning about football would

> be playing in the game; he or she would be affecting the game and, in the process, obtaining knowledge about it - the knower would be learning by participating or acting. (p. 9)

This view of the knower was not intended by Dewey to suggest that the construction of knowledge was an individualistic action. Instead, Dewey stressed the social nature of knowledge construction both in individual learners and with respect to the development of the public bodies of knowledge that make up the various disciplines. The views of Dewey, according to Phillips (1995) would have ramifications for the classroom. He goes on to say that:

> Starting from the constructivist position that the knower is an 'actor' rather than a 'spectator', Dewey staunchly advocated the use of activity methods in the schoolroom - for students are potential knowers, yet traditional schooling forces students into the mold of passive receptacles waiting to have information instilled, instead of allowing them to move about, discuss, experiment, work on communal projects, pursue research outdoors in the field and indoors in the library and laboratory, and so forth. (p. 11)

Jean Piaget has been described as "the most prolific constructivist in our century" (von Glasersfeld, 1989, p. 125). Phillips (1995) tells us that Piaget is "generally regarded as a foundational figure by many constructivists" (p. 6). Piaget based constructivism on the psychological development of the child. He wanted teachers to understand the steps in the development of a child's mind, for this understanding would lead to better interactions with the child within the classroom setting. SEDL (1995a) relates that Piaget considered the fundamental basis of learning to be discovery. They go on to say that, from Piaget's perspective, "to understand is to discover, or reconstruct by rediscovery, and such conditions must be complied with if in the future individuals are to be formed who are capable of production and creativity and not simply repetition" (p. 1).

J. B. Taylor (1996), in her guests' editorial to Childhood Education's annual theme issue, tells us that "Piaget's theory provides the most scientifically accurate and comprehensive explanation of how understanding develops" (p. 258). Understanding is built up step by step through active involvement. Kamii and Ewing (1996) add to the importance of Piaget by offering us reasons why teaching in today's schools should be based on Piaget's constructivism. They go on to offer three main reasons for this, namely:

> 1) it is a scientific theory that explains the nature of human knowledge, 2) it is the only theory in existence that explains children's construction of knowledge from birth to adolescence and 3) it informs educators of how Piaget's distinction among the three kinds of knowledge changes the way we should teach many subjects. (p. 260)

Knowledge for Piaget results from a "collection of conceptual structures that turn out to be adapted or ... viable within the knowing subject's range of experience" (von Glasersfeld, 1989, p. 125). The three kinds of knowledge, referred to in Kamii and Ewing (1996), offer us a modern perspective on how constructivists view knowledge and the attainment of it. There exists physical knowledge, which is knowledge of objects in external reality, such as the color or weight of an object. The second kind of knowledge is social knowledge, which consists of written and spoken language, and other conventions of interacting with each other. The third kind of knowledge is logico-mathematical knowledge, which consists of relationships created by each individual and is the hardest kind to understand. The source of logico-mathematical knowledge is in each child's mind, constructed within to suit a particular situation. This distinction on the three kinds of knowledge has provided us with a more realistic picture of the abstractive nature of knowledge, and it has bridged the gap between traditional views of knowledge and the more modern constructivist views.

Von Glasersfeld (1989) summarizes Piaget's theory of cognition as consisting of two basic concepts, namely assimilation and accommodation. While there are varying interpretations of what these concepts mean, for von Glasersfeld (1989), "the learning theory that emerges from Piaget's work can be summarized by saying that cognitive change and learning take place when a scheme, instead of producing the expected result, leads to perturbation, and perturbation, in turn, leads to accommodation that establishes a new equilibrium" (p. 128). Phillips (1995) adds that Piaget, while individualistic in his approach to how knowledge is constructed, did "place enormous stress on the fact that the young knower is both mentally and physically active; indeed, knowledge growth is described ... in terms of the dynamic processes of assimilation, accommodation, and equilibration, and the construction and internalization of action schemes" (p. 9). The individualistic nature of Piaget and others has become a point of criticism for their theories, and this criticism will be explained more fully later in this paper. One further point, noted by von Glasersfeld (1989), involved the significance of social interaction in the construction of knowledge, which many would argue is missing from Piaget's theory.

This leads us to Vygotsky, whose importance to constructivism has not always been clear to the English-reading public because of political constraints and because of mistranslations from his native Russian. Fischetti, Dittmer, and Kyle (1996) attributed Vygotsky with been "able to demonstrate the complex role sociocultural forces play in the development of thinking and the critical role language plays as the medium for turning 'external speech' into 'internal speech' or thought" (p. 192). They go on to explain how Vygotsky looked at the processes of development in all of their complex wholeness and that children learn concepts out of a tension between their everyday notions and adult concepts. The child must work out his or her own ideas based on prior conceptions and the introduced concepts. In essence, the child constructs his or her own knowledge. Steffe and D'Ambrosio (1995), in reaction to Simon (1995a), tell us that Vygotsky takes the current knowledge of students seriously and gives it a central place in the design of instruction. Phillips (1995) parallels Vygotsky with Piaget as "concerned with how the individual learner goes about the construction of knowledge in his or her own cognitive apparatus" (p. 7). Manus (1996) also puts Vygotsky in the same vein as Piaget by labelling both of them psychological constructivists. She goes on to summarize Vygotsky's views by saying that he "perceived that thought evolved from both the experiences and maturation process of an individual [and that] an individual's consciousness evolved from mediated activities that would then be internalized into higher forms of cognitive functions" (p. 314). So, while some researchers continue to question whether Vygotsky is a constructivist or not, others see his stress on children creating their own concepts as constructivist to the core.

Ernst von Glasersfeld was another of the so-called proponents of constructivism. Phillips (1995) lists him among his constructivist authors as someone who has had a "great influence in the contemporary international science and mathematics education communities" (p. 6). He goes on to tell us that "Ernst von Glasersfeld is not simply putting forward a view about the teaching of mathematics and science; it is clear that he is also advancing an epistemology, a psychology, and his own interpretation of the history of science and philosophy" (p. 7). Von Glasersfeld (1996) describes for us his form of constructivism as "a theory of rational knowing ... [where] we come to know other persons in the same way in which we come to know cups and spoons, water and fire, stairs and bicycles - by learning to live with them in the course of more or less viable interactions" (p. 19). Elsewhere, von Glasersfeld (1989) says:

> we come to realize that 'understanding' is a matter of fit rather than match. Put in the simplest way, to understand what someone has said or written means no less but also no more than to have built up a conceptual structure that, in the given context, appears to be <u>compatible</u> with the structure the speaker had in mind - and this compatibility, as a rule, manifests itself in no other way than that the receiver says and does nothing that contravenes the speaker's expectations. (p. 134)

Von Glasersfeld's constructivism has been described by some as more of a radical type (Kent, 1995; Phillips, 1995). This distinction will be further explained later in this report. Phillips (1995) tells us that von Glasersfeld acknowledges a significant debt to Piaget, but unlike

Piaget who was mainly concerned with the individual construction of knowledge, von Glasersfeld appears to also be concerned with how human communities have constructed the public bodies of knowledge.

This review of some of the more prominent constructivist authors is by no means a complete list. Indeed, an expanded list could easily be generated, and would include such people as Immanuel Kant, Thomas S. Kuhn, Jurgen Habermas, and others (Phillips, 1995). The Open Learning Technology Corporation (OLTC) Limited (1996) has also identified Bruner as a major figure in the constructivist movement. They summarize Bruner's work as saying that "learning is an active process in which learners construct new ideas or concepts based upon their current/past knowledge [and] the learner selects and transforms information, contrasts hypotheses, and makes decisions, relying on a cognitive structure to do so" (p. 1). However, much of Bruner's theory is linked to child development research, especially the work of Piaget. Whomever the theorist, it has become apparent that constructivism has become established as a major focus for education and will have significant impact on the route education takes into the next century.

Theories of Education: Shifting Paradigms

Presently, within the current context of educational reform, there exists a new paradigm about teaching and learning. Roth (1993) tells us that "much of current teaching is still grounded in an epistemology which is referred to as objectivism, positivism, or realism" (p. 113). Educators are rethinking all aspects of schooling and a shift is occurring. Constructivism and the related research on cognitive development form the basis of the new paradigm. These are competing with the old paradigm based on reductionist principles and behavioral theory (Fischetti et al., 1996). Before we explore this shift in paradigms however, let us look more closely at the nature of any theory of education.

Hein (1995) offered us an explanation into theories of education as depicted in Figure 1.1. There are two major components to any educational theory, namely a theory of knowledge and a theory of learning. Knowledge exists either independently of the learner,

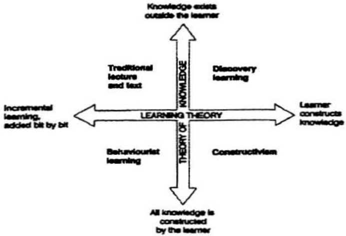

Figure 1.1: A Theory of Education

(Note: Source for Figure 1.1 is Hein, 1995, p. 3) as an absolute, or it consists only of ideas constructed in the mind. With learning, two extreme positions exist as well, namely, that either learning consists of the incremental assimilation of information, facts and experiences, or learning consists of the mind constructing schemas and selecting and organizing from the wealth of sensations that surround us. If we put both these dimensions together, we see the resulting diagram that describes four possible combinations of learning theory and epistemology.

The top left quadrant is labelled the traditional lecture and text paradigm which is predicated on the basis that the teacher understands the knowledge to be taught and presents it appropriately so that the student can learn. There is a logical order of teaching, starting with the simplest elements of a subject and moving to more complex elements, until the entire field is covered. The second educational position, depicted on the top right quadrant of Figure 1.1 is labelled discovery learning. Hein (1995) tells us that "it subscribes to the same positivist belief about knowledge as the previous one, but it takes a dramatically different view about how knowledge is acquired" (p. 2). He goes on to suggest that in order to learn, students need to have experience; they need to do and see rather than to be told. The teacher organizes the subject so that it can be experienced, and through this experience, misconceptions will be replaced by correct conceptions. Constructivism occupies another quadrant on the diagram. From a constructivist perspective, both knowledge and the way it is obtained are dependent on the mind of the learner. Those who support this view have claimed that learners construct knowledge as they learn; they don't simply add new facts to what is already known, but rather reorganize and create their own understanding as they interact with the world. A fourth quadrant in the diagram represents behaviorism, which ascertains that knowledge is gained incrementally but need not have an existence outside the learner.

Fischetti et al. (1996) tell us that "one primary characteristic of a new theory is its explanatory power" (p. 190). They add that "when a new paradigm is able to explain phenomena better than an older one, the new paradigm gradually takes over, and the older one becomes subordinate and eventually recedes into the history books" (p. 190). The older paradigms of positivism and behaviorism are in stark contrast to the new paradigm of constructivism. Only time will tell whether or not the new paradigm will replace the older ones. Meanwhile, the adoption of the new paradigm will have significant implications for the teaching and learning environments, and these will be discussed in more detail later in this paper.

Gruender (1996) relates the objections to behaviorism and positivism from a constructivist perspective. He says that:

> What the constructivist movement dislikes about behaviorism is what they take to be its insistence that the only model for learning in conditioning, together with behaviorism's hostility toward the conception that people have an internal mental life with ideas of their own 'intervening variables', and that it is these ideas which are most important in people's lives. (p. 23)

He goes on to add that conditioning is a factor in learning simple tasks, but there are many other factors that are important as well. Behaviorism does not recognize this fact. The objections to positivism are also strong. However, Gruender (1996) found this to be puzzling, especially in view of the fact that positivism was constructivist to the core. He goes on to say that:

> The early years of positivism saw numerous efforts to design large philosophic systems, the purpose of which was to construct human knowledge of the external world using our immediate perceptual experiences plus the tools of the new logic as the sole resources .... In tandem with behaviorism, this movement found it had restricted itself to a base of resources that proved inadequate to account for human knowledge. (p. 23)

It was clear that positivism failed to explain how knowledge of external objects and events could be established solely from our internal states. This view was too limited, for there were many exceptions to this notion in our everyday existence.

Whenever there are adjustments in our way of thinking about teaching and learning, there are bound to be some obstacles which must be overcome. Wheatley (1992), in his review of a problem-centered learning model in mathematics based on constructivism, tells us that the task of establishing the correct environment is a complex one for the teacher and a huge obstacle to overcome. Fischetti et al. (1996) identified five obstacles that are worth noting in this instance. They included a resistance to change by those who want to retain familiar and comfortable practices. Also, there was the challenge of initiating and supporting the paradigm shift within all related constituencies at the same time. Thirdly, there was the tendency to get so absorbed in a new paradigm that we lose sight of the fact that new theories will challenge and change it in ways we cannot understand today. A fourth obstacle was the widespread failure of educators to recognize the ever-widening gulf that exists between childrens' in school experiences and what happens to them outside of school. The final obstacle concerned the role teachers have in schools today. Unless schools become places where teachers grow and develop, then they will never be able to create the learning conditions needed for students to grow and develop. Edwards (1994) offers us one model of the process of teacher change but warns that a much deeper, more thorough understanding of teacher change is necessary. The process is very complex, and much more research is needed into how it actually comes about. By identifying these as some of the obstacles to a shift in paradigms, we are able to put the paradigm shift into perspective and realize that there is a great deal yet to overcome before constructivism becomes entrenched as the main view on teaching and learning in our educational systems.

Lerman (1989) summarized his view on the shift in paradigms for us by saying that:

> the shift from behaviorism to cognitive psychology focused attention on teaching for understanding, but the problems of how to carry this out, and how to identify that 'it' had happened, remained as ongoing and major ones for mathematics education. It is suggested here that central to the difficulty is our notion of 'understanding', tied as it is to the idea of certain and absolute concepts. According to this view, the process of coming to understand a concept is one that takes place in the mind of the individual, and the final step of achieving that full understanding of a timeless, universal notion is a very private, almost mystical one. It is certainly beyond the

> power of any outsider, such as a teacher, to know that the process has taken place in full. (p. 221)

Thus, the shift to a constructivist paradigm still has its obstacles to overcome. Lerman (1989) continues that it is imperative that we continue with our belief that if we create the right environment, in the classroom, and in our teaching, then learning and understanding will take place. Just what that environment is like will be discussed later in this paper.

A Constructivist Perspective

Now that we have looked at the historical foundations for constructivism and some of the prominent figures in its evolution, as well as the apparent shift in paradigms that is affecting education presently, we will now look at constructivism in more detail. Constructivism will be formally defined, and some of the major principles about the theory will be highlighted. As well, we will look at what this means in general terms for the teaching and learning environments. More specific implications for the classroom will be discussed in a later section of this paper.

Fosnot (1989) tells us that constructivism can be defined by four principles. The first of these is that knowledge consists of past constructions. In other words, we can only know the world through our own logic and this logic is itself constructed and evolved as we interact with our environment. Smith (1995) would place this principle in the realm of the sociocultural and not in the theory of constructivism. Knowledge refers to socially negotiated and accepted forms of understanding whereas knowing seems to capture the more dynamic sense that is common with the constructivist views. Cobb (1995), in reacting to Smith, disagrees with this argument and says that individual knowing and shared knowledge are both critical from the constructivist perspective. The second principle defining constructivism according to Fosnot (1989), is that constructions come about through assimilation and accommodation. These concepts were of course the work of Piaget. Assimilation refers to the logical framework or scheme we use to internalize or organize information. When this scheme is contradicted or found to be insufficient, we accommodate, or develop a higher-level thinking to encompass the information. The third principle says that learning is an organic process of invention, rather than a mechanical process of accumulation. Learning is only partially the accumulation of facts; rather the learner experiences different things and in turn builds new constructions along the way. The teacher does not dispense knowledge and hope that learners acquire it, but instead creates learner-entered, active instructional experiences for the learner. The fourth principle relates that meaningful learning occurs through reflection and the resolution of cognitive conflict, and thus serves to negate earlier, incomplete levels of understanding. Again, the teacher can only serve to mediate this process.

It has become clear that the constructivist perspective is clearly divergent from earlier views on education that presumed we could put or pour information into students' heads. The University of Massachusetts Physics Education Research Group (UMPERG) (1996) summarizes the premises of constructivism, as an epistemology, to be that knowledge is constructed, not transmitted; prior knowledge impacts the learning process; initial understanding is local, not global; and building useful knowledge structures requires effortful and purposeful activity. This suggests that the whole process is a dynamic event. Schulte

(1996) reiterates the importance of prior knowledge when she says that "learners bring their personal experiences into the classroom and these experiences have a tremendous impact on students' views of how the world works" (p. 25). She goes on to add that "students come to learning situations with a variety of knowledge, feelings, and skills, and this is where learning should begin" (p. 25).

Treagust, Duit, and Fraser (1996) agree that what the learner already knows is of central importance. They use this point, however, to separate the different forms of constructivism. While many educators have accepted that prior knowledge is important, the same cannot be said for learners constructing their own representation of the truth. Educators, particularly in science and mathematics, have great difficulty in accepting that each learner can construct their own viable and useful knowledge about the world outside. This form of constructivism has been called by some, especially von Glasersfeld (1989), to be radical constructivism. This term was used to distinguish this form of constructivism from that mainly or only built on prior knowledge. Still other researchers, as Treagust et al. (1996) report, believe that knowledge is not only personally constructed but it is also socially mediated. This suggests that although individuals have to construct their own meaning of a new idea, the process of constructing meaning always is embedded within the social setting that the individual is a part of. This brings forth another form of constructivism, which we may call social constructivism.

Whatever the form of constructivism, it has become apparent that the teacher's role within the classroom will have to be re-examined. Simon (1995b) tells us that "the teacher has the dual role of fostering the development of conceptual knowledge among his or her students and of facilitating the constitution of shared knowledge in the classroom community" (p. 119). Linek, Sampson, Sampson, Mohr, and Botha (1996) agree that "the instructor [has] to become a facilitator of learning rather than the source of knowledge" (p. 402). This role of the teacher as a facilitator of learning is shared by many others (Anderson, 1996; Falk, 1996; Hand, 1996; Nelson & Hammerman, 1996; Prevost, 1993; Yackel, Cobb, Wood & Merkel, 1990). Anderson (1996) goes on to elaborate on the teacher's role by saying that "instead of being the provider of information, you'll be the provider of opportunities for students to gather their own information" (p. 49). Assessment takes on a new approach for the teacher here as well. Now, the teacher uses assessment techniques to try and understand how students are thinking rather than whether or not they understand. Savery and Duffy (1995) summarize the role of teachers for us with their eight instructional principles that can guide the practice of teaching and the design of learning environments. The principles include anchoring all learning activities to a larger task or problem, supporting the learner in developing ownership for the overall problem or task, and designing an authentic task. In addition, the teacher must design the task and the learning environment to reflect the complexity of the environment they should be able to function in at the end of the learning. As well, the learner should be given ownership of the process used to develop a solution, and be continually challenged and supported in the thinking. Lastly, the learner should be encouraged to test their ideas against alternative views and alternative contexts, and be provided with the opportunity for and support of reflection on both the content learned and the learning process itself. This had presented teachers with a most arduous role to play within the classroom, but one which will help lead to the establishment of a constructivist environment and a better learning situation for the children. The next section will look in more detail at the implications constructivism can have on the classroom as a whole, including teachers, but also students and the curriculum as well.

Implications for the Classroom

In order to adopt a constructivist approach within the classroom, a major shift in the assumptions about teaching and learning has to occur. Nelson and Hammerman (1996) tell us that a change can only occur when we change our beliefs about the nature of learning. Some of those beliefs include perceiving students as empty vessels waiting to be filled, that students learn by being told what to do and how to do it, that the subject consists of a series of isolated facts and topics which should be taught in a certain order, that instruction should follow the textbook, and that students' confusion should be relieved by the teacher. These and other beliefs can be seen as hindrances to a changing philosophy for how we look at teaching and learning.

Hand (1996) relates that in order to get past these traditional beliefs, teachers must develop different knowledge bases to work from. He goes on to describe a five-stage model of in-service education for implementing this change, which included identification of the teacher's knowledge of classroom practice, students' knowledge of the subject, developing of pedagogical concept knowledge and a refining of that knowledge, and eventually the final stage of developing a constructivist teaching framework. Following this model, according to Hand (1996), can lead to a change in teachers' approach to the classroom to be more in line with constructivist notions. SEDL (1996b) in its "Resources for Constructivism" article identifies a book by Sharon F. Rallis and Gretchen B. Rossman called Dynamic Teachers: Leaders of Change, in which the dynamic teacher should adopt no less that seven roles. Previously, we have spoken about the facilitator role, but others include the moral steward, the constructor, the philosopher, the inquirer, the bridger, and the changemaker. This certainly makes the task of being a teacher even more demanding and crucial.

If we look into a typical constructivist classroom, we can see a much different environment than the traditional classroom. Once teachers adopt their new roles, students and the curriculum will soon follow suite, and a true constructivist atmosphere will be created. Brooks and Brooks (1993) offer us six insights into a constructivist classroom that are worthy of our consideration. The first says that student autonomy and initiative are accepted and encouraged. This allows students to attain their own intellectual identity and to take responsibility for their own learning and become good problem solvers. Secondly, in a constructivist classroom, the teacher asks open-ended questions and allows wait time for responses. This encouragement of reflective thought is synonymous with the inquirer role noted earlier. A third insight into a constructivist classroom sees that higher-level thinking is encouraged. The teacher continually challenges students to go beyond simple factual responses and to analyze, predict, justify and defend ideas. Also, in a constructivist classroom, students are engaged in dialogue with the teacher and with each other. This social interaction is critical to helping students change or reinforce their ideas. A fifth insight is that students are engaged in experiences that challenge hypotheses and encourage discussion. Students are permitted and even encouraged to make predictions and to test their hypotheses through group discussions of their experiences. Lastly, the constructivist class uses raw data, primary sources, manipulatives, physical and interactive materials. This involves students in real-world situations and helps them generate the abstractions that bind phenomena together. These insights into a constructivist classroom help us see that the environment has certainly changed from the more traditional one, but we can also see that the change will be for the better. SEDL (1995b) in its article entitled "Constructing Knowledge in the Classroom" reiterates these insights as critical to establishing a constructivist classroom. They add that it is crucial to gradually start adopting constructivist practices within the classroom. Human nature is such that we don't always let go of established practices and ideas, so a radical shift to constructivism would certainly be met with some hesitation.

Anderson (1996) compares a traditional classroom with a constructivist classroom and reiterates much of what Brooks and Brooks (1993) had said. The curriculum is guided by students' questions and the emphasis in the curriculum is on big concepts. While this may seem alright in theory, an inherent fear in this instance would be on what gets lost from the curriculum. The students work together in cooperative groups on various activities and the teacher checks for understanding by seeking students' points of view and using assessment techniques such as observation, student exhibits, and portfolios interwoven throughout the teaching process. DeVries and Zan (1995) add another important element to this constructivist classroom, that being "a sociomoral atmosphere ... in which respect for others is continually practiced" (p. 5). They go on to add that this is a mutual, two-way respect between the teacher and children and between children. Hwangbo and Yawkey (1994) also add their piece to the picture by identifying ten key elements which "stress wholistic, integrated experiences and activities and meaningful generalizations" (p. 210). In this classroom children are able to construct their own experiences and thoughts and to develop their own understandings. This exemplifies what a true constructivist classroom is like. The task for all those connected with the educational process is how to achieve this type of classroom environment.

Responding to Criticisms of Constructivism

Despite the attention that constructivism has received by the current reform movements in education, especially in mathematics and science, there remain some concerns about it. Most of these concerns have come from those that espouse more traditional, behavioral approaches to education. One of the biggest concerns, according to Brooks and Brooks (1996), is "that constructivism ignores the central role of curriculum in education" (p. 33). Other concerns deal with the notion that teaching in a constructivist manner is very complex, difficult, and time-consuming. Still others, as reported in Treagust et al. (1996), criticize constructivism on four different levels, namely, that it is simply common sense, that it has epistemological flaws, that it leads to the denial of the existence of the physical world, and that its excessive focus on the individual does not take social issues into account. Zevenbergen (1996) would agree that the focus on the individual construction of meaning within constructivism has ignored the wider socio-political context within which learning occurs, and the implications of that learning beyond the formal school context.

Treagust et al. (1996) identify four beliefs that serve as impediments to the constructivist view of teaching and learning. These beliefs are based on a traditional, transmissionist approach to teaching. The beliefs include teachers' view of the learner and the content as separate and static entities that must be reconciled, the tendency to equate activity with learning, the distinction between comprehension and application giving rise to the idea that learning is hierarchical and that generalization leads to transfer, and lastly that the curriculum is a fixed entity consisting of well-ordered content to be mastered according to predetermined criteria. These beliefs resemble the constraints that a particular teacher might experience within a particular school climate, and the feeling of not being strong enough to affect change. The current beliefs of many are strong and persistent in our school system, and will have to be changed if constructivism is to gain an inroad into our education system.

The most common criticism of constructivism, according to Brooks and Brooks (1996), is that in a constructivist classroom, anything goes. The belief is that if the students are not interested in the topic, it does not get introduced or completed. This is certainly not the case. Rather, the constructivist teacher tries to help students find relevance in the topics specified in the curricula. Hence the topics themselves are not as important as the approaches used in introducing and exploring them. Anderson (1996) tells us that as a teacher, "you'll continue to consider district and state curricula, but what you teach will become more of a collaborative effort between you and your students" (p. 49). The constructivist teacher does not eliminate the curriculum; they help to make it more meaningful for their students by posing important questions and letting their students construct their own knowledge.

Another criticism of constructivism has to do with its complexity. Brooks and Brooks (1996) agree that constructivist teaching is difficult to do, but the same can be said about any task for which individuals lack the necessary skills and dispositions for. They summarize what it takes to be a constructivist teacher by saying that:

> Constructivist teaching requires negotiating skills, insights into human behavior, sensitivity to human emotions, integrated subject knowledge, self-confidence, the disposition to handle risk, and the ability to say, "I don't know," "Let's find out," and "What do you think?" It requires inherent trust in students' abilities to pose meaningful questions and to answer them. It requires teachers to subordinate slavish adherence to sequential curricula to the abilities and interests of their students. It requires the willingness to withhold one's own answers so that students may discover answers for themselves, so that students will be able to fully explore important issues in their worlds, so that students will want to engage in an exploration. (p. 34)

This list of skills is complex indeed, but not at all unreasonable to expect of teachers who have to work in the complex environment of today's classroom.

A related criticism to the complexity issue has to do with the fact that constructivist approaches are very time-consuming and therefore interfere with coverage of the curriculum. In today's schools where coverage of the curriculum is so important for assessment and promotion reasons, this is a legitimate criticism. Brooks and Brooks (1996), however, point out that if we view coverage of the curriculum from the perspective of identifying major concepts and topics, and increasing understanding among our students, then this criticism of constructivism is unfounded. We have to recognize that less is more, that students should be encouraged to construct their own meaning, and that we should acknowledge and value what the student knows rather than what the student doesn't know. Once we have reached this point, the issue of time will no longer be a consideration.

The criticism that the main principles of constructivism are simply common sense was reported by Treagust et al. (1996). However, when they looked more deeply at this claim they found that we must approach it with caution, for oftentimes what gets accepted in theory may never be put into practice. In other words, the theory of constructivism may very well be acceptable to those involved in education, but how and even if that theory ever gets practiced is questionable. Another criticism reported by Treagust et al. (1996) was that constructivism has epistemological flaws. Most notably, the claim that experiences are the key source of learning is not accurate for constructivism. More important, it can be argued that new knowledge does not come from experiences alone, but involves a number of other factors such as prior and preinstructional conceptions. Another critique, specifically of radical constructivism, is that it denies the existence of a physical outside world. Treagust et al. (1996) tell us that this is not correct, for radical constructivism is consistent with a real existing world outside, and it only denies the possibility of any knowledge of that reality. We must construct our own knowledge of that outside reality. The last criticism reported by Treagust et al. (1996), and supported by Zevenbergen (1996), says that radical constructivism focuses too much on the individual and doesn't take into account the social realities that people exist within. As a leading proponent of constructivism, von Glasersfeld (1989), does indeed recognize the social nature of knowledge construction and includes social interaction as an integral part of any human subject's experiences.

Zevenbergen (1996) goes further in his criticism of radical constructivism. While it is important to recognize the individual construction of knowledge, when this knowledge is compared with legitimate knowledge in the field, then discrepancies arise. Knowledge that a student creates, based on his or her history, may be quite viable, but when compared to legitimate knowledge is quite invalid. This is where constructivism fails, for there are no processes for the construction of legitimate knowledge. In reacting to this criticism, we turn again to the role of the teacher in this constructivist environment. The responsibility is on the teacher to organize the learning environment in such a way to evoke certain forms of knowledge construction, and while this should not be a restrictive atmosphere, there are certain limitations in the construction of any knowledge.

Discussion

Constructivism has become more widely accepted in the education field today as a legitimate theory of teaching and learning. It is a complex theory to grasp and to implement into teaching practices. However, much research agrees that it is a worthwhile theory to guide our education reforms into the next century. Phillips (1995) accounts that "constructivism also deserves praise for bringing epistemological issues to the fore in the discussion of learning and the curriculum" (p. 11). Much debate is ongoing within the education journals which is healthy for the field as a whole. More important, constructivism has given teachers insights into how children learn, and in turn these teachers are able to make better decisions about how to teach. After all, as Anderson (1996) points out, the job of teachers "is to help children become lifelong learners by facilitating the most authentic learning experiences possible" (p. 51).

One of the biggest problems to overcome in reforming education to fit more in line with constructivist notions is teacher education programs. If teachers are to teach in a constructivist manner, then they should themselves experience constructivist learning. Much of traditional learning was in the form of being told the facts or how to do something and going out and doing it. In terms of teacher education programs, this often meant studying the theory behind teaching and learning, then observing other teachers in the field and modelling them in one's own practices. If constructivist practices are to become the norm in our education system, they should become the norm in teacher education programs and in-servicing programs as well. Falk (1996) tells us that "changes such as these in teacher education will support teachers in becoming powerful thinkers, [and] powerful thinkers make powerful teachers" (p. 29). As regards those teachers already in the field, Nelson and Hammerman (1996) agree that a change is needed, but they warn that the research literature on teacher change is modest, and much remains to be learned about the process of teachers changing their practice within the classroom. This paucity of research literature can be filled by teachers themselves, who need, as Fosnot (1989) relates, to become researchers in their professions. She presents a model for this to occur, as teachers reflect on their practices, on how students know and come to know, and on their disciplines and the modes of inquiry within them. In the end teachers will themselves become agents of change. This is what is needed for constructivism to gain more prominence within the field of education.

Conclusion

Constructivism's importance within the field of education is both productive and healthy. It is productive because it has forced us to question the traditional beliefs about teaching and learning and the acquisition of knowledge. By doing this we are indeed opening up the field to much debate and debate is certainly a healthy endeavour to be involved in. Amidst debate, the field of education can only change and prosper, and the winners in the long run will be the students who are the main stakeholders in the education system. Even amidst this reform movement that we seem to be constantly in, we must not lose sight of the fact that education is for the student and any changes we make in philosophy, or policy, or practice must have the students' interest in mind. Constructivism has offered an alternative to the traditional views that seemed to have outlived their relevance, and the time is upon us to grasp the views of constructivism, struggle with coming to understand their meaning, and adapt them to fit our own situations.

Folio Two: Constructivism in Mathematics Education as Exemplified by the NCTM Standards

Introduction

Among the disciplines taught in our schools, mathematics has probably been the object of the greatest disservice. Fosnot (1989) related that "it is often taught solely as arithmetical computation, with little or no attempt made at facilitating reasoning or development of logic" (p. 71). She went on to describe situations where children spent countless hours practicing algorithms that they often don't understand, and teachers assumed that higher-level concepts are understood as long as children are computing successfully. While this appeared to be a somewhat dramatic account of the situation with mathematics in our schools, it probably was at least partially correct. Society in general sometimes pointed the finger of blame at teachers, but oftentimes teachers know of no better approaches since they themselves are products of the same system.

In response to such claims, the National Council of Teachers of Mathematics (NCTM) have proposed dramatic changes in the content, instruction and assessment of school mathematics (Edgerton, 1992). The Curriculum and Evaluation Standards for School Mathematics (Standards) (1989) was the first document to address these changes. Subsequent documents that have grown out of the Standards (1989) document included the Professional Standards for Teaching Mathematics (1991), and the Assessment Standards for School Mathematics (1995). These documents have become the primary basis for the present reform movement in mathematics education.

This report will look at the historical developments in mathematical reform, culminating with the recent standards documents. The underlying theoretical basis of these documents will be the focus of this paper. Constructivism has emerged as that basis. The philosophical underpinnings of the notion of constructivism from a mathematical perspective will be examined. In particular, the focus will be on how to establish a constructivist environment in the mathematics classroom. There will be a number of practical suggestions investigated in this light. The implications for teaching and learning will be discussed and a number of models will be highlighted to further our understanding of where the research literature in this area has been focused. The standards documents and the evolving constructivist approaches have had an impact on teacher education programs as well. This area will be investigated and suggestions will be brought forth on how to incorporate a constructivist approach into teacher education programs. Lastly, the future of mathematics education will be discussed and future research endeavours will be highlighted. The mathematics education movement enjoys an interesting time. Amidst an ever-changing society, there is a need to reform mathematics education based on the theory of constructivism.

Mathematical Reform

Reform is not a new concept in the field of mathematics education. Lacampagne (1993) summarized the major reform movements of the past fifty years for us. First there was "the 'new math' movement of the 1950s and 1960s [which] emphasized the unifying mathematical concepts of logic and set theory" (p. 1). Bossé (1995) related that this so-called 'new math' movement was actually difficult to define. He contended that the movement was actually "all [of the] educational movements during the 1950s and 1960s that had an aim of reforming, repairing, or enhancing mathematics" (p. 173). He went on to suggest that limiting the definition of the new math movement to include components like set theory and conceptualizing mathematics would do injustice to the many issues that dominated those times in mathematics education. In any case, the new math did not receive widespread acceptance, mostly because it did not pay attention to how students learn and what they are capable of learning at different ages (Lacampagne, 1993). Bossé (1995) reiterated these shortcomings of the movement and attributed it to an absence of a cohesive philosophy, and to the inappropriate materials that eventually reached the classrooms. These materials were not what the reformers had envisioned on both a curricular and philosophical level.

Following the new math was "the 'back to basics' movement which emphasized rote memorization of arithmetic facts and the learning of paper-and-pencil algorithms" (Lacampagne, 1993, p. 1). This movement lasted throughout the 1970s and 1980s. The present reform movement emerged as a result of the inherent weaknesses in the back to basics movement. Specifically, there was a neglect of higher order thinking and problem solving skills. Also, our students were not preforming on par with other countries, as shown in a number of international studies. If we include changing mathematical skills for the work force, new research finding on teaching and learning mathematics, and the increasing uses of calculators and computers, then we can see that the back to the basics movement failed in its attempt to address these issues (Lacampagne, 1993). Burns (1994) related that "the call for reforming mathematics teaching [was] made loudly and strongly" (p. 471). She went on to provide us with an account of where the call for reform was coming from. Within the field of mathematics education itself, in 1989, two important documents were released, namely, the NCTM Standards and Everybody Counts: A Report to the Nation on the Future of Mathematics Education, sponsored by the National Research Council and published by National Academy Press. In addition, the following year, the Mathematics Sciences Education Board (MSEB) released Reshaping School Mathematics. These and other publications in educational journals presented a consistent message: "teach the children to solve problems, reason, communicate, value mathematics, and become confident in their ability to do mathematics" (Burns, 1994, p. 471). Outside the field, reports in the general media also called for a change. Burns (1994) tells us that Parenting magazine, Newsweek, and the Wall Street Journal also got in on the reform agenda and specially had articles dealing with reform in mathematics education. The NCTM embarked on its current reform movement beginning in 1986. The Standards (1989) document emerged from that initiation. Primarily, the new standards envisioned a shift in the teaching and learning of mathematics in five major areas. Specifically, Lacampagne (1993) related that these areas are in making mathematical communities within the classroom, using logic and mathematical evidence as verification, reasoning mathematically, conjecturing and problem solving, and connecting mathematics.

Much has been said about the philosophy behind each of the mathematical reform movements. Bossé (1995) examined both the new math and the NCTM standards' movements and concluded that only the standards movement emerged under one common philosophical stance. Constructivism emerged as the unifying paradigm of mathematics education. Bossé (1995) related though that "the NCTM entered the process easily as epistemologically fractioned as the New Math Movement had been" (p. 183). The key for the standards' movement was their ability to latch onto this theory of how learning occurs and incorporate it into the very fabric of the documents. Wilson (1994) supported this notion of constructivism being the central view of learning defined by the standards documents. Greenes (1995) also agreed that constructivism fueled the reform in mathematics curriculum, pedagogy, and assessment, which formed the basis for the standards movement. So, while there appeared to be some lack of unity at the beginning of the standards reform movement, the end results were documents that "focused upon one epistemological paradigm to which all developers acquiesced - Constructivism" (Bossé, 1995, p. 187).

If we look at the standards documents themselves, we can see a connection to constructivism as the central view of learning. The NCTM Standards (1989) described that "learning does not occur by passive absorption . . . instead, in many situations individuals approach a new task with prior knowledge, assimilate new information, and construct their own meanings" (p. 10). The document went on to add that "this constructive, active view of the learning process must be reflected in the way much of mathematics is taught" (p. 10). The NCTM Professional Standards for Teaching Mathematics (1991) also supported this constructivist view by reporting that "educational research findings from cognitive psychology and mathematics education indicate that learning occurs as students actively assimilate new information and experiences and construct their own meanings" (p. 2). The standards then have put forth the vision and issued the challenge. Before we look more closely at this challenge as reflected in the standards, we will turn our attention to the notion of constructivism and examine its basic principles from a mathematical perspective.

Constructivism: A Mathematical Perspective

Reid (1991) defined constructivism as "a theory of knowledge acquisition which holds that knowledge is constructed by the learner [and] that knowledge is not only assimilated but also accommodated by the learner" (p. 81). Others interpreted this as meaning that constructivism was based on two main principles (Lerman, 1989; Roth, 1993; Wheatley, 1991; Wilson, 1994). The first dealt with the active construction of knowledge by the subject rather than the passive receiving of knowledge from the environment. This notion was generally widely accepted by mathematics educators (Balacheff, 1991). The second principle dealt with how we come to know. It suggested that this process was adaptive and served the organization of the experiential world, not the discovery of the preexisting world outside the mind of the knower. In other words, we can only come to know the world through our own experiences. This notion was troublesome for many (Wheatley, 1991; Wilson, 1994). Lerman (1989) indicated that the second principle of constructivism was controversial on two levels. The first dealt with "whether it is ever possible to understand what anyone else is saying or meaning, that is, problems of private languages" (p. 211). Secondly, Lerman (1989) added that the problem arises as to "what kind of meaning can thus be given to what we all accept as known, that is, the nature of knowledge in general and of mathematical knowledge in particular" (p. 211). This second principle of constructivism has raised a number of concerns, not only with the acquisition of mathematical knowledge, but knowledge in general. We find ourselves, therefore, redefining knowledge from a constructivist perspective. In the ensuing redefinition of knowledge we find that the questions of truth and meaning also become evident.

Wheatley (1991) revealed that "from a constructivist perspective, knowledge originates in the learner's activity preformed on objects" (p. 10). He went on to stress that knowledge is contextual and never separated from the knower. Simon (1995b) reinforced this notion by saying that "we construct our knowledge of our world from our perceptions and experiences, which are themselves mediated through our previous knowledge" (p. 115). As well, the search for truth was replaced by a search for what is viable, for what will work as it fits our experiential world. Wheatley (1991) told us that "in constructivism, no claim to truth is made . . . instead, we consider our positions viable" (p. 11). Thus we take information as given when our experiences have not yet proven otherwise. Some concept works as long as "it does what we need it to do: to make sense to our perceptions of data, to make an accurate prediction, to solve a problem, or to accomplish a personal goal" (Simon, 1995b, p. 115). The knowledge was then said to be viable.

Another important aspect of this view of knowledge from a constructivist perspective dealt with "the fact that we cannot transmit meaning but must construct it for ourselves" (Wheatley, 1991, p. 11). Meaning was not passed on from individual to individual. Rather, it was evoked in individuals as a result of experiences they have. This notion presented difficulty in the traditional view of mathematics as a body of knowledge to be passed on to individuals. From a constructivist perspective, mathematics should be viewed as an "activity of constructing relationships and patterns" (Wheatley, 1991, p. 11). There was then a need for a shift in the learning environments of children so that they can construct their own meanings in a social setting conducive to that construction. This view of learning parallelled the social constructivist paradigm, or as Lerman (1996) called it, the sociocultural view of learning. He went on to criticize radical constructivism, which is a major theoretical orientation in the mathematics education community in relation to children's learning, on the basis that it concentrated too much on the individual as a meaning-maker with no influence from the cultural setting that individual is a part of. Clearly, the social setting does have an influence on the knowledge that is acquired and how the children come to understand that knowledge. This has a number of important implications for the teaching/learning process and environment of the mathematics classroom. Before we look at those implications, however, let us examine in more detail the implications the standards documents have had and will have on the field of mathematics education.

The Standards Documents

Bossé (1995) related that "the Standards was not intended as a curriculum as much as a document defining an educational philosophy" (p. 175). This view was supported by others connected with the reform movement (Crosswhite, Dossey, & Frye, 1989; Frye, 1989). The vision, as it has often been called, was what the Standards were designed to promote. What was that vision? Crosswhite, et al. (1989) tell us the "vision is that all these students have a suitable and sufficient mathematics background" (p. 669). That vision also considered equality of opportunity and clearly articulated that it was possible for all students to attain mathematical power. Frye (1989) further clarified this vision by saying that, as a teacher, it is indeed worth the effort to make it possible for every student to achieve this mathematical power. She continued that "this power is the ability to explore, conjecture, and reason logically as well as use a variety of mathematical methods to solve nonroutine problems effectively" (p. 6). The epitome of realizing the vision inherent in the Standards would be to produce students with this mathematical power. Simon and Blume (1996) summarized that:

> The standards documents promote a vision of classroom mathematics in which students engage in explorations of mathematical situations, oral and written communication of ideas, and verification, modification, and validation of those ideas. Thus, students actively participate, taking on a role that is analogous to the role of mathematician, creating mathematics, evaluating mathematics that has been created by members of the classroom mathematics community, and negotiating shared approaches to and standards for these activities. This vision contrasts sharply with traditional mathematics classes, where the teacher and textbook serve as the source of mathematics and the evaluators of mathematical validity. (p. 3)

Hence the vision was fully articulated. Now the question remained as to how that vision could get realized in the mathematics classroom?

The task would not be an easy one. How would students be able to become full participants in a discipline that promoted absolutism in terms of set procedures (algorithms) and correct answers? Greenes (1995) described one model for students to engage in investigation and exploration as the standards documents stressed. She added that "learning mathematics, thinking mathematically, and solving mathematical problems are complex, nonlinear, procedures involving at least five cognitive processes" (see Figure 2.1) (p. 91). Each of these processes involves all the others, and may be revisited several times during the investigation, exploration and learning.

The educational journals flourished with articles on how to make the standards a reality in the classroom. Hirsch and Schoen (1989) described one such approach for implementing a common core curriculum for grades 9-12. They proposed a radical shift in the curriculum from what was presently the practice. This would mean a shift in focus on all levels, including governing bodies, textbook publishers, and at the classroom level. Curriculum through middle school grades would have to change as would the mathematics curriculum at the college level. From this review, it had become evident that the vision the

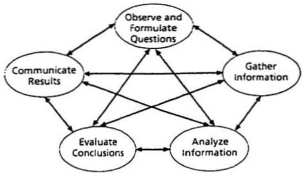

Figure 2.1: The Investigative Process.

(Note: Source for Figure 2.1 is Greenes, 1995, p. 91) standards were promoting would have significant impacts on all levels of the mathematics education community. Our focus, however, will now turn to the implications that the standards had for the teaching and learning processes at the K-12 levels. In particular, we want to look at how the approaches to teaching and learning mathematics changed as a result of the standards documents.

Implications for Teaching and Learning

If we adopt a constructivist view, this has a number of implications for the teaching and learning of mathematics. The current beliefs of both teachers and learners will be examined as a starting point for overcoming some of the obstacles. Learning becomes very much a personal matter, "accomplished by constructing and elaborating schemes based on experiences" (Wheatley, 1991, p. 12). The classroom is not a workplace, where students are paid for their products with praise and grades, rather it becomes a learning place, where meaning is central and discussing ideas with others is common. This environment demanded a different role for the teacher as well. The teacher must become a facilitator of the learning process rather than the sole authority on learning matters. Wheatley (1991) tells us that "in the learning place the goal is learning, not completing tasks" (p. 13), which is the goal of the workplace. The students in this learning place take on the role of explorer/inventor. Both the role of the teacher and the students will be discussed in more detail later in this section. These changes in the classroom, and indeed in the teaching/learning process itself, are viewed as essential to making the shift to a constructivist environment.

The greatest stumbling block to change was the current beliefs and conceptions of mathematics and mathematics education. McLeod (1993) related that the current beliefs of students often led them to respond negatively to problem-solving activities. They viewed mathematics as a set of rules, and when they were presented with a nonroutine problem, they became frustrated and quit trying to find an answer to the problem. Our culture believed and promoted that learning mathematics depended more on ability than on effort, and only geniuses can be creative and successful in mathematics. Battista (1994) referred to these current beliefs of students and others about mathematics as having an incompatibility that is in essence blocking reform. While this view may not be entirely the case, there is some merit in considering his argument. He went on to offer suggestions on how to change these beliefs, concentrating mainly on the areas of mathematics curriculum and the teaching and learning of mathematics. While the Standards attempted to deal with mathematics curriculum and the subsequent evaluation of students, the underlying vision implied a radical change in how we view teaching and learning. Frye (1989) related that "change is a process of growth rather than a movement to a plateau" (p. 7). Schifter (1996) also warned that "there is no point of arrival, but rather a path that leads on to further growth and change" (p. 499). Change will occur once you, as a teacher, reflect upon your current beliefs and compare them to those envisioned in the Standards. Garet and Mills (1995) reported that this change in practice "is beginning to shift in directions consistent with the NCTM's Curriculum and Evaluation Standards (1989)," at least in high school mathematics. They continued that change is occurring more rapidly in some aspects of practice, such as the use of technology, than in other areas, such as the use of new forms of assessment. Garet and Mills (1995) summarized the argument by reporting that "change entails the construction of practice, which is facilitated by departmental leadership that encourages teacher collaboration, collegiality, and shared decision making and supports teachers in developing a new set of values, beliefs, and routines" (p. 387).

The most common view among typical, everyday mathematics teachers was that they were powerless to affect any change in vision in their schools or districts. Hatfield and Price (1992) referred us to the shift that was occurring away from district management of schools to site-based management. This shift, they argued, could provide the right environment for a change in focus, especially for mathematics education, bringing us more in tune with the reforms. In our present climate, with the increasing popularity of site-based decision-making groups, such as school councils, this view of Hatfield and Price (1992) could be realized. The context is right to implement major reforms in mathematics education especially if administrators and parents can be brought on side in recognizing the need and value in reform.

Mumme and Weissglass (1989) reiterated the importance of individual teachers in implementing the Standards. They suggested an incremental approach to change on the part of teachers in their respective classrooms. As well, they argued that a teacher can do things outside his/her classroom, such as getting involved in curriculum committees; educating administrators, school boards, and parents; and inviting others to come into their classroom and see how the new approach to teaching and learning mathematics is working. The importance of teachers leading this reform movement from the ground-up (Hitch, 1990) was essentially what the NCTM had in mind when they began work on the Standards almost a decade ago. The teachers' role, therefore, has become even more complicated. Not only must they facilitate changes in their own beliefs and practices within their individual classrooms and environments, but they also must extend that work beyond the walls of their classrooms to affect changes on a much broader basis. P. C. Taylor (1996), however, warned that because "the overwhelming majority of secondary school mathematics teachers are subject to the enculturating influence of their immediate school communities, including administrators, peers, and parents ... it is important to avoid the danger of perpetuating the myth of the teacher as an heroic individual" (p. 169). He went on to add that it is important for teachers to "become communicatively competent in forums beyond their classrooms" (p. 169) and to promote reform as much as they possibly can. Hatfield and Price (1992) sense that the conditions for reform are right for the implementation process to succeed. They reported that "teachers' early involvement in the process, administrative support, provision of materials, follow-up in the classroom, strong leadership, and a sense of direction framed by NCTM's curriculum standards" (p. 36) are all factors that will lead to the success of the change process.

If change occurred, we would want to be assured that the change would be for the better. Duit and Confrey (1996) reported that there are a number of assumptions underlying a reorganization of the curriculum and teaching, based on a constructivist perspective. They included that constructivist approaches usually give more emphasis to the applicability of mathematical knowledge than do more traditional approaches, that the curriculum would have to deal with issues about the nature and range of mathematical knowledge, that it is impossible to totally replace students' conceptions of mathematics with so-called true mathematical knowledge, that approaches to mathematical understanding would be student-centered, and that the norms and routines of the classroom interaction have a significant role to play in the formation of mathematical knowledge. These assumptions lead us to look at the mathematics curriculum and the teaching of that curriculum in a new light. The constructivist teacher has an enormous task to accomplish, but one that is certainly achievable. Brooks and Brooks (1993) listed five principles that should guide the teaching process in a constructivist classroom. They included posing problems of emerging relevance to students, structuring learning around primary concepts, seeking and valuing students' points of view, adapting curriculum to address students' suppositions, and assessing student learning in the context of teaching.

The next question deals with how we plan our learning activities so as to promote meaningful learning from a constructivist paradigm. Educators, who recognize that the traditional explain-practice method of instruction does not work, may turn to the notion of active learning. Wheatley (1992) warned us however, that this shift in instructional practice does not always result in increased mathematical learning. He argued that simply putting more activities into the mathematical environment will not suffice. The environment must also encourage reflection on the actions that were taken to solve a problem. This notion of reflection had appeared to become central to the theory of constructivism.

Hart, Schultz, Najee-ullah, and Nash (1992) identified reflection as a key ingredient in the teaching process. If a change in practice is needed, it can only be ascertained through reflecting on one's own teaching. Edwards (1994) would agree that reflection is critical, especially to initiate the change in teacher beliefs about how students learn from the constructivist approach. The model (see Figure 2.2) he proposed was developed during a two-year study of mathematics teachers' implementation of an innovative curriculum program. At the heart of this model was metacognition, which is the uniquely human ability to monitor one's own reflective activity. Edwards (1994) reported that "beliefs form a foundation for the reflective cycle of the change" (p. 12). In addition, "beliefs color a teacher's interpretation of classroom interactions and help to determine which aspects of practice a teacher finds problematic, as well as the ways in which the teacher addresses the problematic" (p. 12).

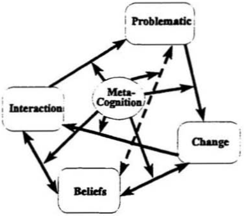

Figure 2.2: A Constructivist Model of Teacher Change Based on Beliefs and Monitoring by Metacognition

(Note: Source for Figure 2.2 is Edwards, 1994, p. 14)

Hence, in order to change teaching practice, one must first contemplate a change in beliefs. This was by no means an easy undertaking, but one that reflection can help initiate.

Reflection was also important for the student. The teacher, however, has to initiate the process. This can be done in a number of ways. One of the key notions in constructing one's own knowledge was to make connections between old ideas and new ideas. Students engaged in problem solving activities can be encouraged to reflect by the teacher who asks such questions as: How does this fit with what you already know? or In what ways is this problem like other problems you have experienced? or What is it about this problem that reminds you of a previous problem? Brutlag and Maples (1992) agreed that reflecting on connections within students' mathematical experiences is essential to true mathematical understanding. They suggested writing in journals, making presentations, discussing in seminars, and working on projects as means to accomplish this end. Krulik and Rudnick (1994) also stressed that reflection on the part of students is important, for it improves their creative thinking skills, and motivates them to explore for possibilities and find alternative solutions.

Quite often, even after there has been a change in the belief system of mathematics teachers, as a result of reflection or not, there still remains the inherent question of what to do in mathematics class. This question remains because most mathematics teachers have come through a system where knowledge transmission was the norm and the explain-practice methodology was commonplace. Constructivism has provided us with the basic tenets upon which to build models of teaching (Simon, 1995a; Steffe and D'Ambrosio, 1995). The research literature has provided us with some alternatives to the traditional methods of instruction. One of the most notable instructional strategies was problem-centered learning (Wheatley, 1991). This strategy has three components, namely, tasks, cooperative groups, and sharing (see Figure 2.3). In short, the strategy employed the teacher to select problematic tasks for students, allow them to work on these tasks in small groups, and then to share within a whole class setting. The teacher's role was that of a facilitator and every effort was made on the part of the teacher to be nonjudgemental but encouraging. Wheatley (1992) related that "problem-centered learning is not to be confused with active learning or what is sometimes called 'hands-on math' in which manipulatives are used to help students learn" (p. 530). The first step of identifying tasks can be challenging for the teacher, who must choose

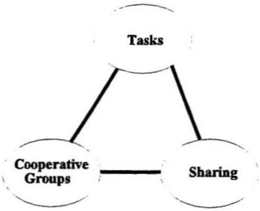

Figure 2.3: Problem Centered Learning

(Note: Source for Figure 2.3 is Wheatley, 1991, p. 16) tasks that reflect the central ideas of the discipline and appeal to students' understandings. In the end, the teacher must make judgements about the appropriateness of the activities available. The second step involved the students working in small groups. This step recognized that "learning [must occur within] the social context of classrooms, which are heavily influenced by interactions among the members of this intellectual community" (Wheatley, 1991, p. 19). Knowledge was coconstructed in this instance. The third step involved students coming together as a whole class to share their methods of arriving at a solution to the task. It was important in this step for the teacher to be nonjudgemental but to assume a facilitative role.

Cobb et al. (1991) reported on a year-long project involving ten second-grade classes where instruction was generally compatible with a socioconstructivist theory of knowledge. The ten project classes were based on a problem-centered instructional approach and "were compared to eight nonproject classes on a standardized test and on instruments designed to assess students' computational proficiency and conceptual development in arithmetic, their personal goals in mathematics, and their beliefs about reasons for success in mathematics" (p. 3). The results of the project showed that the computational performance levels were comparable between the two groups, but the project students had a higher level of conceptual understanding, held stronger beliefs about the importance of understanding and collaborating, and attributed less importance to conforming to the methods of others, competitiveness, and task-extrinsic reasons for success (Cobb et al., 1991). As well, a pedagogical belief's questionnaire completed by all teachers indicated that the project teacher's beliefs were more compatible with a socioconstructivist perspective than their nonproject counterparts. This study was found to be broadly compatible with the NCTM reform recommendations, even though it did not set out to test those recommendations.

In another study, referred to in Wheatley (1992), called the Mathematics Learning Project, teachers at the Florida State University Laboratory School used problem-centered learning as their primary instructional strategy. The teachers assessed their pupils using an informed professional judgement technique. The students did not get grades nor were they administered tests, except for required state or national assessments. Instead, the teacher kept notes of the students' activity in which there was consideration given for "persistence, confidence, co-operation, communication, and the quality of their mathematical constructions" (p. 531). Another key part of the project involved establishing an environment which encouraged reflection. The teacher's role, besides selecting tasks and assessing, also involved negotiating social norms, which is the essence of being a facilitator of learning. Wheatley (1992) concluded that "students who have experienced problem-centered learning, in which reflection is central, are able to solve non-routine problems and to construct new knowledge" (p. 540).

Yackel, Cobb, Wood, and Merkel (1990) summarized the aspects of constructivism as they have been applied to a number of research studies involving problem-centered learning. It was important for the teacher to understand students' mathematical experiences as a starting point for creating a constructivist classroom environment. Then, as students worked on the tasks set down for them, they interacted with both the teacher and other students. This interaction provided them with crucial learning opportunities. Finally, during the whole-class discussion, students are expected to give explanations of their problems and solutions, and respond to questions or challenges posed by others. Yackel et al. (1990) indicated that this type of discourse increased the amount of time students actually spend participating in problem-solving activities, but more important, due to social interaction, they learned to reason analytically. This was consistent with the NCTM's standards on communication, reasoning and connections.

Problem-solving based models are evidently the most effective in promoting the notions of constructivism within the classroom. Savery and Duffy (1995) offered us another related model of teaching and learning which was very similar to the problem-centered learning model. They related that the problem-based learning model used in medical education since the mid-1950s can be applied to the creation of a constructivist learning environment. The generation of real problems relevant to the content domain, the cooperative groupings that work on solutions to the problems, the presentation of the problem solutions, and the facilitator role that the teacher takes all resembled the problem-centered approach described above for mathematics problem solving. Silver (1994) would go even a step further with problem-solving models, and propose that students themselves become involved in posing mathematical problems to solve. This can be done before, during, or after the solution of a problem. It has become evident that solving problems was the key to establishing a constructivist environment in the mathematics class. Barba (1990) took the stance that problem-solving can be taught. She cited George Polya's four stages to problem solving as being critical to becoming successful problem solvers. The stages are understanding the problem, devising a plan, carrying out the plan, and looking back. The task for the teacher however, has not become any easier. Teachers cannot simply come up with a number of problems, put students together in groups, and hope they come up with the solutions. Taback (1992) said that teachers have to become problem-solvers themselves, in order to acquire the mathematical know-how in solving and reflecting upon problems. Then we will have teachers who are able to fully realize their role within the problem solving activity their students are engaged in.

If models such as problem-centered learning and/or problem-based learning become more of the norm in our mathematics classrooms, then we, as teachers, must revisit how we teach. Prevost (1993) offered a practical approach to implementing change in how we teach. He suggested that we return to the three Rs - reflect, risk, and revise. The essence of reflection has already been investigated, but Prevost (1993) made some practical suggestions of what to do. For example, he suggested that teachers should take some time each day, week, or semester to jot down what they believe and what they do. After they have formed their theory of teaching, the next step in reflection is to share their best classroom creations with colleagues. This opens up the classroom and the teachers' practices for examination by others. Prevost (1993) went on to include reading and suggested several sources of information. The reading, he believed, will expose alternative suggestions for teachers and give them something different to try in certain situations. The next step was to integrate the new approaches that were discovered into the existing schema (i.e., take the risk).

Suggestions mentioned underneath this step included getting help from faculty and programs at a local college or university, planning staff development activities, planning a lesson with specific goals in mind and discussing that lesson with a colleague who has observed you, and changing other factors that influence the way you teach. This may be something as simple as the physical arrangement of your classroom. The key was to experiment and find out what works for you. The third step involved revising. This was an important step for not everything we try is successful. It involved reflecting on the attempts we have made to change and evaluating or reviewing our efforts. Then if we feel there is a need to revise our approach, lesson, arrangement, or whatever, we should do so. Prevost (1993) concluded that "in the constructivist tradition . . . we must do the learning, and we must reconstruct our own view of teaching" (p. 78).

Another model of mathematics teaching was offered by Jaworski (1992), and is called the teaching triad (see Figure 2.4). Jaworski (1992) claimed to have constructed this model as a result of extensive observations of mathematics classrooms. In addition, she linked this model to a constructivist philosophy with the classroom teaching of mathematics. If we briefly examine the three elements of this model, we can see that management of learning dealt with the creation of a learning environment. This encompassed classroom organizations, curricular decisions, establishing ways of working, and establishing classroom values and expectations. The sensitivity to students involved developing both a knowledge of individual students' characteristics and need, and an approach to working with students being consistent with those needs. Lastly, mathematical challenge involved stimulating mathematical thought and enquiry, and motivating students to become engaged in mathematical thinking. Jaworski (1992) related that "only students themselves can construct their mathematical knowledge, relative to their own individual experiences" (p. 14). The teacher, however, can influence and interact in these constructions. Management of learning created the opportunity for influence, sensitivity to students built the knowledge and opportunity for influence, and mathematical challenge offered the content of influence and interaction in a more interesting and motivating way. This model then offered us an approach to teaching that is consistent with the constructivist views of knowledge and learning.

Figure 2.4: The Teaching Triad

(Note: Source for Figure 2.4 is Jaworski, 1992, p. 8)

The implications of constructivism on teaching and learning are significant. The greatest barrier to implementing change seemed to be the mind set of both teachers and students connecting with the learning process. There existed many traditional classroom examples to serve as models exemplifying the old ways of teaching and learning. Models such as problem-centered learning offerred optimism for the future. The key to initiating a change, however, rests with the classroom teacher. Individual change cannot be mandated from above but rather must come from within. The NCTM standards have provided us with the vision for change. The view of the literature is that it is incumbent upon us all, as educators, to help move toward achievement of that vision.

Teacher Education Programs

The NCTM standards documents have put us in the midst of a mathematics education revolution. These documents have provided us with a vision of change, but that vision may be difficult to implement into practice. Gadanidis (1991) reported on a project that attempted to "facilitate the growth of teachers so that they take ownership of the construction of their personal visions of mathematics education and of their implementation into practice" (p. 126). This project was carried out with two mathematics methods classes of pre-service secondary teachers. The project had two major components. One involved pre-service teachers defining their practice and their visions of mathematics education, and using reflection as a means of bridging the gap between the two. The other component employed a student centered approach by taking advantage of, and building on, the experiences, beliefs, and understandings of the pre-service teachers. The results of the project have important implications for teacher education programs. The pre-service teachers in this project saw a definite need for developing an understanding of their practice, visions, and path for professional growth. Also important in the project was the instructors' attempt to establish consistency between visions and practice through reflection. These suggestions offer teacher education programs a means to initiate a change in focus for mathematics teachers.

Bridges and Hallinger (1996) reported on a problem-based learning approach to the professional development of school administrators. They recognized that administrators, like teachers, are being asked to move away from command and control models of leadership to more transformational styles. The importance of administrators adopting such an approach was critical because they are the leaders within an individual school, whose teachers are in the midst of reforming their practices, and they will serve as models for that reform. The professional development of those administrators was seen as crucial to ensuring success of the current educational reforms now under way.

Professional development of mathematics teachers was also seen as critical to making the reform happen. Corwin (1993) agreed that while the standards are there as a guide to teacher education programs, professional development sessions, and in-service days, they rarely get mentioned in such activities. The time has come to create a new mathematical culture, where teachers reflect on their practices, learn about their pedagogy and about children's learning of mathematics, and engage in and construct mathematics for themselves. Then we will have teachers who are able to effect change within their teaching and within how their students come to understand mathematics.

Future Research Issues

The research community must also continue to seek out through projects and studies, what works in the mathematics classroom built from a constructivist perspective. The North Central Regional Educational Laboratory (NCREL) (1994) reported on several ongoing research projects that are investigating mathematics programs and how well they mesh with the NCTM standards. Some examples included the Algebra Project out of Cambridge, Mass.; the Cognitively Guided Instruction (CGI) project from the University of Wisconsin - Madison; and the University of Chicago School Mathematics Project (UCSMP). Kwartler (1993) also reported to us about the Primary Mathematics Education Enhancement Program (PMEEP), which is an ongoing collaborative project of Kent State University and eleven school districts in a primarily rural midwestern county. The project will have included 200 teachers from grades K-2 in workshops, keeping journals, peer coaching, and helping in a summer curriculum development project. The project focused on a constructivist approach to mathematics education. These and other research projects indicate to us the direction the research community is going in this regard. It is clear that NCTM's vision has certainly been well accepted both inside and outside the education field. The focus now has turned to how best we can realize that vision.

The challenge to teachers has been issued by NCTM and the Standards. It is now up to teachers to respond to that challenge. The Research Advisory Committee of the NCTM (1990) outlines a need for both transformative and monitoring research in the area of mathematics education, in light of the Standards document. The transformative agenda deals with what ought to be, while the monitoring agenda will study the effects of the Standards on the teaching and learning of mathematics. Teachers need to become a part of these research agendas. In essence, teachers are those charged with implementing the Standards, therefore they are in a prime position to research and report on the effects that the Standards are having on our mathematics education system. There is an inherent need for teachers to become researchers. The Research Advisory Committee (1990) identified six areas that offer extensive research possibilities, namely, assessment, changes in curriculum materials, mathematics as communication, policy-related issues, effects of technology, and secondary core curriculum. Hence, there is a further challenge being issued to teachers. If the reform movement is to maintain its momentum, teachers must become involved in all aspects of reform, including awareness, acceptance, implementation, and research into the Standards and the vision for mathematics that will bring us into the twenty-first century.

Conclusion

The research literature on constructivism and the NCTM standards indicate to us that the mathematics classrooms of the future will look much different from those of the past, with few exceptions. Edgerton (1992) summarized the argument for change when he said that "there will always be a few people that defy change and a few that relish it" (p. 22). For teachers presently in the system, there must be some reason to want to change. By showing people that the traditional way of doing things has weaknesses, the incentive is there to change practices. However, it will not be a simple, nor quick process. Smith (1996) alerted us to yet another challenge for reform among teachers, that being their own sense of efficacy.

Teachers in the field who have been using the traditional methods of teaching by telling, and gaining results, at least in the short-term, will be difficult to reform. The Southwest Educational Development Laboratory (SEDL) (1994) in its online newsletter, Classroom Compass, however, gave us a picture of a future world that will be much different than that of the past. It is this future world, which is so rapidly changing, that students will have to be prepared for. The traditional methods of teaching mathematics will not prepare our students for this future world. For those teachers in training, we would hope that their education programs reinforce the visions of constructivism as exemplified by the NCTM standards documents, and prepare those teachers to take on the challenge of establishing a constructivist mathematics classroom.

A formula for change does not exist. There are, however, a number of supports that can be put in place to foster and guide change in the mathematics classroom. Teachers need time to process what they are learning and to adapt it to their situations. This may require time away from school and the responsibilities it imposes. One-day, evening, weekend, or even summer workshops can help the process but are not the definitive solutions to the problem. Teachers need extended periods of time to work on mathematics in problem situations, to talk with their colleagues, observe other teachers at work, and to try out their innovative activities with opportunities for reflection, feedback, and revision. Parents also need time to change their views of the education system and where it is heading with reform. They have come from the traditional classrooms where knowledge was transmitted and rote memorization was common. They are doubtful about what the future holds and need to be educated about the reform movement in mathematics. Students also need time to adjust to this new way of approaching problems and coming up with solutions. However, if the vision of mathematics education, as portrayed in the literature, is to establish a constructivist environment within the mathematics community, then the time and supports must be put in place to help achieve this goal.

Folio Three: Problem Solving in Technology Education as a Model of Constructivism

Introduction

We are in the midst of very exciting times within the field of education. This has been the result of the unprecedented change in every aspect of twentieth century life. Bender (1988) related that "more change has occurred in this century, in fact, than has occurred in all of previous human existence" (p. 171). Most would agree that the magnitude of change has been almost overwhelming. The education field has had to react to the rapid change in society by modifying and adjusting its programs so that it could "keep up with the times". As well, the field has had to rethink its view of the teaching/learning process. Amongst this re-examination of how teachers teach and learners learn, constructivism has emerged as one of the more prominent views underlying the very philosophy of education.

Technology has been looked upon as an indicator of this rapidly changing society. Bender (1988) reported that "modern society is increasingly shaped by technology" (p. 174). The dynamic and cumulative nature of technology has set it apart from many other human endeavours. This atmosphere has led us to respond quite drastically to how we view human learning and has thrust the education field into a period of reform unheard of throughout history. Questions arose as to what exactly is technology, and how should we institute the teaching and learning of technology, or in other words, what is technology education? Balistreri (1991) reported that "many educators equate 'technology' with enhanced delivery mechanisms such as computers, videodiscs, long distance learning, etc" (p. 107). He went on to discredit this narrow view of technology. Britton (1992) defined technology as "the processing of knowledge related to industry, science and the humanities, demonstrated by a person's ability to adapt to and shape the environment" (p. 3). Hence technology is more of a process, rather than a physical product. Others hold similar views on a definition of technology (Government of Newfoundland and Labrador, 1996; Todd, 1990; Wicklein, 1997; Wright, 1995). Britton (1992) went on to elaborate on his definition by saying that "technology is an instrument by which people can alter human condition and effect economic interaction, finance, commerce, communication, transportation, and manufacturing" (p. 3). It has become apparent that technology affects every aspect of our existence. Wright (1995) elaborated on the various definitions of technology as hardware, as organization, or as process. Technology as hardware was computers, lasers, supersonic aircraft, and so on. This view led to the development of technology education which taught high tech skills, as students attempted to master these technologies. Technology as organization referred to the way people structure themselves to produce products and services. The education that resulted from this view dealt with the impacts of technology on society, and became more of a social studies type of education. Technology as process, however, became the more widely accepted view, and led to the development of technology education as "the study of knowledge application, creativity, and resource use to solve problems and extend human potential" (Balistreri, 1991, p. 107). He went on to summarize his view of technology education by saying that "with its roots in industrial education, technology education is a dynamic area of study that will help students develop technological literacy through problem-solving activities that address tools, materials, and processes of today and tomorrow" (Balistreri, 1991, p. 107).

In this paper, we will look at the technology education field, and in particular, the problem solving approach that it promotes, and describe how this approach in technology education is based on constructivist notions. In particular, we will first look at the technology education field itself as being a very dynamic field, and explore such concepts as technological literacy, integration, standards, curriculum focus, and technology's support for educational reform. Next we will turn our attention to constructivism and briefly define what it is, but more importantly look at the implications constructivism has for practice, and in particular for technology education. The problem solving focus of technology education will also be explored, and an argument will be made that it exemplifies the very basis of constructivism, and can become a model for other disciplines to look at in their reform agendas. Lastly, we will look to the future for technology education and project where it may go as a discipline. Throughout this report, an effort will be made to relate what has happened and is happening in technology education to the notions of constructivism, and as Sanders (1993) reiterated, "as educational policy makers struggle to revitalize our schools, they would be well advised to look closely at the methods routinely employed by technology education" (p. 2). Hence while we will specifically look at technological problem solving as a model of the constructivist environment, indeed all of technology education could be looked at as a model to reform our school system.

The Technology Education Discipline

A great many people equate technology with computers. Sanders (1997) related that within the technology education field itself, this was generally not the case, however, "the fact remains that computers are technology to virtually everyone outside our field. For them, the equation reads: Computers = Technology" (p. 1). This has become a major obstacle that technology educators must overcome within our education system. While everyone would agree that computers are an important and integral tool of technology education, there is more to technology education than computers. Within the field, this equating of technology with computers has led to a debate over one being technologically literate versus computer literate. Wiens (1995) reported that "literacy is defined as having the knowledge and skills to function successfully within a given society at a given time" (p. 121). He went on to add that this definition implies that literacy means more than being able to read and write, that literacy is site and time specific, that literacy is itself in a state of flux, and that literacy exists at different levels and is situation specific. With this as a basis, Wiens (1995), quoting from Dyrenfurth and Kozak, defined technological literacy as:

> A multi-dimensional term that necessarily includes the ability to use technology (practical dimension), the ability to understand the issues raised by our use of technology (civic dimension), and the appreciation for the significance of technology (cultural dimension). (p. 121)

Computer literacy, however, might simply be defined using the first part of the technological literacy definition, that being the ability to use the computer. Zoller (1992) raised another important distinction, between being technically literate and technologically literate. Technical literacy meant having the ability to handle or use technology, and may be equated with computer literacy, although this term refers specifically to computers. Technological literacy, however, referred to the capacity to critically assess technology as a basis for rational decision making and action. So while technical literacy, which incorporates computer literacy, is obviously important, technological literacy is more of what technology education is all about. Van Horn (1991) summarized the debate for us as follows:

> Technological literacy is an exciting idea. Computer literacy was a shortsighted term. It is not enough to be computer literate, one must now be technologically literate. Knowing about a computer means knowing about only one of the many things that will change education. Becoming technologically literate means learning new things, and that is exciting. (p. 2)

Thus the goal of any technology education program should be to produce technologically literate individuals, and not just computer literate people.

If we accept the goal of producing technologically literate people, the next question becomes how should we structure the curriculum to achieve such an end? What should the focus of a technology education curriculum be? Sanders (1997) reiterated that the debate over technology being more than computers will have to be put to rest, for technology in all forms is making its way into our school systems in spite of the debates going on within the field. He added that teachers in all disciplines will be involved in technology education, and while we may not agree with the way things are being done, we must realize that as technology education teachers, we have certain responsibilities to uphold amidst this ever-changing landscape. In particular, Sanders (1997) reported that technology education teachers "must continue to demand more flexible modules from vendors whose primary motivation is sales rather than education" (p. 2). The modules needed should offer open-ended problem solving opportunities, and not consist of step-by-step procedures that in essence only masquerade education. Also, technology education teachers should do everything within their power to make certain that the school network makes its way to the technology education laboratory, and lastly, there must be a concerted effort to develop an articulated curriculum for technology education that spans the K-12 arena. There has never been a vision in place, according to Sanders (1997), for technology education as a discipline among the other disciplines within our school system.

Technology education's roots are in industrial education or what many people have called "shop" (Roberts & Clark, 1994, p. 44). Petrina (1994) reported that the profession was in the midst of a paradigm shift in the late 1980s, from industrial arts to technology education. The curriculum that was taught oftentimes reflected the clienteles' interests, motivation, or sometimes lack of both. The industrial education program became a dumping ground for those students who couldn't make it in the regular academic-type classes. Today's picture looks quite different. Technology education has demanded that the student and teacher be dynamic, enthusiastic, and ready and willing to embrace difficulties along the road to discovery. As Wicklein (1997) reported, "the era of the independent technology teacher determining the content of curriculum based on personal interests is quickly becoming a practice of the past" (p. 5). He went on to describe three criteria that are essential for implementing a convergent curriculum that addresses technology education comprehensively, and they are:

1. Identification of curriculum themes based on what we really know about the study of technology, the processes used by technologists to solve problems, and the impact technology has on society. We must be able to get beyond our infatuation with the technical gadgetry.

2. An understanding of how people learn and discerning the most effective methods for utilizing this learning. Learning theory must be a strong focal point for the curriculum we develop for technology education. This may mean challenging and possibly changing some of our existing instructional approaches to better serve the learners.

3. Commitment on behalf of the entire profession (i.e., teachers, teacher educators, professional associations, administrators, supervisors, textbook publishers, equipment suppliers, etc.) to rethink, reskill, reorganize, and apply a thematically focused curriculum in the classroom. (p. 5)

The need has become apparent, and if technology education is to take its place among the other disciplines within our schools, then a consistent and focused vision for implementing that curriculum must be put in place.

The Government of Newfoundland and Labrador (1995), in its Technology in Learning Environments (TILE) document, attempted to establish a vision for technology integration on the local scene. The results of this comprehensive study were dramatic, and their vision for technology integration into the K-12 education system can be summarized as follows:

(a) develop a technologically enriched curriculum which promotes active learning, develops links to multidimensional work and life situations, and expects students to share responsibility for their own learning; (b) use information and communications technologies to develop global learning strategies; (c) use technology to expand the concept of the classroom beyond the traditional physical and intellectual walls by creating links to other cultures, other opinions, and to other concepts of time and place; (d) provide learners and educators access to the expanding worldwide information resources and knowledge bases; (e) use a variety of real-time and time-shifted interactive information and communications technologies to create home/school/community links; to expand notions of learning, of who constitutes the learning community, and the learning time; and to increase/improve collaboration between/among learners, educators, and parents; (f) develop an infrastructure/infostructure which provides learners, educators, parents and the community with access to appropriate and timely information and services. This system will integrate the learning community with the provincial/national infrastructure/infostructure; (g) encourage learners to take responsibility for their own education by developing a community concept of lifelong learning; (h) engage the entire education community in identifying, comprehending, developing, and implementing a continuous improvement process in education. (p. 52)

This vision has been embraced by the community and at least some parts of it have become reality. The study and resulting document, however, are more a reflection of the information age we hear so much about in the media and elsewhere, so the stress on information accessibility and availability is predictable. Another major shortcoming of the document was the apparent lack of regard for the technology education field itself, as the study was more interested in determining how technology could fit into the already existing curriculum within our school system.

Other disciplines, particularly mathematics and science, have in recent years addressed their reform agendas with standards. These standards have, as Sanders (1993) noted, addressed the role of technology in their curriculum. The National Council of Teachers of Mathematics (NCTM) (1989) have certainly stressed the role of technology in their standards. A challenge has been issued then for technology education, and as Sanders (1997) reiterated, "with phase two of the Technology for All Americans Project now underway, we enter the most critical phase in the history of our profession" (p. 1). The next decade will either see technology educators become the leaders with the infusion of technology into education, or other disciplines will lead the way with technology in their respective arenas. Galluzzo (1996) reported that the standards movements in recent years have succeeded in spawning change in the structure of our education system. He offered several reasons why the public views the need for a standards-based education, and they include the following: 1) many people have lost faith in the ability of teachers and schools to deliver students to the workplace prepared to excel on the job; 2) new technology has proliferated the volume of information available to an increasingly larger segment of the population; 3) many of the reform efforts of the past have come under attack, which has fueled public skepticism and eroded confidence in education and educators; 4) low SAT scores; 5) consistently low scores when compared to other countries leads to fears that our children will not be capable of competing in the ever-increasing global economy; 6) education is becoming too much process-oriented rather than product-oriented; 7) concern over the social well being of students has lead to promotions that were not justly deserved and; 8) equity of education has eroded the excellence in education agenda. All of these reasons have led to an outcry from the public for a more standards-based education for our youth. Several of our school disciplines have conformed, and the formulation of standards have led them to reexamine their content and methods within their respective disciplines. If a call for standards accomplished this for science and mathematics, then technology education would be well advised to pursue such a path as well, if for no other reason than to place technology education within the same category of importance as other disciplines within our school systems. The public has certainly realized the importance of technology, so now is the time to solidify its place within our school environments.

Several approaches have been tried to implement technology education into our school system. Petrina (1994) reported that "simple solutions and claims to 'one best way' of organizing curriculum in technology education are suspect" (p. 45). He went on to suggest that to organize curriculum, one must deal with issues such as scope and depth of offerings; selection, sequence/order, and continuity of subject matter; orientations to and models of teaching; and the shape of learning environments. Hence the task of organizing a technology education curriculum becomes a difficult one. Draghi (1993) added another important factor to the debate over curriculum, that being the school program decision makers, who ultimately decide what curriculum gets offered and what doesn't. He reported on a study to determine the factors that influence technology education program decisions in Ohio school districts. He noted several points that are relevant to our discussion of curriculum. First, the study showed that a majority of Ohio school program decision makers perceive that they are knowledgeable and possess an understanding of contemporary technology education goals, whereas in reality they have a difficult time staying current with the rapid and substantial changes taking place within the profession. It has become critical then that technology educators seek every opportunity possible to keep school program decision makers apprised of curriculum changes within this rapidly changing discipline. Secondly, Draghi indicated that there is not a clear distinction on the part of school program decision makers between the traditional industry-focused curriculum content and the more contemporary technology-systems-focused content. This misconception could lead to a technology education curriculum that still stressed occupational skills acquisition as their primary focus. Thirdly, school program decision makers ranked student interest as the primary factor in deciding to add a course to the existing technology education curriculum, so therefore the technology educator has the task of measuring and reporting on student interest to program decision makers in order to promote and maintain technology education course offerings. The technology educator must become a strong voice in the decision to promote technology education within the schools' curriculum. According to Draghi (1993), too many misconceptions exist that could guide technology education in the wrong direction as it becomes one of the core disciplines within our education system.

Treagust and Rennie (1993) reported on a study conducted with six secondary schools in Western Australia that attempted to implement technology into the school curriculum. Their findings concluded that three of the six school were successful in becoming a technology school. However, there were a number factors identified as crucial for success of the school-based curriculum initiatives. They were:

> First, there is a need for continuous coordination by someone who has the resources (particularly time) to reflect about, and maintain an overview of, what is happening in the school. Second, there needs to be thorough documentation about what is intended and what is happening, so that faculty (particularly new faculty) are kept informed about direction and progress. Finally, success requires time, time for the faculty to accept ownership of the program, time to plan modifications to their curricula and teaching strategies, time to implement those changes, and time for them to be reflected in student outcomes. (p. 8)

With these factors in mind, it has become apparent that curriculum initiatives in technology education will not be an easy process, and one that will require considerable time and effort on the part of all involved to make it a reality. It will not be sufficient to equip schools for technology education, and hope that they have success with implementing it. Much guidance and assistance on the part of those most knowledgeable - technology educators - will be needed.

Another important factor critical to establishing technology education as a discipline has to do with the overall perception of what technology education is, what it hopes to accomplish, and how it fits within the general education curriculum of primary, elementary, junior high, and secondary schools. We have already alluded to the confusion that exists in defining technology and technology education. Daugherty and Wicklein (1993) reported to us on a study conducted with mathematics, science, and technology teachers' perceptions of technology education. They noted that the characteristics perceived to exemplify technology education were not constant across disciplines. They concluded with a number of recommendations that are worth noting, and they include:

1. The technology education profession should develop strategies to overcome stereo-typical perceptions of the discipline.

2. Technology education potential can not be fully reached until there is a clear understanding across disciplinary boundaries as to what characteristics exemplify technology education.

3. Technology education can more effectively emphasize the connections between mathematics, science, and technology education.

4. Coordinated planning that includes professionals from mathematics, science, and technology education is a critical component for the future of integrated curriculum among the three disciplines.

5. Workshops and presentations should be provided for mathematics and science teachers in an effort to improve their perception of the technology education discipline.

6. Further study should be conducted examining the public perception of technology education as a discipline in the secondary school.

7. Research should be conducted investigating methods of overcoming stereo-typical perceptions often held by associated secondary education faculty members. (p. 10)

The perceptions of technology education as a discipline then will greatly influence its development, and more importantly will effect its status as a distinct discipline worthy of our attention. Will technology education become that distinct discipline or will it become incorporated within other well-established disciplines within our school system?

Many have reported on the integration of technology education into other more established disciplines, mostly science and mathematics (Adams, 1994; Kooulaidis & Tsatsaroni, 1996; LaPorte & Sanders, 1995; Laridon, 1996; Schell & Wicklein, 1993). Sittig (1992) went further and argued a case for integration of technology into a kindergarten's language arts class. Children's literature was looked at as presenting problems to be solved, and the children went about determining ways that characters in their story books could solve their problems. This view of technology as a process seemed to be quite successful in this case. Another example, reported in Adams (1994), involved the integration of science and technology into a small rural school. In this case, the school "integrated science and technology courses into a single 'activity-oriented' curriculum" (p. 9). The new curriculum was based on recent trends in technology education, the applied academics curriculum of science, and the design technology programs from England, and according to Adams, seemed to be working quite well. This example resembled the Science, Technology, and Society (STS) curriculum, as reported in LaPorte and Sanders (1995). There appeared to be a missing part however, and that was the "Society" connection. It appeared that Adams' (1994) example left the impacts of science and technology on society for the students themselves to arrive at, which leads us to conclude that his integration model was not doing justice to the field of either technology education or science education. In another example, Laridon (1996) related the connections that mathematics has with technology education, especially in its present day approach to real-life problem solving, and its movement away from the absolutist epistemologies of the past. In all these examples, we can conclude that while there exists a place for technology education within any and all of our school disciplines, the field itself must lead the way and provide direction as to how technology gets integrated into any discipline. Otherwise, important issues and concerns will get left out and the end result will be a haphazard approach to technology education in our school environments.

McCormick (1991) related that there are well established traditions for the formulation of a technology education curriculum. The key for those involved will be to collectively share in the establishment of a direction for technology education. Technology educators will have to take a lead in this, for they are the experts, just as the science, mathematics, or English teachers led the way with their reform efforts. The science, mathematics, art, industrial arts, and design teachers all have their own respective traditions to draw upon, and as McCormick (1991) reiterated, "it is not enough to draw up good proposals for technology education; the role of interest groups that exist either in support of or in opposition to technology education must also be taken into account" (p. 51). The result can be a technology education curriculum that is one of the core disciplines within our schools.

Technology and technology education have also been looked at as a means to bring about reform of our educational system. The US Department of Education (1993) sponsored a study to determine how technology could support educational reform. The study was in reaction to the apparent piecemeal attempts at reform that seemed to get swallowed up by the various levels of an education system that preached status quo. Technology was looked upon as a means of bringing about the revolutionary changes that were being proposed. After all, "technology has transformed the workplace, and, indeed, most of our communications and commercial activities" (p. 1), so the pressure was on from the business community and the public in general to have comparable change within the schools. There was a generally held belief that technologies used in education would support superior forms of learning. The research in this area with educators and psychologists provided an important source of ideas to back up such a belief. Along with this, we had examples of successes, where we saw some unexpected benefits for students from the use of technology in education. However, there were also a number of failures. From these, we have learned that implementing technology into education without thoughtful planning and support was a futile activity. Hence, while technology can support educational reform efforts, we need to be careful in our approach to integrating it into our educational environment, and realize that there will not always be success stories.

A Case for Constructivism

Constructivism can be simply defined as a theory about knowledge, but more importantly, as Savery and Duffy (1995) explained, it "is a philosophical view on how we come to understand or know" (p. 31). Therefore, the process whereby we acquire knowledge about the world around us becomes more important in our description of constructivism than the actual knowledge we acquire. This notion of process for constructivism will be key to our connections with technology education, which we will explain later in this report. Fosnot (1989) related that the object of constructivism is to develop an "empowered learner ... who is an autonomous, inquisitive thinker - one who questions, investigates, and reasons, [and] an empowered teacher [who] is a reflective decision maker who finds joy in learning and in investigating the teaching/learning process - one who views learning as construction and teaching as a facilitating process to enhance and enrich development" (p. xi). The implications for schools are obvious. Brooks and Brooks (1993), in promoting a constructivist environment, presented us with a vision of a new school with a whole new set of images. The images of control that dominated past schooling are gone in favor of:

> images that portray the student as a thinker, a creator, and a constructor. Schools can become settings in which students are encouraged to develop hypotheses, to test out their own and others' ideas, to make connections among 'content' areas, to explore issues and problems of personal relevance (either existing or emerging), to work cooperatively with peers and adults in pursuit of understanding, and to form the

disposition to be life-long learners. (p. 126)

This becomes the school that present day educational reform efforts strive for. The research literature on constructivism advocated that this environment is possible if there is a concerted effort on the part of all stakeholders connected with education to make it a reality.

Savery and Duffy (1995) offered us a characterization of constructivism as consisting of three primary propositions. First, understanding comes about as a result of our interactions with the environment. This has been identified as a core concept of constructivism. What we understand can be viewed in terms of the content, the context, the activity and the goals of the learner. This suggested that understanding was an individual undertaking, which means that we cannot share understanding, but rather can test our understanding against others. Secondly, constructivism involved cognitive conflict or puzzlement as the stimulus for learning and determiner of the organization and nature of what gets learned. There has to be some goal for learning, and that goal becomes the primary factor in determining what the learner attends to, what prior experiences the learners brings to bear in constructing understanding, and what understanding in eventually constructed. Thirdly, constructivism involved the evolution of knowledge through social negotiation and through the evaluation of the viability of individual understandings. Hence, while understanding itself may be looked at as an individual affair, we use the social surroundings to test our understandings, and in essence, reformulate our learning based on this interaction. Others share similar views on this notion of social negotiated knowledge (Pannabecker, 1991; Yackel, Cobb, Wood, & Merkel, 1990) The concept of knowledge is not absolute truth, but rather the most viable interpretation of our experiential world.

Hill (1995), in his review of Hopkins' Narrative schooling: Experiential learning and the transformation of American education, reiterated the importance of the experiential world and noted that "learning occurs in the process -- not altogether prior to the process" (p. 1). Strommen and Lincoln (1992) agreed that the processes by which children create and develop their ideas is central to constructivism. Hence, constructivism, by its very nature, presented us with a view of learning as a process that our old teaching method of transmission failed to accommodate. Strommen and Lincoln (1992) concluded that this has created a rift between the teaching and learning in the schools and the ways of obtaining knowledge in society at large. Therefore, what we have seen is an estrangement of the schools from society, and from the children who live in it. This seemed to be somewhat of a harsh account of the situation and only partially true, for there are obviously examples where this is not the case. It has led however, to schools in general, and specific disciplines in particular, to rethink their approaches to teaching and learning within their respective areas. It has resulted in a switch in focus for education from being primarily based on behaviorism to being based on constructivism.

This shift in focus from behaviorism to constructivism has parallelled the shift that has occurred in technology education. Johnson and Thomas (1992) related that traditional industrial arts instruction, with its emphasis on the development of specific skills, was based on behaviorist notions. Technology education, with its emphasis on improving student understanding and thinking skills, parallelled constructivist ideas. This research in the area of cognitive science has provided us with new ways of teaching and clarified instructional strategies by identifying where and when they can be most effective. For the teaching of technology education, Johnson and Thomas (1992) presented five general principles that are worthy of our attention. They included making thinking and learning easier by helping students organize their knowledge, building on what students already know, facilitating information processing, facilitating deep thinking, and making thinking processes explicit. We can help students organize their knowledge by teaching them to use strategies such as concept mapping, or other visual representations. Prior knowledge has already been identified as a key component of the learning process, and strategies such as advance organizers, or the use of analogies could help ensure that students have the prerequisite knowledge that is needed to understand and remember something new. We can help facilitate information processing by providing a real life context for instruction. By using techniques such as modeling, where the technology teacher him/herself routinely models solving unfamiliar technological problems, the students are able to see the procedures being employed, the errors being made, and the difficulties one faces when coming up with solutions. In order to facilitate deep thinking, students could be asked to elaborate on the material, to work in cooperative groups, to explore peer tutoring or to work in pairs to solve a problem. The strategy of thinking aloud, also reported in Duncan (1996), could be employed here to further enhance students thinking abilities. Finally, in order to make thinking processes explicit, a strategy such as reciprocal teaching could be employed. This involves students themselves taking on the role of the teacher. While this may not be prevalent in technology education, the potential certainly exists for it to become so. If students have to teach what they understand about a concept, it would make their understanding even more meaningful. Therefore, as Johnson and Thomas (1992) reiterated, "because a primary goal of technology education is to improve student understanding and thinking skills, a constructivist learning theory is more appropriate" (p. 7). We next turn our attention to the instructional strategies used in technology education that exemplify this constructivist environment.

A Problem Solving Approach

Technology education uses a problem solving approach in much of its daily routine. Problem solving may be looked at as one of the many instructional strategies used in technology education, but one that has received a great deal of attention in recent years. Other disciplines, particularly mathematics and science, have also investigated such an approach in the teaching and learning of their disciplines (Barba, 1990; Krulik & Rudnick, 1994; Roth, 1993; Silver, 1994; Taback, 1992). Wu, Custer, and Dyrenfurth (1996) reported as well that "problem solving has been identified and promoted by many disciplines including mathematics, psychology, the physical sciences, the arts, and more" (p. 1). Our argument will be that the problem solving approach employed in these disciplines, and in particular in technology education, is a good model of a constructivist environment described in a previous section of this paper. Before we look at the problem solving approach used in technology education, let us first define the term instructional strategies. For most people, instructional strategies refer simply to teaching methods, but as Schwaller (1995) reported, they are much more than that. He related that "instructional strategies are used to describe all of the elements that comprise the teaching/learning process" (p. 422). These included the way material was presented or the delivery system, consideration for learning theory, student motivation, approaches used to teach the content of technology education, the use of higher order thinking skills, and teaching in the different domains of knowledge, which included the cognitive, psychomotor, and affective domains. Thus the simple interpretation of the term was not sufficient enough to explain its full meaning. Problem solving also has many meanings depending on the context in which it is used. Boser (1993) reported on its many meanings to include: "(a) a teaching method that encourages active learning, (b) a generic ability to deal with problem situations, (c) a method used in such subjects as mathematics and science, or (d) an empirical investigation" (p. 1). In addition, others may describe problem solving as a higher-order thinking skill and a way of learning. Whatever the view, problem solving can be seen as a teaching method, or more appropriately as an instructional strategy, and as Boser (1993) pointed out in his study of the development of problem solving capabilities in technology teacher education programs, "technological problem solving refers to the systemic way of investigating a situation and implementing solutions" (p. 1).

There are a number of instructional approaches currently being used in technology education. Boser, Daugherty, and Palmer (1996) related that "technology teachers use a variety of instructional approaches such as interdisciplinary technology education, self-paced modular technology education, and problem-centered technology education to inform students about technology and its affects on society" (p. 1). Much debate in the field concerns which approach is best to use in technology education. Schwaller (1995) reported that there are currently five approaches being used in teaching technology education. They included a systems approach (see Figure 3.1), an interdisciplinary approach, a social/cultural/environmental approach, a conceptual approach, and a futuring approach. The systems approach, as depicted in Figure 3.1, "provides the teacher with the flexibility to teach the total concept of technology education, and it facilitates students' learning about technology as a whole, rather than just the individual segments or parts that make up the whole of technology" (p. 432). The advantages of using this approach, according to

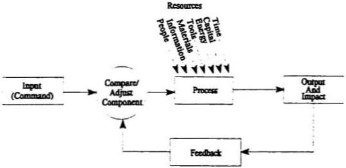

Figure 3.1: All Technologies can be Studied Using the Systems Model.

(Note: Source for Figure 3.1 is Schwaller, 1995, p. 432)

Schwaller (1995), included the following:

> (a) specific technologies can be taught as they relate to solving problems in each of the technological areas in the study of technology education; (b) each activity in the technology education classroom can have meaning to a larger social/cultural problem; (c) students can constantly see the impacts, both positive and negative, of each technological system; (d) students can see how each specific technology relates to the overall technological system; and (e) students can be encouraged to think in the analysis and synthesis levels of the cognitive domain. (p. 433)

The interdisciplinary approach allowed the technology education teacher to draw upon other disciplines when teaching. The previously mentioned Science, Technology, and Society (STS) movement was an example of such an approach. Some of the advantages to such an approach involved the cooperation among teachers, the broad perspective from which students can view the content, and more meaning being placed on technology education because of its connection to other disciplines. The social/cultural/environmental approach involved teaching technology education as the content related to our society, culture, and environment. Problems within these three areas are addressed, and the impacts that technologies have on them are central. Many advantages can be gathered from this approach as well, including the study of technological impacts, the interrelationships of technology with society and social institutions, and improvements in students' decision making capabilities about technology. The conceptual approach viewed technology as being very broad and rapidly changing, hence a study of specific concepts and principles about the technological system are undertaken. This approach has the advantages of teaching concepts, which remain more constant than specific technologies, and making the overall curriculum easier to manage. The futuring approach involved forecasting future problems and taking steps to solve them. Such techniques as trend analysis, scenario development, and cross-impact analysis are used in this approach. The main advantages included involving students in realistic problems, enhancing student creativity, and enabling students to think and learn using higher level thinking skills such as synthesis and evaluation. Whatever the approach used, all stressed the ability to solve problems, both routine and non-routine, as being central to their technology education program. Other researchers would agree that problem solving should be a key ingredient of any technology education program, and such a program should even teach problem solving methodologies (Harstein & Cohen, 1996; Mioduser, 1996).

Johnson (1994) went on to offer us some strategies that could be used for teaching problem solving. The teacher's role is crucial for establishing an environment that fosters problem solving rather than inhibits it. Some strategies that could help a teacher in this regard included a focus on processes rather than just information, an effort to develop experts rather than novices, explicit teaching of problem solving, doing problem solving rather than exercise solving, structuring problem solving activities around rich, real-world problems, emphasizing problem solving competencies rather than stage models, and providing opportunities to practice problem solving. Technological problem solving is a complex task, both for the student and for the teacher. An effort must be made, however, to make it an integral part of any technology education program, because the benefits to the students in the end justify the time and energy invested. In Volk's (1993) study of technology education in developing countries, for example, "the most important guideline suggested the encouragement of creative thinking and problem-solving skills [and] a goal that may be developed from this guideline would be to structure technology education programs in order to encourage such skills" (p. 80). Patrick (1993) stressed the teaching of problem solving as well. He listed demonstration and practice as essential steps in the process, but also emphasized cooperative learning experience, where students worked together and learned from each other. In particular, brainstorming and thinking aloud were two of the methods that would lead to improvement in students' problem solving abilities. The top-down problem solving methodology (see Figure 3.2), highlighted by Patrick (1993), was a common problem solving

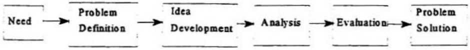

Figure 3.2: Top-Down Problem Solving Method

(Note: Source for Figure 3.2 is Partick, 1993, p. 3) approach used in engineering and science, and could certainly be applied to technological problem solving. While this model was an improvement over past bottom-up type models that stressed trial and error, there was still considerable room for improvement.

The Government of Newfoundland and Labrador (1996), in its curriculum framework for technology education document, emphasized design as a problem-solving strategy to be employed in technology education. The model (see Figure 3.3) was based on a marketplace model and incorporated the development of a design brief. Ritz and Deal (1992) explained that "design briefs are instructional tools used to stimulate creativity, critical thinking and problem solving abilities of technology education students" (p. 33). The cyclical nature of

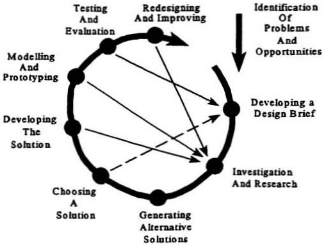

Figure 3.3: Cyclical Design Model

(Note: Source for Figure 3.3 is Government of Newfoundland and Labrador, 1996, p. 56) the design model was the biggest improvement over earlier models, which were more unrealistic in the linear nature. Problem solving can be seen as a very interactive activity, and students should not be forced to follow a step-by-step methodology in solving problems. Such linear methodologies go against the preachings of the constructivist movement as well, for they restrict students in their quest for understanding, when they have a formula to follow to arrive at a solution. The cyclical design model, on the other hand, fostered transactional teaching techniques (enquiry, activity, design and problem solving) being employed in the technology education classroom. The Government of Newfoundland and Labrador (1996) recognized that these techniques "tend to be a natural approach for technological problem solving. This is a constructivist approach which assumes that knowledge is constructed in the mind of the learner. It is based on teacher as facilitator, student as performer and learner. By engaging in design experiences which draw on connections with life experiences outside the school, students construct new knowledge" (p. 58). This summarized what technological problem solving was capable of achieving and could certainly be a model for other disciplines to follow in their quest to establish constructivist environments within their classrooms.

The design process is but one of five problem solving processes reported by DeLuca (1992). In his study, the design process was used always or usually by 79.7% of the teachers he surveyed. Other processes have potential for technology education, however, and they included:

1. Troubleshooting/Debugging: Isolate the problem, identify possible causes, test, implement solution, test solution.

2. Scientific Process: Observation, develop hypothesis, experimentation, draw conclusions.

3. Design Process: Ideation/brainstorm, identify possible solution, prototype, finalize design.

4. Research and Development: Conceptualize the project, select research procedure, finalize research design, develop proposal, conduct research, analyze results, report results, evaluate research project.

5. Project Management: Identify project goals, identify tasks to reach the goals, develop a plan to accomplish the tasks, implement the plan, evaluate the plan. (p. 26)

Whatever the problem solving process employed, the most important outcome from a teachers' perspective, should be what students experience during the process of solving problems. The true benefit to students would be for them to become good problem solvers able to deal with our complex and ever-changing world.

Problem solving approaches are many and varied, but according to the research literature, they are an essential part of any technology education program (Garcia, 1994). Lee (1996) offered that problem solving become the intent and content of technology education. He warned however, that more research and development efforts are needed in order to comprehend how to employ a problem solving approach effectively in technology education. What gets preached in theory sometimes doesn't always get lived out in practice. The generally feeling among the field however, was that problem solving as an instructional strategy would be beneficial, so the climate was right to put the necessary supports in place and institute a change in actual practice.

Conclusion

The future for technology education certainly looks bright. The field itself is a very dynamic one, and while it can be considered a relatively new field, it does look to its roots with industrial arts education. From here, some of the older traditional ways of teaching and learning have carried over to today, only with newer, more modern day tools and equipment. These methods are slowly disappearing however, and the field is moving forward, and establishing its own identity as a distinct discipline worthy of our attention. Problem solving methodologies are central to today's technology education programs, and these methodologies can be looked at as a model for other disciplines to follow in their quest to have their students become good problem solvers. More importantly, the notions of constructivism, where students, either individually or cooperatively, construct their own understandings of phenomena, are an integral part of technology education today. Possibly, this is what the field needs to do in order to gain more prominence among the other fields in education. By adopting such a philosophy as constructivism, the field would have a theoretical basis on which to move forward, and the success of any future programs could be measured from that basis.

Society in general has recognized the importance of technology, and all of the major disciplines have stressed its importance in their recent reform agendas. Integration of technology into other disciplines is a common practice today. The technology education field itself, however, contains a wealth of teaching and learning strategies, and has a great deal to offer other disciplines as they move forward. The time has come for the technology education field to become more involved in future research and development efforts. Only through research can the field grow in importance and become a model for other fields to follow. As we have said earlier, the methodologies employed by the technology education field are the ones that other fields are struggling to implement. With more technology education research, these techniques and methods will be available for others to critique, and modify to suit their own situations. The benefits will not only come to those other disciplines, but to the technology education field as well. Technology educators must lead the way in a renewed research agenda, that will help guide our education system into the next century.

Summary and Implications

Constructivism has been described as a theory of teaching and learning. Some would argue that "theory" is not what is important in education, but rather "practice". One cannot exist without the other. Behind all good practice in the field of education lies some theory. They, in essence, co-exist in the field. One cannot separate the two, although many of the current educational documents dealing with curriculum in our schools show an absence of theory. More specifically, the absence is that the theory is not explained, but rather is implied by the very essence of the documents. Hence the readers, which are usually teachers within the schools, are left with a set of outcomes, and suggestions on how to implement the curriculum to achieve these outcomes, yet do not have the theoretical basis on which these outcomes are based. Some would argue that teachers would only ignore the section on theory anyway, and while that may be true in some instances, it would not always be the case. The time has come to inform teachers more of the theory behind certain curriculum developments and to let them internalize that theory so that it becomes more entrenched in their everyday teaching. Leaving the theory underlying teaching and learning practices to educational journals does not suffice either, for many teachers do not read educational journals on a regular basis. Most do, however, read the curriculum guides and related documents concerning the courses they teach.

With a theory such as constructivism, and all that it implies, a mere surface treatment of the concepts is not enough to fully bring about implementation of the ideas involved in establishing a constructivist atmosphere within our classrooms. Education today is too much based on formula and set procedure, where if you as a teacher do these activities and teach in this way, then there will be favourable results for the majority of your students. This scenario is too much like the older and often outdated theories of behaviorism and positivism. The implications of a theory such as constructivism then are far-reaching and affect every stakeholder in our education system, including students, parents, teachers, administrators, teacher education programs, governing bodies, school board personnel, curriculum development teams, and so on. There are also a number of implications for further research in this area, particularly as we move forward with constructivist notions permeating some of our disciplines within the schools, especially mathematics and technology education.

Probably the most immediate impact on education and in particular on curriculum comes about with the establishment of new programs for our schools. This is most evident when new courses and programs are been field-tested for our schools. It is here that a group of teachers test the program and collectively modify, adjust, and sometimes rewrite the guides that will eventually become the main resource for future teachers of these programs. This makes the job of the curriculum development teams, and those field-testing the programs, crucial for the eventual outcome of a certain program. What is lacking from these stages of program development is an explanation or discussion of the actual theory underlying the approaches being suggested in the programs. If technology education or mathematics, for example, promotes problem-solving as a main goal of their respective disciplines, then a discussion should ensue about the very nature of problem-solving and what development of problem-solving skills will do for our students. This can only happen if we step back and look at the theory behind the practice and have an opportunity to examine, critique, and evaluate the theory as it applies to our own situations. Just as constructivist notions allow students to form their own understandings of a certain event or situation, so too should teachers be allowed to form their own understandings of a particular teaching and learning style. Framework documents and curriculum guides that have been written for specific disciplines have not given teachers that opportunity. The intent is good but there needs to be that added discussion of theory, rather than just a concentration on practice.

As a follow-up to these program guides, in-service and conference proceedings should also have a component on theory. Many in-service sessions lack that at the present time. A recent mathematics in-service in this province, for example, made no mention of the notions of constructivism, which form the basis of the NCTM standards that guide the reform movement in our province. There was too much concentration on practice, and giving teachers a model to follow in their teaching practices. It would have been best to let teachers experience what they would want their students to experience, to let them problem-solve so as to gain a better understanding of the processes involved and to let them discuss the ideas behind a theory such as constructivism. The research literature on constructivism certainly supports such an approach to teacher in-servicing and indeed to teacher education programs as well. There must be more careful planning put into teacher education programs so that teachers themselves experience the same frustrations as students would. The technology education training program in this province has taken a step in the right direction toward achievement of this end. The challenge has been issued then toward those that decide on in-servicing and teacher education to make that critical jump beyond just giving teachers a specific model to follow, rather let them evolve their own model over time, based on good sound theory about the teaching and learning process.

We have begun to cross over the gap between theory and practice, at least in mathematics and technology education. While there remains considerable work to be done on improving the system, at least we have taken a step in the right direction. The mathematics discipline has made a concerted effort over the past several years to reform the approach it takes toward mathematics, and while there still remains much work to be done in this area, the process has at least started, and is gaining more acceptance among the various stakeholders in the mathematics community. Various levels of government within our school system have recognized the importance of this reform movement and have made significant strides toward its achievement. Students, parents, and the general public have in recent years become a stronger voice in these movements, and have speeded up the process of reform in a number of instances. Administrators, while sometimes restricted by their superiors, need to become leaders in these reform efforts, and need to guide their school communities toward these new practices based on constructivism. The whole school improvement movement should become a basis for these reforms, for a shift toward a constructivist environment can be looked at as school improvement. At the very least, the school will be viewed as looking forward to the future, and not harking on the past, in its efforts to prepare students for the challenges that awaits them as we move into the next century.

Another area that will be impacted significantly by these constructivist notions will be the area of educational research. Much of the literature calls on teachers themselves to become researchers in their own field, for they are in the midst of the subject of most research. With a movement toward constructivist ideals, at least in mathematics and technology education, researchers will have to be constantly studying the overall effects of such a shift. Does a constructivist environment increase student performance? Only time and research can tell us the answer to this very important question. Are there further modifications that must be made with the theory of constructivism to make it better suit our educational settings? Again, only research into this area can provide an answer. The challenge has been issued then to all researchers, be they classroom teachers or not, to continue with their work of determining just how effective constructivist principles are as they relate to the various disciplines within our schools.

In summary, the implications of a theory such as constructivism can be dramatic on our education system. Various stakeholder groups have to maintain their roles in the process as we move toward more constructivist ideas, especially in the fields of mathematics and technology education. Those that have a direct influence on the classroom teacher, be they board officials, administrators, or government officials, must begin to generate discussions on the merits of such theories, and with educational research as their support, must continue to affect change within our education system. Teachers too must play a critical role in this change process, for ultimately they are directly impacted, as are students and parents. In all, a collective effort toward reform must be made if it is to become a reality.

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