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PHYSICS TEACHING AND THE DEVELOPMENT OF THINKING SKILLS

A Dissertation Presented

by

ISAAC KING AMUAH

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University of Massachusetts in partial fulfillment
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Education

PHYSICS TEACHING AND THE DEVELOPMENT OF THINKING SKILLS

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ABSTRACT

PHYSICS TEACHING AND THE DEVELOPMENT OF THINKING SKILLS

SEPTEMBER 1989

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In the last decade there has been a great deal of interest among educators and researchers in the need to teach thinking in the schools. There are differences of opinion, however, as to what constitutes thinking, why it is necessary or desirable that students should be taught to think, and how such teaching can be accomplished. Equally of interest to researchers and educators is whether thinking can be best taught in a "content-free" way, say in stand-alone courses that are adjuncts to the standard curriculum, or as an integral part of the traditional content courses. This study was based on the premises that there are certain aspects of thinking that are teachable and that this could be achieved through instruction within the content of the subject.

This study examined the effects of teaching high school physics teachers (N=4) to improve thinking among their students through physics instruction. Teachers in experimental classes received training (3 one and one-half-hour sessions) on how to infuse and teach thinking skills in their day-to-day physics lessons. All students (N=168) in both the experimental and control classes completed physics and thinking skills pretests in September and posttests in December. Six students from each of the groups were interviewed in December to obtain verbal protocols of students' use of thinking skills in solving physics problems. Teachers' classroom instructional behaviors were videotaped to obtain a measure of post-treatment student behavior and classroom processes.

Results showed better performance on the physics and thinking skills posttests by students in the experimental classes. The study showed that initial ability in physics affected how students responded to the treatment. The between-classes analyses indicated that the instructional strategy had a more positive impact on higher or medium ability students than on lower ability students in terms of physics achievement scores. In the within-classes analyses, the lower ability students benefited more from the treatment than the higher ability students. It was also observed that the effect of treatment was independent of gender. Finally, age affected students' response to the treatment.

TABLE OF CONTENTS

Chapter

APPENDICES

LIST OF TABLES

Table

LIST OF FIGURES

Figure

CHAPTER 1

INTRODUCTION

The Teaching of Thinking: A Historical Perspective

In Plato's Republic, Socrates, we are told, admonished the citizens of ancient Greece that their offspring should be educated and assigned by merit to three classes: rulers and thinkers, auxiliaries, and craftsmen. Socrates went further to advise that every decent and stable society must ensure that these ranks are honored and that citizens accept the status conferred upon them (Gould, 1981). "But how can this acquiescence be secured?" asked Glaucon, a curious student of Socrates. Socrates, unable to devise a logical argument, fabricates a myth. With some embarrassment, he tells Glaucon:

> I will speak, though I really know not how to look you in the face, or in what words to utter the audacious fiction...They [the citizens] are to be told that their youth was a dream, and that education and training which they received from us, an appearance only; in reality during all that time they were being formed and fed in the womb of the earth. (Gould, 1981, p. 20).

Glaucon, overwhelmed, exclaims: " You had good reason to be ashamed of the lie which you were going to tell." " True," replied Socrates, "but there is more coming; I have only told you half."

> Citizens, we shall say to them in our tale, you are brothers, yet God has framed you differently. Some of you have the power of command, and in composition of these he has mingled gold, wherefore also greatest honor; others he has made of silver, to be auxiliaries; others again who are to husbandmen and craftsmen he has composed of brass and iron; and the species will generally be preserved in the children... (Adapted from Gould, 1981, p. 21)

A fanciful tale, to be sure, but consider the fact that the same tale, in different versions, has been promulgated and perhaps believed until the beginning of this century. Though the justification for ranking groups by inborn worth has varied with the tide of Western civilization, it is worth noting that the spirit of Socrates' concepts of an ideal society had until the dawn of this century influenced almost every decision pertaining to the education of citizens of every nation. Formal schooling, which originated from ancient Greece, became the primary agent by which the stratification of the society (and for that matter Plato's myth) could be validated.

Thus, formal schooling, whether in the United States or anywhere else, from the onset was not designed to provide for the same education of the whole population. It was geared toward a selected few who would end up becoming the elite in the society. This elite constituted the so-called thinkers, rulers and kings of the society. The others received an education also, but of a different sort.

A critical examination of the history of education in the United States demonstrates that the Socratic principle influenced heavily the educational policies of this country until the early part of the twentieth century when the status quo was undermined as a result of social, political, and economic changes.

The eighteenth century was one in which education for the youth in the United States was largely classical in nature. Classical in the sense that the Latin Grammar schools showed no evidence that science was part of the academic curriculum [Fay, 1931 (a)]. The function of these schools was the teaching of Latin and Greek. The belief then was that learning the logic imbedded in Latin, for example, should yield improved performance in general thinking abilities or better learning in other seemingly unrelated fields(cf. Perkins et al, 1989). Even today, the argument is often made that learning to program computers in a powerful language such as LOGO should improve students' reasoning and thinking abilities.

It should be acknowledged that a variety of studies, initiated as far back as the turn of the century, generally failed to uphold these predictions. Thorndike and Woodworth (1901, 1923) reported experiments, some on a large scale, showing that training in such fields as Latin and Greek has no measurable influence on the cognitive functions, thus dispelling a then prevalent belief promulgating a "classic" education.

The academies which began to appear in the middle of the nineteenth century rejected the nearly exclusive emphasis on the classics. Instead, utilitarian values and practical outlook became the criteria for including a subject in the curriculum. The academies started offering courses in mathematics and science.

The worth of a subject in the early 1900's was still largely measured in terms of its value in training the mind's faculties (mental discipline). At the turn of the century, physics instruction, and for that matter science, was reputed to have formal discipline value, and achieved a prestigious position in the curriculum similar to the one possessed by the subjects of mathematics and Latin [Fay, 1931 (b)].

Historically, if we examine educational institutions during the period between the eighteenth and nineteenth centuries, we see that the academies and the Latin Grammar schools did not treat education of the whole school-going population as within their purview. Schools for the whole school-going population (or the masses) originated from a different root and are a much more recent phenomenon in the history of education in this country. Specifically, mass education in this country began at the turn of this century and the idea was reinforced after the second world war. Education for the masses derives from what Resnick and

Resnick (1977) call the "low literacy" tradition, aimed at producing minimal levels of competence in the general population. It must be stressed that the mass education system which evolved focused on elementary education. Almost everyone went to elementary school, although few finished the entire eight-year course. The elementary schools served the masses and concerned themselves with basic skills of reading and computation, and with health and citizenship training (Resnick, 1988). Secondary school education was still exclusive, despite the fact that elementary education was made available to the bulk of the school-going population.

Early in the twentieth century, responding to changing economic and social conditions, more and more of the younger population began to seek high school education, and educators gradually began to treat secondary education of a much larger and more varied population as being their concern (Resnick, 1988). Over the next few decades, the secondary schools were to become the mass institutions that the elementary schools had been.

The growth of this new secondary school population marked the beginning of a debate that continues even today. As a result of this growth, the question that was debated among educators was, "what should be the appropriate curriculum for the secondary schools to accommodate the unique and diverse needs of high school students?"

The debate led to the formulation of new objectives for the secondary schools by various educational organizations, but the most influential report was published by the National Educational Association in 1918. The report was prepared by the Commission on Reorganization of Secondary Education, and appeared in a publication entitled the Cardinal Principles of Secondary Education. The report, among other issues, provided a theory and reason for the place of a vocationally-oriented curriculum in the high school as part of a diversified secondary program adapted to the different types of students. The following objectives were enumerated in this report: "1. Health. 2. Command of fundamental processes. 3. Worthy home membership. 4. Vocation. 5. Citizenship. 6. Worthy use of leisure. 7. Ethical character" (NEA, 1918).

A committee under the leadership of Otis Caldwell attempted to adapt the methods and concepts of science to the seven cardinal principles. For this reason, an overriding theme of Caldwell's committee was an endeavor to relate science courses to the problems concerning the students' environment (Fray, 1931 (c)).

The redefinition of goals for secondary education undoubtedly encouraged the development of physics courses which were informational and utilitarian in character, in order to meet the needs and interests of pupils. One result was the emergence of textbooks that were repeatedly "watered down". Such titles as

Physics of the Household, and Everyday Science appeared in the classroom (Gatewood, 1969). It was widely believed that, due to the coming of the technological age, students should study more useful facts and less of subjects considered abstract. "The pupils should learn something useful to them. Socially significant topics, such as Our Water Supply were introduced because when the well was near the barnyard, typhoid and other water-borne diseases were commonplace" (Watson, 1967).

Two courses in physics began to evolve, one for the college preparatory students, and the other for the terminal high school pupil. The college preparatory physics course was mostly offered at the academies or the private schools, which only a minority of high school-going population attended. The curriculum at these schools was strictly academic. In other words, emphasis was placed on extensive reading and writing, textual criticism, and the like, which were believed to promote creative thinking, or problem solving. The practical course (terminal physics) employed the use of laboratory manuals, many of which contained instructions for measuring quantities in spoonfuls instead of cubic centimeters. Although today, we may not easily recognize that the nineteenth-century academy curricula inculcated thinking and problem-solving skills, it is fair to suggest that the academies or the private elite schools, to a considerable extent, succeeded in developing intellectual performance beyond the ordinary.

The tension between vocationalism and traditional disciplines as the center of the high school program has never been resolved. Responding to post-World War II manpower needs, the 1950's and early 1960's saw a greater emphasis on traditional disciplines, especially mathematics and science. However, developments in the later 1960's and 1970's led to a complete abandonment of traditional core curriculum, even for students in the elite private schools. Though schools continued to require academic courses, the requirements were often minimal and the course content focused increasingly on application and practical topics, often replacing more traditional, demanding material (Resnick, 1988). The consequence of these developments, according to Resnick, was that activities that engaged higher order skills all but disappeared from the curriculum.

The effect of all these changes has been to reduce, and sometimes to drive out of existence, the high literacy or thinking skills objectives that had been the focus of the academies and their preparatory institutions (Resnick, 1988, p.18). It must be stressed, however, that the taste for such objectives has survived and can be seen in recent efforts to revive interest in higher-order thinking skills teaching. This revival takes place in an educational and social context that dictates an extension of high literacy goals to a broader segment of the American population than has ever before been considered capable of such learning. In reflecting on this trend, Resnick (1988) expresses her sentiments in this way: "Today, we are committed to educating all Americans in the secondary schools and a large proportion (higher than in any other country in the world) in some form of post-secondary institution. These students' educational needs cannot be met by traditional vocational programs that no longer prepare students for productive participation in an increasingly diversified economic environment" (p. 8.).

Importance of the Problem

Despite the many calls and efforts to refashion educational practices to cultivate more thoughtful learning within and across subject domains, the fact of the matter is that most educational practices remain doggedly committed to imparting facts and algorithms. Regrettably, E.D. Hirsch (1987) and others have even based their negative arguments on recent studies showing high school students ignorant of basic geography and history facts and have urged that schools should reduce attention to higher-order thinking skills so that more time may be given to building students' factual base in a subject.

This seems particularly unfortunate. The argument for the teaching of higher-order thinking becomes more compelling than earlier times when one considers that employers are seeking prospective employees who have the ability to write and speak coherently, the ability to learn easily on the job, the ability to use quantitative skills needed to apply various tools of production and management, the ability to read complex material, and the ability to build and evaluate arguments (Resnick, 1988). The abilities demanded of high schools today go well beyond the routinized skills of the old mass curriculum. In fact, in the 1983 College Board book, Academic Preparation for College, the abilities listed above are listed as paramount for college-bound students.

Though it is a laudable idea for high school students to acquire these abilities, teaching such competencies to the mass of students remains a formidable challenge. The calls for increasing thinking and reasoning skills among high school graduates are not really new to educators. In fact, as indicated in the opening pages of this thesis, teaching thinking abilities has been the goal of some schools as far back as the time of Socrates and Plato. What is new about the current debate is the call to include thinking skills in the curriculum of every school. Lauren Resnick, one of the leading voices on the new drive for teaching thinking, expressed it best when she said:

> It is possible to take seriously the aspiration of making thinking and problem solving a regular part of a school program for all of the population, even

> minorities, even non-English speakers, and even the poor. It is a new challenge to develop educational programs that assume that all individuals, not just an elite, can become competent thinkers (Resnick, 1988, p. 7).

This new challenge also raises the question: Can teachers encourage thinking in their day-to-day teaching of content academic subjects? This thesis seeks to answer this question.

The Research Problem

There have been several other seemingly successful efforts to teach thinking skills of some generality in recent years. For example, the development and testing of Project Intelligence, a general course to teach skills of problem solving, decision-making, inventive thinking, and other sorts (Herrnstein, Nickerson, Sanchez, and Swets, 1986) and the guided design perspective developed by Wales and his colleagues (Wales & Nardi, 1984; Wales & Stager, 1978) provide instances where attempts have been made to teach thinking skills. A general resource of reviewing many such programs is Nickerson et al. (1985). The collection edited by Segal, Chipman, and Glaser (1985) offers somewhat earlier assessments of several of these programs. Resnick (1987) has authored a monograph appraising the promise of work in this area, with cautiously optimistic conclusions. It is important, however, to point out that almost all of the work done so far in this area deals with the teaching of general thinking skills, and very few projects deal with the development of physics instructional materials that enhance the acquisition of content knowledge in physics as well as thinking and learning skills. It is the view of this author that much could be accomplished if we effectively use existing knowledge about human cognition in developing physics instructional materials. It is the firm belief of this investigator that if this approach is critically examined, it may have significant impact on the problems of thinking and learning skills of black students in South Africa, and among inner-city students in the United States.

While understanding science may be a necessity for functioning well in this scientific age, evidence is ample that many students in the South African black school system and the public schools in the United States never acquire the skills necessary to learn and make use of scientific concepts and phenomena.

In the United States, it is reported that science-related corporations and firms seem reluctant to hire workers with little or no knowledge of science because they view them as more likely to injure themselves and their fellow workers, and furthermore they view them as more likely to cost the corporations or the firms large sums of money for instruction in basic science (Lauterhorn, 1981 cited from Locke, Spirduso, & Silverman, 1987). Of 800 companies Lauterhorn (1981) surveyed, 35% thought it was necessary to supplement their employees' education with basic science and English. The increasing sophistication of modern weaponry and support equipment, along with the failure of the armed forces to attract more highly educated recruits, has led the United States army to invest $37,000,000 over a four-year period in the research and development of instructional systems in basic science, English as a second language, and cognitive learning strategies (Begland, 1981). Thus, ability to understand scientific principles and phenomena is of more than personal benefit; it is related to the economic and defense interests of this nation.

Moreover, a number of research studies on the "thinking abilities" and cognitive skills of students finishing high school or entering college draw the same conclusions (Karplus, 1974; Renner & Lawson, 1973; Tomlinson-Keasey, 1972): "It is possible to finish 12 to 13 years of public education in the United States without developing much competence as a thinker. Many students are unable to give evidence of a more-than-superficial understanding of concepts and relations that are fundamental to the subjects they have studied, or they cannot apply the content knowledge they have acquired to real-world problems" (Nickerson, 1988, p.3). These observations make a compelling case that something must be done to improve the level of thinking in our schools.

Recently, investigations of educational achievement among black students in South Africa and minority students in the United States reveal certain targets for educational improvement that seem relevant across virtually all subjects and grade levels (Resnick, 1988; Mehl, 1986):

- Improved general skill of thinking and learning
- Better understanding of key concepts in the subject matter.

With respect to improved skills of thinking and learning, many educators believe that educational systems in general have not done as good a job as possible in teaching students how to think. The present instruction in schools does little to encourage critical thinking or to convey learning skills by which students can equip themselves with better understanding and wider content mastery (Lochhead, 1987).

As to better understanding, key concepts in science routinely escape the grasp of the majority of students who instead focus on rote facts, definitions and formulae. Undoubtedly, the difficulty derives in part from our limited understanding of human cognition and its development. In spite of many years of observation and speculation, and a few years of research, very little is understood today concerning how the mind works, and what can be done to facilitate the realization of its potential. It seems likely that the problem is only partially one of lack of knowledge. While there clearly is a great need for research on cognition, cognitive development, and how that development can be enhanced, there are reasons to believe that much might be accomplished if existing knowledge were more effectively applied to improve students' thinking skills.

Considering what it is known today about human cognition, there is little doubt that well-prepared physics instructional strategies, and materials for teachers and students, can enhance general thinking and learning skills and better understanding of physics concepts, and consequently improve student learning outcomes. It is no exaggeration to state that physics texts used in schools and physics instruction in general do not encourage students to engage in creative and critical thinking. More importantly, they do not inculcate into students the necessary learning skills that will help them to better understand key physics concepts. The problem is how to design instructional strategy intervention that would ultimately enhance students' learning and thinking skills and lead them to better understanding of scientific concepts.

Purpose of the Study

The objective of this study was to develop and evaluate a physics instructional program to teach thinking and learning skills at the 10th to 12th grade levels in South Africa and the

United States. The use of the materials must enable high school students in general, and particularly minority high school students in the United States and Black students in South Africa, to perform a wide range of intellectually demanding tasks. Intellectually demanding tasks refer to tasks that require careful observation, deductive or inductive reasoning, the precise use of scientific knowledge in memory, hypothesis generation and testing, problem-solving, inventiveness and creativity, and analytical skills.

The study is in three phases; (1) the development of the physics program and training; (2) implementation, and (3) evaluation.

The development of the materials was based on the assumption that the quality of intellectual performance or thinking can be affected by several factors. In this study, four types of student outcomes were emphasized: (a) abilities, (b) methods, (c) knowledge, and (d) attitudes. Abilities here refer to general tasks at which the students were expected to be proficient at the end of the study. Methods refer to structured ways of approaching scientific tasks. Knowledge refers to scientific concepts and principles that students should understand after instruction. Attitudes refer to the points of view, perspectives or opinions students should develop that enhance their intellectual performance.

Abilities

The focus on abilities in this study was deliberate. It was expected that at the conclusion of the study, students would be able to perform certain activities which involve effective performance of intellectually demanding tasks. Examples of the tasks students would be expected to perform include the following:

* Compare and contrast physical quantities in terms of their scientific definitions
* Sort collections of quantities into two or more classes as defined by shared characteristics
* Decompose or resolve complex quantities into simpler components
* Draw valid inferences from stated premises
* Generate hypotheses regarding possible causes of specified scientific phenomena
* Infer from the statement of a problem some characteristic of the problem's solution.

Focusing on the attainment of such abilities has the virtue of making at least some of the goals of the study very precise. It also clarified the task of evaluation, which was an important component of this study. To the extent that objectives were defined in terms of specific tasks the student should be able to perform, success could be measured by determining whether they performed them.

An ability to distinguish physical quantities or adopt appropriate scientific procedures was crucial to most of the tasks listed above. Such an emphasis was maintained throughout the development of the instructional strategy and materials, and it was the principal means by which transfer from one problem to another was encouraged both explicitly and implicitly. Analysis of one's observations helps one to recognize not just whether two quantities or problems are similar or different from one another, but exactly how they correspond or differ. This, in turn, allows students to systematize their knowledge: new quantities or problems would have to be seen not as entirely novel, but as analogous at least in part to previously considered problems. Consequently, approaches that students have learned for specific problems could gradually evolve into approaches for classes of problems.

Similarly, the analysis of complex procedures might yield a set of widely applicable problem-solving steps, such as identification of similarities and differences, deduction through the process of elimination, and the search for disconfirming or contradictory evidence. It is believed that as students develop a repertoire of such basic methods, fewer and fewer problems will appear to be wholly novel. Eventually, an efficient approach to a wide variety of problems would be possible through new combinations and perhaps minor adjustments to familiar sequences. In short, the emphasis on analytical abilities was intended to foster the development of mental structures that are supportive of the productive transfer from one problem situation to another.

Methods

Some efforts to enhance thinking skills emphasize the importance of learning to use specific methods that are thought to be effective ways to approach certain types of tasks. Such methods are sometimes called strategies or heuristics.

Although some methodological principles were introduced in the development of the instructional strategy and materials, it is important to point out that methods presented in the materials were not means for accomplishing particular tasks, but tools for making their accomplishment easier or more manageable.

Knowledge

As indicated in the earlier pages, educational systems have been criticized for concentrating on increasing students' knowledge to the exclusion of increasing their ability to make effective use of that knowledge. However, it does not follow that the way to correct the imbalance is to try to stop increasing knowledge and to focus exclusively on skills for using the knowledge that students have acquired.

The purpose of this study was to teach physics with the ultimate goal of enhancing thinking skills. Consequently, it was felt that materials that are frequently used in classrooms must serve as a vehicle for thought. This study attempted to provide students with subject matter knowledge, but also provided them with the skills to use it, e.g. to interrelate various aspects and to draw inferences from it, using the thinking skills emphasized in the lessons. Such generalization was a critical step towards building the mental structures that would enable students to transfer from the abstract formal procedures to be learned from the lessons to the sort of real-world problems they would face beyond the classroom.

Among other reasons for the focus on thinking while students were acquiring scientific knowledge was the desire to improve the students' ability to reflect upon and monitor their own cognitive performance. To this end, the theme of understanding what one is doing, and why one is doing it, was promoted in the development of the instructional materials. The students were frequently encouraged to think not only about the problems or tasks on which they are working, but about the ways in which they were approaching those problems or tasks.

Attitudes

It is difficult to imagine anything students can acquire that will have a greater influence on their intellectual development than certain attitudes towards learning, towards knowing, towards themselves, and their abilities and their work. Consequently, as part of this study, attempts were made to promote those attitudes believed to be most conducive to intellectual growth and achievement. Examples of such attitudes include the following:

- A strong belief in the importance of learning and in the usefulness and intrinsic value of knowledge
- A lively sense of curiosity and inquisitiveness
- A proper regard for one's own intellectual potential and also for one's own fallibility
- A sense of pride in one's work and an appreciation of the importance of carefulness: careful listening, careful reading, and careful work

Significance of the Study

Resnick (1987b) notes that public schools in the United States are the inheritors of two educational traditions, one aimed at the education of an elite, the other at that of the masses. While the teaching of higher-order cognitive skills has always been an objective of the former tradition, mass education has been concerned with the production of minimum levels of competence in the general population (Resnick & Resnick, 1977).

> Mass education was, from its inception, concerned with inculcating routine abilities: simple computation, reading predictable texts, reciting religious or civic codes. It did not take as goals for its students the ability to interpret unfamiliar texts, create materials others would want and need to read, construct convincing arguments, develop original solutions to technical or social problems (Resnick, 1987b, p. 5).

The observation made by Resnick on mass education in this country is also valid for Bantu education in South Africa. In fact, in a recent document released as part of the Harvard University/University of the Western Cape project to improve science education programs for black high school students in South Africa, Lochhead noted:

> The materials (instructional) will be based on the contemporary cognitive psychology of problem solving and learning, and will convey mental models and thinking strategies designed to enhance subject matter understanding and mastery. The materials will also attempt to "infiltrate" the rote emphasis with ways of learning to think and learning to learn in the subject matter. (Lochhead, 1987).

Mehl makes the point even more compellingly:

> Even a cursory examination of South African textbooks will demonstrate that the integration of thinking skills and content has not happened to any significant degree on any level of black education... It is now important to take seriously the aspiration of making thinking and problem-solving a regular part of a school curriculum for all of the black school population. (Mehl, 1987, p. 35).

To sum up, it is perhaps accurate to argue that the educational system in South Africa has not encouraged thinking and learning skills among Black students. Similarly, it is possible to state that reasoning and thinking have never had a prominent place in mass education curriculum in the United States. Recently, however, there have been calls on the part of educators to reverse the trend in both countries.

It is the view of this author that a particularly powerful way to begin transforming the school program is to concentrate on curricular materials whose basic aim is not only to have students acquire some scientific knowledge, but also acquire some knowledge about thinking in general, and about their own thought processes in particular. This approach is significant for these reasons. First, any success in developing physics instructional strategy and materials that enhance thinking and learning skills has significant educational implications. One implication is the replication of products and results of the study in other disciplines. Evidence that students do not necessarily learn to think well as a consequence of completing many years of secondary or even post-secondary education are easy to find and quite compelling. Assuming that the development of whatever potential one has to think well and independently is a desired objective for everyone -- an assumption that deserves more explicit discussion than it has received (Nickerson, 1986a) -- it seems that there is a need to teach thinking and that that need is not currently being met by the educational system. The outcome of this study could contribute significantly to how best to address this need, i.e., how to enhance thinking in traditional content courses.

Secondly, the study is significant for the reason that employers today complain that they cannot count on schools and colleges to produce the caliber of graduates who can move easily into more complex kinds of work (Resnick, 1987c). "They seem to be seeking general skills such as the ability to write and speak effectively, the ability to learn easily on the job, the ability to use quantitative skills needed to apply various tools of production and management, the ability to read complex material, and the ability to build and evaluate arguments" (Resnick, 1987a, p.7). These abilities call for education that goes beyond routinized skills of the old mass education curriculum in the United States and in Bantu education. Reid (1983) also notes that the workforce of the future will have to be far more highly-skilled and adaptable than the workforce of the past. If Resnick and Reid, among others who have drawn these similar conclusions about the changing needs of the United States economy, are right, then they have identified one compelling practical reason for a much greater emphasis on thinking and learning skills in public education in the future than has been evident in the past.

Thirdly, the outcome of this study would indirectly shed light on how the problem of students' preconceptions and misconception in physics could be addressed. Recently, researchers have focused on the role of preconceptions (including misconceptions) in subject matter learning (Caramazza, McCloskey & Green, 1981; Clement, 1981; Minstrell, 1982; Resnick, 1987b). Students usually face learning tasks with some preconceived notions (naive theories), and approaches to instruction that ignore this fact are likely to fail. Learning is now being viewed as a process of conceptual change, of the restructuring of old ideas and the revising of one's existing cognitive models of aspects of the world (Posner et al, 1982). The kind of change that can lead to new and deeper understanding requires that the learner actively process, think about, and construct meaning from new information. As Posner et al put it, effective studying is thinking critically about the material.

Limitations of the Study

The general goal of this study deals with the use of instructional materials to improve thinking and learning skills. The difficulty that arises here is the question of what is meant by the term "thinking and learning skills." Scholars offer many different definitions. For example, to a philosopher, "thinking and learning skills" may mean engaging in logical reasoning, while to a developmental psychologist "thinking" may refer to metacognition. An educator may emphasize training in study skills and problem-solving as constituting thinking and learning skills. The failure to have a common definition for "thinking and learning skills" makes the evaluation of the skills very difficult. It is to accommodate these different definitions and to simplify the problem of evaluation for the purpose of this study that we think of intellectual performance or "thinking and learning skills" in terms of the four factors (abilities, methods, knowledge and attitudes) described in the previous pages. Results of the evaluations of the instructional strategy and materials developed as part of this study would be valid only under this definition of thinking and learning skills.

While the attitude instruments to assess attitude change are manageable in terms of administrative ease and objective scoring, they do have disadvantages. They can raise sensitivity to the issues in question. As a result, an individual may respond according to what he or she thinks he or she should feel rather than how he actually feels. An additional problem with the Likert-style scale may arise if the respondent does not interpret similar statements to equally express "agree" or "disagree" values.

A teacher's cognitive style may influence his or her way of teaching (Witkin, 1977). While this interaction was beyond the scope of the study, it may be a limiting factor. Though the intervention with teachers was designed consciously to balance methods of presentation, one must consider the possibility that, in spite of good intentions, teachers' teaching styles may have subconsciously influenced the way they used the instructional strategies.

The instructional materials used in this study dealt with few topics in physics. Thus, generalizations could not be made to the broad range of physics topics nor to all disciplines.

CHAPTER 2

LITERATURE REVIEW

Introduction

While the traditional expository method of teaching is to create conditions for meaningful learning and encourage higher-order thinking, it will only be effective for students if they are specifically taught thinking skills and how to use them. In order to narrow the range of important variables that enter into the teaching of thinking, the investigator was guided in surveying the research literature by the following questions.

What is thinking and can it be taught? Why is it important to be taught, how much such teaching can be accomplished and in what form?

Both in South Africa and in the United States, there is a great deal of interest among educators and researchers in the teaching of thinking. This interest stems from the assumption that enhancing thinking and learning skills will help students, especially minorities in this country and Blacks in South Africa, perform better in disciplines such as science and mathematics. Since much of the innovation in teaching thinking during the last decade has taken place at the elementary and college levels and in the form of a thinking skills laboratory model, does empirical research support advocates' claims and can it be extended to high school, and if so, in what form?

These concerns led the investigator to review the literature in six areas:

1) approaches to the enhancement of thinking skills
2) attempts to integrate thinking skills into content subjects
3) identifying the thinking skills to be used in the instructional treatment
4) rationale and empirical basis for selecting these skills
5) a model for assessing the effects of the thinking skills instructional strategy
6) limitations of previous studies on questions which this study addressed.

Approaches to the Enhancement of Thinking and Learning Skills

Thinking, as pointed out earlier, has different connotations to various researchers and educators. Critical thinking, creative thinking, reasoning, problem-solving, and decision-making are among the topics around which substantial research literatures have developed, sometimes interrelated and often remarkably distinct. Even within the articles and books that are focused on the enhancement of thinking and learning skills, one can still find numerous definitions and characterizations of thinking, or more commonly, of specific types of thinking (e.g. Baron, 1985; Dressel and Mayhew, 1954; Eisner, 1965; Kahane, 1984; Nickerson, Perkins & Smith, 1985; Resnick, 1987b). If there is one area on which all these investigators agree, it is that thinking is complex and many-faceted and, in spite of considerable productive research, is not yet very well understood.

Programs and approaches that have been developed to encourage thinking in the classroom reflect the many-faceted nature of thinking and differ not only in methodology, but also in goals: Some focus on the development of basic cognitive processes that are assumed to be essential to cognitive competence; some on the learning of heuristic methods for problem-solving or decision-making, and some on the development of a more explicit awareness of one's own thought processes and a better understanding of how to monitor and manage one's thought processes.

Considering the different areas of emphasis on teaching thinking, the definition of thinking in this study will be sufficiently broad to encompass all the aspects cited above. Consequently, it would be convenient to assume that the quality of enhancing thinking and learning skills could be affected by these four factors:

- Abilities (basic operations)
- Methods or principles and tools of thought
- Knowledge
- Attitudes or values

Abilities [Basic Operations]

Many researchers consider performance of certain basic operations or processes as rudimentary constituents of thinking. Prototypical of this approach is Science--A Process Approach (SAPA) (Klausmeier, 1980), which focuses instruction on eight "basic processes of science": observing, using space/time relationships, using numbers, measuring, classifying, communicating, predicting and inferring. Other programs that emphasize certain operations or processes or abilities include Instrumental Enrichment (Feuerstein, Rand, Hoffman & Miller, 1980), The Structure of Intellect Program (Meeker, 1969), BASICS (Ehrenberg & Sydell, 1980), Thinking Skills Program (Marzano, 1986), Tactics for Thinking (Marzano & Arredondo, 1986), Project Intelligence - Foundations of Reasoning (Nickerson, Perkins & Smith, 1985), and Whimbey & Lochhead's (1982, 1984) program for high school and college students.

It is recorded that as far back as 1901, two researchers, Thorndike and Woodworth tried to increase attention, observation and discrimination abilities in learners through training. The results were generally discouraging. Thorndike from 1906 to 1913 conducted numerous empirical studies of training on a variety of mental tasks and found little evidence of transfer from one task to another. He subsequently concluded that training on specific mental operations did little to improve general mental functioning. More recent studies have shown encouraging signs. Jacobs and Vandeventer (1972) analyzed, from about 200 intelligence tests, items that seemed to test "cognition of figural relations (CFR)." From twenty-two tests that contained ten or more such items, they found a total of 1,335 items, all figure-analogy type problems. Jacobs and Vandeventer identified a set of twelve relations in terms of which they were able to classify nearly all of the items in their sample. One way to test for the training of at least one aspect of intelligence ("CFR intelligence"), they suggest, would be to train subjects on a subset of the possible pairings of features and look for transfer to pairings other than that used in the training sessions. In a series of experiments with primary school pupils, Jacobs (1966) and Jacobs and Vandeventer (1971a, 1971b) obtained such transfer of training effects with stimulus materials like the figure-analogy items on Raven's colored progressive matrix test. Transfer effects were obtained even after relatively short training periods (e.g. 30 minutes) and were found to persist upon retesting three months after training.

Evaluative data have been obtained on some programs that focus on basic operations or processes. Several evaluations of Instrumental Enrichment have yielded positive results (Savell, Twohig & Rachford, 1986). Evaluation was a major emphasis in

Project Intelligence and significantly greater gains were made by participating students than by control groups on a variety of standardized and specially-constructed tests (Herrnstein, Nickerson, Sanchez and Swets, 1986). Results of evaluations of SAPA, the Structure of Intellect Programs and BASICS all indicate positive findings (Nickerson, Perkins and Smith, 1985). Whimbey and Lochhead's intelligence training program, stresses social mediation in learning cognitive skills. They suggest that when students are engaged in a pair problem-solving process in which students alternate the roles of problem-solver (one student thinks and solves problem aloud and the other acts as a listener and a critic), they are more likely to perform better. Evaluation of the Whimbey and Lochhead training program shows positive effects, although the effectiveness of the approach is still being debated.

Methods [Principles of Thought]

The idea that there are certain formal and informal methods (strategies, heuristics) that are applicable in many knowledge domains gets support from a variety of sources. Comparative studies of expert and novice problem-solving in different subject areas have revealed certain ways in which the performance of experts tends to differ from that of novices, ways that are not attributable solely to the differences in the amount of knowledge they possess in the subject matter. Research studies have shown that experts tend to spend more time thinking about and trying to find a representation for a problem before doing much of what would usually be classified as selecting a solution, and they tend to work with qualitative representation of problems before applying quantitative methods (Chi, Feltovich & Glazer, 1981; DeKleer, 1985; Larkin, 1979; Lesgold, 1984; Sternberg, 1977; Voss, Greene, Post & Penner, 1983).

Resnick (1987b) notes that certain kinds of higher-order thinking skills may be seen in the performance of highly skilled individuals, whether they are doing mathematics, solving scientific problems, or repairing equipment: "Experts elaborate and reconstruct problems into new forms; they look for consistencies and inconsistencies rather than seeking quick solutions and sticking with initial ideas; they reason by analogy to other situations (p.15)." This suggests, she notes, the possibility that there may be general thinking methods that are applicable across a wide range of problem areas; if such methods exist and are teachable, then considerable leverage could be obtained from programs to teach them explicitly.

Several approaches to the teaching of thinking and learning have included within them the teaching of specific formal and informal principles of thought. Numerous books and articles have given detailed accounts of various problem-solving strategies and heuristics that are assumed to have wide usefulness. The first and most well-known of these is Polya's (1957) How to solve it. More recent examples include Bransford and Stein (1984), Halpern (1984), Hayes (1981), and Ruggiero (1984).

What is the evidence that the teaching of specific informal and formal strategic or heuristic methods improves performance on intellectually demanding tasks? Examples of attempts to teach problem-solving heuristics in the classroom include Rubinstein's (1980) Patterns of Problem Solving course at the University of California, Los Angeles, Schoenfeld's (1979, 1980, 1985) heuristic instruction in mathematical problem-solving and the Practicum in Thinking course developed at the University of Cincinnati (Wheeler & Dember, 1979). Most of these examples involve instruction at the college level which is where most of the work on teaching problem-solving heuristics has been done. Project Intelligence contains lessons on problem-solving for use at the middle school level (Feehrer and Adams, 1986). All of these programs can point to evaluative data with positive effects on problem-solving performance resulting from the classroom instruction. Summaries of these evaluative findings cited above are all given in Nickerson, Perkins and Smith (1985). Other examples of successful attempts to teach children problem-solving skills that have transferred to disciplines other than those in which they were taught include those of Anderson (1965) and Wittrock (1967).

Knowledge about the effectiveness of strategies in the abstract and specific feedback about the consequences of one's use of specific strategies both seem to enhance strategy acquisition and use (Borkowski & Krause, 1985). Kurtz and Borkowski (1987) obtained some evidence that providing fourth through sixth grade students with information regarding the value of a learning strategy had a beneficial effect on learning over and above that resulting from the teaching of the strategy itself. Even first graders may make better use of strategies if they have been informed about their usefulness than if they have not (Paris, Newman and McVey, 1982).

What emerges from the above analyses is evidence that suggests that the teaching of formal and informal principles of thought such as strategic approaches to problem solving or learning is more likely to be effective when it is coupled with the acquisition of knowledge than when it is not.

Knowledge

Many investigators have stressed the importance of knowledge that is specific to a particular discipline as a major determinant of ability to solve problems and reason in that discipline (Gagne, 1980; Simon, 1980; Voss, Green, Post & Penner, 1983). Not only do experts know a great deal more about a specific subject than novices, but the knowledge they have tends to be organized differently (Chi, Glaser & Rees, 1982; Lesgold, Feltovich, Glaser & Wang, 1981). Experts are likely to organize their knowledge on the basis of concepts, principles and abstractions that reflect a relatively deep understanding of the subject matter, whereas novices are more likely to organize their conception of a problem around literal objects and relationships explicitly mentioned in the problem statement.

The importance of subject matter knowledge to thinking is crucial to the whole process of formal education. To think effectively in any discipline, one must know something about the discipline and, in general, the more one knows, the better. Most researchers and educators who have done extensive work in this area acknowledge the importance of both general thinking ability and subject matter knowledge to effective intellectual performance. Glaser (1985), for example, who has emphasized the importance of specific knowledge, has argued that subject matter knowledge is not adequate by itself, and has also argued that acquisition of knowledge should be taught so as to enhance thinking. Sternberg (1985) has also pointed out that subject matter should be taught so as to facilitate the acquisition of thinking and learning skills.

One point on which there seems to be considerable consensus among educators and researchers is that teaching that has the rote acquisition of specific knowledge as its primary objective is unlikely to foster thinking and will probably fail even to produce the desired knowledge acquisition. Researchers who emphasize the importance of subject matter knowledge to thinking also stress the need to teach traditional subject matter in a thought-provoking way to help students understand the content deeply, and to challenge them to apply the acquired knowledge outside the learning context.

Attitude

There appears to be an increasing awareness among researchers of the critical importance of attitudinal and dispositional variables as determinants of the quality of thought (Baron, 1985; Nickerson, 1986a; Resnick, 1987b; Schrag, 1987; Swartz, 1987). Attitudes that are seen to be conducive to good thinking include fairmindedness and openness to evidence on any move, respect for opinions that differ from one's own, inquisitiveness, a desire to be informed and a tendency to reflect before acting.

Attitudes towards oneself and one's capabilities and how they relate to thinking have been the focus of attention for some researchers. Several investigators have noted that successful problem solvers are more likely than unsuccessful ones to comment favorably on their own abilities, whereas unsuccessful ones are more likely to express negative feelings about themselves and their abilities (Goor & Sommerfield, 1975; Henshaw, 1978).

Researchers have also noted the possibility that self-supporting or self-denigrating attitudes may play causal roles in determining the quality of students' performance.

An attitude that is widely recognized as highly worth promoting is that of fairmindedness in the most general sense and impartiality in the weighing of evidence in particular. According to Baron (1985), the trademarks of good thinking are sufficient search and fairness. Nickerson (1986b) suggests that the combination of these two ideas conveys the notion of active fairmindedness, which involves not only being willing to treat impartially the evidence that happens to present itself on any issue, but actively seeking evidence that is counter to a claim before accepting it as true.

To be fair-minded in all situations is not a natural thing to do. My own proposition is that active fairmindedness, like many attitudes, can be taught effectively. I also believe this purpose can be served by the manner in which instructional materials are constructed.

One implication of the discussion thus far of the four aspects of thinking is the fact that both educators and researchers have stressed the multifaceted nature of thinking and the need for approaches to thinking that take this into consideration. Each of the four factors that have been discussed in this chapter are considered necessary for good thinking.

Attempts to Integrate Thinking Skills into Traditional Curriculum

Although many educators and researchers are emphatic in pointing out the need for the cultivation of thinking and learning skills as a necessary component of education, there is no unanimity among them as to whether thinking should be taught as a separate entity, or as an integral part of traditional content courses. One school of thought holds the view that thinking skills are unique to each subject, that different fields have different logics and that what one must learn to be effective in one subject should not be expected to be useful in other subjects (McPeck, 1981). This view is challenged by other investigators who argue that, while there are indeed specific aspects of thinking that are unique to some subjects, there are also certain processes, skills, strategies, principles, attitudes and dispositions that are applicable to thinking in many subjects.

Teachers of physics have been prominent among the second school of thought who have promoted the idea that the development of thinking should be a primary objective of physics instruction (Arons, 1976; Minstrell, 1982; Reif & St. John, 1979). Fuller, Karplus & Lawson (1977) explicitly address the question "Can physics develop reasoning?" and argue that it can. They approach the question from a Piagetian perspective and argue that because physics requires certain patterns of reasoning, its study should be useful in helping students become adept at the kind of intellectual activity that Piaget associated with the formal reasoning state of cognitive development. They argue further that physics curricula in the past have been developed for the use exclusively by students who are already capable of formal reasoning, and that consequently the subject has been unnecessarily difficult and dry for students who are not at that stage of development.

A well-known program that focuses on the teaching of problem solving and decision-making skills in the context of subject-matter instruction is Guided Design. There is evidence to support the claim that in several instances, the use of Guided Design has decreased dropout rates among physics students, and increased the level of understanding in the subject-matter concerned. Wales (1979) presents some data in support of the hypothesis that positive changes result directly from the Guided Design program. Other studies have reported positive effects of the Guided Design approach, such as improvement in examination performance and learning skills (Bailie and Wales, 1975; Landers, 1975).

Summary of Literature Review

The preceding literature review has yielded the following findings and observations:

(1) The term "thinking" is difficult to define, though it can be recognized when it occurs;

(2) Effective thinking is the hallmark of successful learning at all levels of schooling;

(3) Some aspects of thinking are teachable;

(4) Current educational practices in the United States and elsewhere by and large do not encourage efforts to teach thinking and reasoning. For example, in South Africa, examination practices inhibit the teaching and cultivation of thinking;

(5) Effective teaching normally occurs in a specific subject matter, but many aspects of thinking run through many several subject-matters and situations;

(6) Embedding instruction in thinking and learning skills within the traditional school content courses has several potential advantages.

What could be concluded from the above review is that there is a need to teach content subjects in such a way as to illustrate the applicability of good thinking in those contexts, and to provide daily opportunities for students to exercise it. This, in effect, is the long term goal of this study. That is, through training, physics teachers could be made to infuse thinking skills into their daily physics lessons and thereby encourage good thinking among their students.

Rationale for Infusing Thinking Skills into Physics Instruction

The most important single outcome of modern research on the nature of thinking is that the kinds of operations traditionally associated with thinking are not limited to advanced levels of development. Instead, these operations are more or less integral parts of even elementary-level reading, physics, and other branches of learning when teaching and learning are proceeding well.

The underlying reason to teach thinking skills in our schools is to improve students' understanding and problem solving in physics. It is believed and, in fact, supported by research that students' physics understanding and problem-solving could be improved by teaching them to use some fundamental cognitive skills. The skills identified and included in the training of teachers involved in this study were defining and describing (operationalized as analysis, conceptual representation, and generation of alternative representations), comparing, thinking of reasons (justifying an answer or procedure), and summarizing. These particular skills were selected because they serve as mechanisms through which the different types of knowledge that make up a physics domain (symbols, quantities, concept terms, procedures) can be related to one another (Swing & Peterson, 1988). For example, when defining and describing a typical physics concept such as force (Force= product of mass and acceleration), the quantities can be isolated, and each can be related to concept terms (e.g., acceleration is related to velocity and time). It must be stressed that performance of the skills involves not only relating knowledge but using knowledge, which results in reinforcing memory of the information that is used.

With the exception of summarizing, the skills that were included have appeared as components of problem solving in conceptions developed by other investigators. Defining corresponds to interpreting or transforming problem information by linking it with a more general concept--mathematical formalization, or knowledge of language and the world (Davis, 1983; DeCorte & Verschaff, 1981; Greeno, 1978; Krutetskii, 1976; Mayer, 1983) or by naming objects (Polya, 1957). Describing involves identifying relevant features; decomposing; identifying unknowns, data, and conditions; and isolating elements in the problem (Davis, 1983; Greeno, 1978; Krutetskii, 1976; Polya, 1957). Comparing may enter into problem solving as a matching process step that occurs in filling schema slots (Davis, 1983), as pattern matching (Greeno, 1983), as using analogy, or as thinking of related problems (Polya, 1957). Justifying also corresponds to Polya's "looking back" and evaluating thinking and learning procedures that should be incorporated into teaching thinking skills.

Empirical Basis for Infusing Thinking Skills into Physics Instruction

It is worth noting that experimental attempts to improve students' thinking skills in several content subjects have involved teaching students to use a strategy approach derived from Polya's (1957) original heuristic approach. Thus, the empirical evidence related to thinking skills has typically pertained to groups of strategies and not to individual strategies.

Defining, Describing, Comparing, and Justifying

Charles and Lester (1984) conducted one of the few experimental classroom-based studies aimed at improving elementary school pupils' mathematical understanding and problem solving by teaching pupils to use cognitive skills and strategies. In that study, fifth-and seventh-grade teachers taught their classes a heuristic that included instructions to find the important information (describe), to draw a picture (define), and to decide if the answer makes sense (justify). Charles and Lester found that the intervention produced a small but statistically significant improvement in pupils' problem solving when compared with regular instruction.

Two other studies provided evidence for the usefulness of defining. DeCorte and Verschaff (1981) instructed second graders in the conceptual meaning of the equal sign and in the meaning and use of the part-whole relation in addition and subtraction. They also taught students to use pictures to represent the part-whole relation. After the lesson, students instructed in these skills made 60% fewer errors on open addition and subtraction problems (e.g., 7?= 5) than they made before instruction. Similarly, Wolters (1983) taught elementary school students to represent addition and subtraction in terms of part-whole relations and found that, as a result of instruction, students showed improvement in their ability to solve two-step combination story problems. Students who were given the part-whole instruction, however, performed worse than control students on two other types of problems.

Mixed results were also reported by Lee (1982), who collected anecdotal data on the usefulness of individual skills as part of her assessment of effectiveness of heuristic instruction. She found that having students draw a picture helped them solve some types of problems but that pictorial representation did not guarantee that students would be able to reach the correct solution. Moreover, even after hours of instruction, students rarely checked to see whether their answers were reasonable (i.e., justified).

Taken together, these four studies found that providing students with training in describing, defining, justifying, and other skills as described in the Teacher's Manual (see appendix H) had some positive effects on students' physics learning and problem solving.

Summarizing

While the cognitive skills of defining, describing, and justifying were derived from classroom-based strategy training studies in elementary school mathematics learning, the fourth cognitive skill of summarizing was derived from successful strategy training interventions in the area of children's prose comprehension. Summarizing was among the skills included by Palincsar and Brown (1984) in their successful reading comprehension strategy intervention with elementary school students. As in prose comprehension, memory for specific content is also essential in physics learning because physics concept learning and problem solving require the learner to remember physics information. The skill of summarizing was included in the development of the physics instructional strategy for this study to aid students' memory of specific physics content presented by the teacher. Summarizing by the learner might help the learner remember physics information by highlighting important points and by requiring the learner to rehearse physics information. In addition, in a good summary, the learner extracts the key points that then might serve as a conceptual framework or scaffold on which the learner can "hang" details (Ortony, 1978; Rumelhart, 1980). Main ideas are easier to remember and, once recalled, might be used by the learner to cue specifics.

In sum, it is apparent from this discussion thus far that both cognitive theory and empirical research have provided some evidence for the possible benefits of classroom-based instruction in the thinking skills of defining, describing, comparing, justifying, and summarizing to aid students' physics learning and problem-solving. However, several limitations exist in the few studies that researchers have conducted and which had been reviewed extensively in the early pages of this chapter.

Limitations of Previous Studies which this Study Addresses

To date, researchers have concentrated on determining the effects of cognitive strategy training by examining only students' performance in physics and problem-solving tests. In the few cases in which cognitive strategy instruction has been implemented by classroom teachers, researchers have not observed teachers' behavior to assess fidelity of treatment implementation. Furthermore, researchers have not directly examined students' actual skill use in the classroom--either through observing students' classroom behaviors or through interviewing students as they learned and worked physics problems. What has been needed are classroom-based studies of cognitive strategy intervention that trace the effects of the skill interventions from physics instruction of the teachers to teachers' actual classroom behavior to students' actual classroom behavior and use of the thinking skills in physics learning and finally to students' physics achievement and problem solving. This was an essential part of the study.

A second major shortcoming of studies done so far and pertaining to thinking skills strategy intervention is that investigators have not explored the possibility of interactions between thinking skills strategy intervention and students' initial abilities. For example, higher ability students may already have the skills and strategies taught in the strategy intervention, whereas lower ability students may not possess the prerequisites for these skills and strategies. In essence, the effects of the thinking skills intervention may depend on students' initial abilities. This point of view is supported by research evidence. Research studies involving training in mnemonic strategies have found that training in memory strategy is particularly effective for younger elementary school students. However, this same training is found to be ineffective for high school students because the high school students have already developed such strategies (Peterson, Stoiber & Swing, 1988).

The third limitation is that researchers have not equally examined the effects of the thinking skills strategy interventions at both the class or group level and at the individual student level. Treatment intervention in this study was implemented by the teachers for the experimental classes. Thus, the appropriate units for educational analysis would be both at the class and the individual student. This means that treatment effects that depend on the ability level of the individual student as well as the treatment effects that depend on the average ability level of a given class must be taken into consideration in the analyses. Although the class was used as the major unit of statistical analysis in this study, to get a better picture of the effects of the intervention, individual students were also used as a unit of analysis. This was done by interviewing selected students.

Educational researchers have emphasized the need to investigate the effects of initial ability of students and treatment interventions (Ability X Treatment Interventions or ATI) at both the class and individual student levels (e.g., Corno, 1980; Cronbach & Snow, 1977; Levin & Peterson, 1984). In the 1980 study conducted by Corno, in which memory support strategies were taught to third-grade students, she found no significant ATI at the individual level. On the other hand, Corno found a significant ATI between between classes. In other words, Corno's study suggested that higher ability classes gained more from her learning skills program than did lower ability classes.

The current study has been designed to seek answers to the limitations discussed above. In an experimental study conducted over the course of a semester, an attempt was made to promote students' use of certain thinking skills and strategies in an actual classroom setting in physics. The intervention effects on students' physics' thinking processes and physics achievement were examined. The effectiveness of physics strategy intervention which was developed to encourage thinking was also examined.

A Model for Assessing the Effects of Thinking Skills Instruction

To assess the effects of the classroom-based interventions, a model developed by Swing, Stoiber and Peterson (1988) was adapted to guide the investigator in analyzing the data. It is important to note that testing the model (shown in Figure 1) was not part of the study. It is, however, used as a heuristic tool to aid in coming to a conceptual understanding of the results.

The model portrays effects that may occur within a given classroom-based intervention and the processes that mediate those effects. The two boxes in the model represent the "class"-level effects. For example, instructional and learning processes occur at the class level. Each class, however, is made up of individual students, as represented by the individual student level effects within each of the two boxes in the model. Thus, each individual student in the classroom engages in cognitive processing and learning as a result of instruction, and achieves at a given level. The arrows represent possible effects among the variables

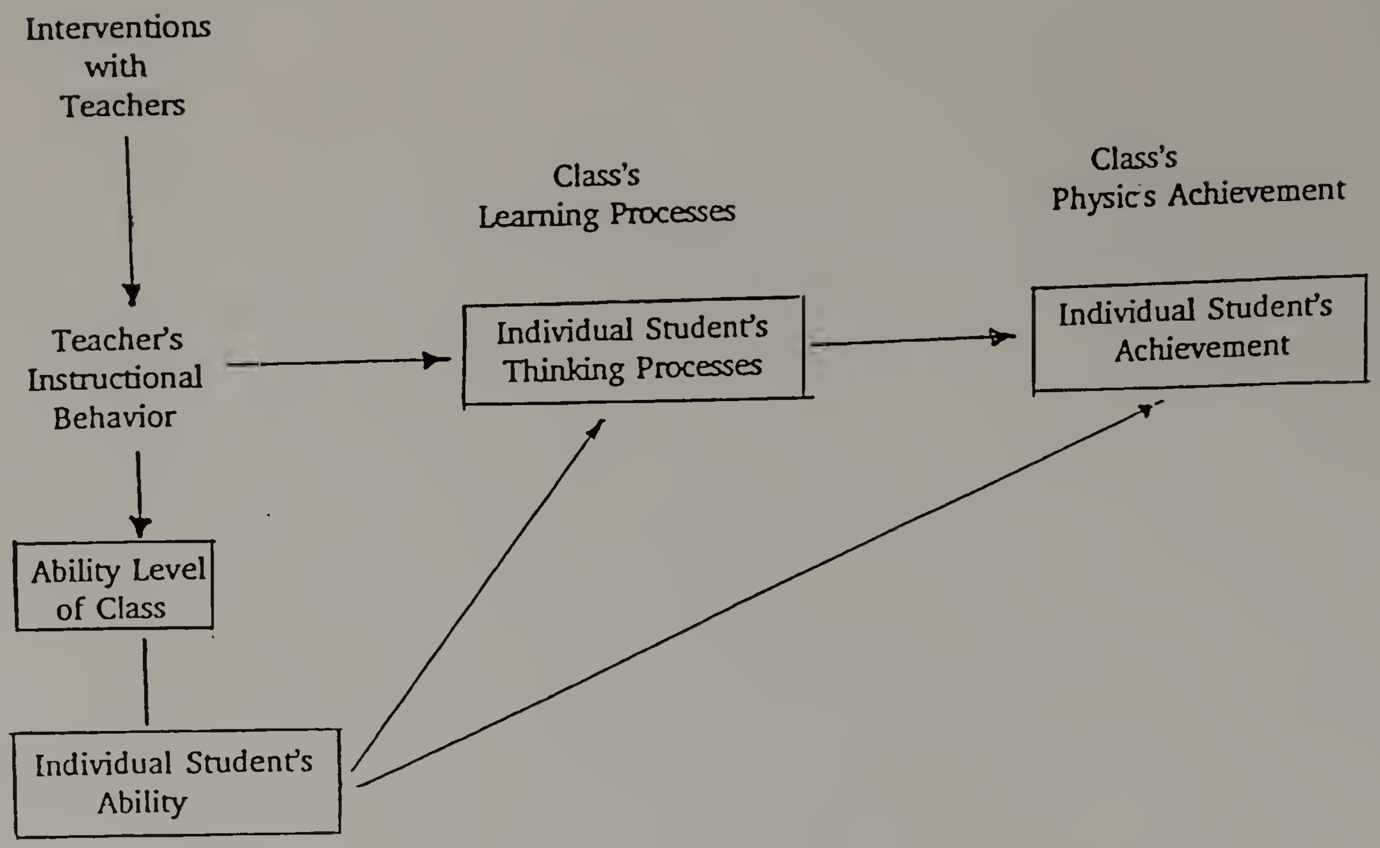

Figure 1: Model for Assessing the Effects of the Classroom-based Interventions

in the model, both at the class level and at the student level.

In this study, teachers in the experimental groups were given training in how to integrate thinking skills into physics lesson plans and how to teach the lessons. It was expected that for any intervention effects to occur, the training would have to result in relevant changes in teachers' instructional behavior. Thus, it was expected that physics instruction using the materials developed for this study would result in an observed increase in teachers' instruction and use of defining, describing, justifying, comparing, summarizing and other skills described in the Teacher's Manual in teaching physics. In turn, teachers' instructional behavior was expected to affect the achievement level of the class through the instructional processes that occurred within a given class. As part of the instructional process within a given classroom, students individually process and learn physics, and this cognitive processing, within the individual student's mind, affects the individual's physics achievement of problem-solving and computational skills as well as reasoning skills. Intervention effects on achievement might be mediated by the ability level of the class as well as by the ability level of the individual student.

Although the class, unlike the individual student, does not have a "mind" per se within which cognitive processing occurs, the researcher conceptualized the instructional processes and discourse that occurred in the class as similar to what takes place in an individual student's mind due to the learning of information that occurs. Moreover, the average ability level of a class might affect the thinking and decision making within the teacher's mind and might ultimately affect his or her behavior. Thus, a teacher might decide to engage in entirely different instructional behavior with a lower ability class than a higher ability class. These issues will be dealt with in detail in the presentation and discussion of the results.

CHAPTER 3

RESEARCH METHOD

Introduction: The Study

This chapter contains the general outline of the study relating to the experimental design and procedure used in the summative evaluation, and the description of instruments chosen and prepared to measure students thinking abilities and physics performance. The outline also includes the description of schools and participants involved in the study.

Description and Selection of Schools

Four high schools with two physics classes each participated in the study. The total population of students in these classes was 168 and was almost equally divided between males and females. The schools from which the classes were selected were located in eastern and western Massachusetts. The schools were chosen because, in the opinion of the investigator, they provided a good match in terms of school size, socio-economic background of students, and the type of city or town. Equally important, the schools were selected for the study because they cooperated with the investigator in the following ways:

a) the school allowed teachers to participate fully in the training session;

b) the school permitted the observation of physics instructional activities before and during the period of the study;

c) the school permitted the administration of both pre- and post tests during regularly scheduled class periods;

d) the school permitted participating teachers to be supervised on matters pertaining to the study such as lesson planning and format.

One high school physics class originally contacted for inclusion in this study was eliminated, since the school committee policy did not permit the investigator to observe classes or administer tests to students.

Description of Participating Teachers

In all there were 8 (6 male, 2 female) tenth to twelfth-grade teachers and their intact classes. The teachers were recruited from high schools within 2 hours driving distance of Amherst, Massachusetts. Four of the teachers taught in public high schools that served predominantly minority populations located in large towns. Two teachers taught in a private school that, according to the school records, served predominantly children from affluent homes. The remaining two teachers taught in public schools that served middle-class populations. All teachers' participation in the study was voluntary and all were paid honoraria to cover travel expenses for attending a post-study seminar at the University of Massachusetts/Amherst. All the teachers in the study were experienced high school physics teachers and all but three were actually certified to teach high school physics. Each had a minimum of eight years of teaching experience.

Experimental Design

The summative evaluation of the study was designed as a formal experiment, specifically a pre-post control design (Campbell and Stanley, 1963) in which the performance of classes of students who were taught by teachers in the experimental groups could be compared with the performance of matched classes of control students. Performance was measured on a battery of objective tests representing a variety of physics problem-solving and reasoning skills. The tests included standard tests of mental abilities and physics tests specially constructed to measure specific skills in physics. All of the tests were administered both before the treatment as a pre-test and again following the treatment as a post-test. There were four experimental groups and four control groups. The experimental groups received a "comprehensive" treatment (30 hours) in which a thinking skills strategy was taught and utilized during physics instruction. The eight physics classes (4 experimental, 4 control) were matched into four pairs by considering the school size, location, and the type of community they serve. Within each of the four pairs, the assignment of one class as experimental and the other as control was based in part on consideration of factors affecting the likelihood of successfully delivering and completing the instructional material during the period of the study. In addition to comparisons between the experimental and control groups, gain scores were also assessed within the experimental groups and at individual student level.

The units of analysis for each of the testing were the mean average scores which the classes achieved on each test. The statistical technique was a one-way analysis of variance F-test, 2-way analysis of variance t-test, and generalized regression analysis. A significant gain in the means of the thinking and physics post-tests would be interpreted as meaning that the intervention with the teachers in the experimental groups contributed to the students' performance gains as measured by the post-tests. On the other hand, a lack of significant difference in the means could be construed to imply that the intervention with teachers had no effect on students' physics achievement and thinking skills. The assignment of the paired classes and the number of students is listed in Table 3.1 below:

Table 3.1. Paired Classes in Experiment

	EXPERIMENTAL	CONTROL
Class 1.	A: 28	A: 21
2.	B: 15	B: 15
3.	C: 23	C: 20
4.	D: 22	D: 19
Total # Students: 88		Total # students: 75

Course Content

Considering the different areas of emphasis on teaching thinking, the course content was designed to encompass the four aspects of thinking discussed in the literature review. However, it was felt by the investigator that these aspects of thinking could be enhanced using the following processes or operations of thinking:

The content is outlined below (refer to appendix H for full details):

1) Abilities

   A. Observing
   B. Describing and Defining
   C. Comparing and Contrasting

2) Methods

   A. Developing Concepts
   B. Differentiating
   C. Summarizing

3) Knowledge

   A. Justifying or Thinking of Reasons
   B. Generalizing
   C. Predicting

4) Attitude

   A. Explaining
   B. Hypothesizing
   C. Offering Alternatives

The physics topics selected to teach these skills emphasized the intuitive nature of physics. Content was presented by lecture and the instructional procedure is fully described in the Teacher's Manual (see appendix H).

The planning and organization of the materials for use in classes at each experimental school was done to ensure that each teacher used the materials in the same way. To achieve this uniformity the investigator met at beginning of every week with participating teachers to read and analyze their lesson materials for understanding of the material content and intent, and then to agree on exactly how the materials would be presented in class. Similarly, the investigator observed each teacher twice every week to ensure that participating teachers were teaching as expected and also to measure postintervention teachers' behavior, students' behavior and classroom processes. All lesson presentations were video-taped.

Instructional Strategy

On Day 1 the teacher was to (a) give a description of the skill along with illustrative examples, (b) provide specific-questions for the skill and explain the meaning of each self-question using examples, (c) model the skill use by thinking aloud and by asking the self-question (thinking aloud questions were provided in the manual), and (d) have students ask and answer self-questions for additional examples. Then the teacher was to teach a regular physics lesson. The teacher was to ask and answer self-questions while teaching the lesson and to prompt students to do so during the lesson and seatwork.

On Day 2 the teacher was to (a) review the concepts and skills covered on day 1, (b) present a rationale for the examples showing how the skill is useful, (c) describe the situations in which using the skill is helpful, (d) have students complete the thinking skills worksheet, and (e) use the skills during physics teaching.

On Day 3 the teacher was asked to review Day 2 and to provide additional examples for clarification if needed. The teacher was asked to follow up on initial instruction throughout the remainder of the week by modeling use of the skill during whole-class instruction and by prompting students to ask and answer thinking self-questions during the teachers' instruction and during seatwork. Finally, the teacher was asked to continue modeling use of the skills and requiring students' use of these skills throughout the period of the study.

Experimental Procedure

The experimental study was conducted during the period February to December 1988. From February through March 1988, teachers were contacted and were given a general description of the procedure and purpose of the study. Each of the teachers who agreed to participate was given a written consent form to read and sign (see appendix A for a sample of the form). Thereafter each teacher was observed for a period of 6 days. The observations were made to assess teachers' instructional behavior, students' behavior and classroom processes.

Prior to the training, four teachers were assigned to the experimental group and four were assigned to the control group. Teachers and their classes were not assigned randomly to the two groups, since the fixed-class enrollment of students negated the possibility of random selection of students. However, teachers in the same school were assigned to the same group to eliminate any possibility of influence across treatments.

Intervention with Participants

During the month of May, teachers who had been assigned to the experimental group participated in three one and one-half hour workshop sessions. During the first workshop, the investigator reviewed the defining and describing skills and discussed the problems that teachers might have in teaching these skills. Teachers were asked to do an example from their teaching of defining and describing. The investigator also discussed comparing and contrasting and focused on how these and other skills could be applied to teaching physics. Below are examples of some of the skills and how they were defined:

Defining and Describing

Defining involves using physics terminology or concepts and pictorial representations to represent the meaning of equations and ordinary-language words comprising a physics problem. A form of defining involves generating alternative methods in finding a solution to a problem. Describing involves analyzing, i.e. isolating the component features or parts of a problems, or concept. For physics problems, defining and describing mean finding and naming the facts, drawing a picture, and describing the problem in one's own words.

Comparing

Comparing is defined as identifying physics phenomena, operations, and problems as similar or different and describing characteristics of the phenomena, operations and problems that make them alike or different.

Thinking of Reasons/Justifying

This involves using general rules in physics knowledge to justify an answer or problem-solving step or procedure. Thinking of reasons occurs, for example, in telling why a particular equation or constant is chosen do a particular physics problem (for example, why is it inappropriate to use quantities such as time and density to define the concept of Force).

Summarizing

Summarizing is defined as putting together the important facts, steps, or principles in a few sentences. Summarizing includes reviewing the main ideas of a lesson, a problem-solving procedure or a concept.

During the second training session the investigator highlighted the important points for teaching the remaining thinking skills described in the manual. However, the emphasis here was on how to integrate thinking skills into everyday lesson planning in physics. Equally importantly, the investigator focused on highlighting the difference between the teacher's using the skills during physics teaching and instructing students in how to apply the thinking skill on his or her own. By the end of the sessions all the skills listed in the course content had been covered with the participating teachers.

At the end of the training session, teachers were provided with a 20-page manual (see appendix H) describing the skills and suggested procedures for teaching those skills to students, as well as samples of lesson plans. Suggested instructional procedures included the following techniques which have been shown to be effective in cognitive training research:

1) Providing explicit instruction in when to apply the skill or strategy (Pressley et al., 1987).

2) Presenting the skills of self-questions (Brommarito & Meichembaum, 1978).

3) Cognitive modeling of the skill or strategy by "thinking aloud" (Palincsar & Brown, 1984).

4) Providing practice in use of the skills with diverse types of physics problems and content.

The manual, among other things, specified that students should be instructed to use the skills by asking self-questions. When working on a problem, for example, a student would be encouraged to ask, "What does this concept mean?" "What do the physics facts mean here?" or "Is my reasoning a good one?" The aim of the self-questioning approach was to provide students with a method of systematically prompting themselves to use strategies during physics classes and thereby to become more active, independent learners. The manual also recommended that students be encouraged to use the cognitive strategies by providing them with reasons for using the skills and with examples to demonstrate the usefulness of the skills. Teachers were requested to teach the strategies during whole-class lecture or discussion and to use content from their regular physics text to demonstrate the ideas. The teaching of each skill as discussed in the manual occurred across several days in a 9-10-week period (Note: The first week was a period for teachers to try the instructional procedures and materials as suggested in the manual).

The Treatments

The general goals of the 10-week, 30-hour program were to (1) teach thinking skills through physics instruction to students (2) to enable students to make specific and immediate use of these skills in learning physics as well as in solving physics problems. Both the teaching of thinking skills strategy for future use and working on students' current thinking needs were covered (Refer to appendix H for physics topics taught during the period of the study).

The classes met in well-lit academic classrooms which had movable desks. Chalkboard and overhead projectors assisted in the instructional procedure. The classes took place during regular day class hours and were scheduled in regular time slots. Instructional procedures included the following techniques which have been shown to be effective in cognitive teaching research:

1) Telling the learner explicitly that use of the skills will improve performance in an important way (Pressley, 1987).
2) Encouraging small group discussions and verbalizing their thoughts.

3) Providing practice in the use of the skills with diverse types of physics problem and topics.

4) Inculcating into students the skills of self-questions.

Teachers in the control classes were requested to cover the same physics material and its order of presentation as those in the experimental classes. All students in the investigation, therefore, experienced the material in the same order of presentation within parallel time frames. The difference in how the students experienced the physics concepts was in the mode of instruction. The investigator requested the teachers in the control classes to use the formal instruction method they were used to.

Administration of Tests

Pre-testing

In September, all students in both the experimental and control groups were pre-tested on the physics achievement test and thinking skills test by the participating teachers. The tests were administered in the early part of September, that is, prior to the start of regular classes, to balance differential effects of test administration on experimental and control groups. Every student was supplied with a test booklet, an answer sheet and a pencil to use in recording his or her answers. Each class was told that the tests would not contribute toward their class grade in physics. The students were allowed exactly forty minutes uninterrupted working time.

Post-testing

In December, all students in the experimental and control classes were post-tested in the physics achievement test and thinking skills test that were different from the physics and thinking pre-tests. The post-testing procedures were the same as those used for pre-testing.

Description of the Instruments

The effects of the intervention on student thinking and learning skills were evaluated using multiple-choice tests. The reasons for the use of multiple-choice tests as the primary means of evaluation in this study were: (1) They permit objective and standardized measurements, (2) they permit an efficiency of administration of the experiment, and (3) there exist standard, well-known multiple-choice tests of physics achievement and thinking skills that were adapted and included in the administration of the tests.

Physics Achievement Test

Students' physics achievement was assessed with a 20-item test (see appendices D and E) derived from a physics achievement tests used by Peterson and Fennema (1985) and by the National Assessment of Educational Progress (NAEP, 1979). All the 20 items were selected to assess four difficulty areas identified by NAEP: Knowledge, problem-solving, understanding, and application. Knowledge and problem-solving constituted 10 items, and understanding and application combined to form 10 items. For example, some physics problems required the student to recall a specific fact or to manipulate an algorithm but did not require the student to understand, interpret, or apply physics knowledge (Carpenter, Corbitt, Kepner, & Reys, 1981).

Scoring for the tests was done by determining the number of correct responses (i.e. each item was scored 0 if incorrect, and 1 if correct). The maximum possible score was 20. The reliability of the Peterson and Fennema physics achievement has been estimated to be 0.82 using the Spearman-Brown proficiency formula with data from 80 males and 97 females. Those data came from " freshmen college students from a mid-west liberal arts college..." (Herman, 1971). Thus, for other populations than the one mentioned, the reliability values quoted can serve only as a general guide. The population involved in this study, however, was basically college bound, and hence it was concluded that there was justification in considering the test reliable with that population.

The 20-item physics achievement tests (pre- and post) was validated as follows. First, all physics teachers participating in this study judged that those tests would measure the four difficulty areas based on the NAEP classification and the content outlined in the teacher's manual.

Thinking Skills Test

A 20-item thinking skills test (see appendices B and C) was administered to assess students' thinking ability. It was hypothesized that students' thinking ability might interact with the treatment interventions to affect achievement. The thinking skills test items were constructed from the Lochhead-Whimbey Analytical Skills Test (WASI), and the New Jersey Test of Reasoning Skills (NJTRS). The New Jersey Test of Reasoning Skills was designed by the Educational Testing Service. The thinking skills tests comprised five multiple-choice sections that address (a) verbal synonyms, (b) numerical series, (c) verbal analogies, (d) arithmetic reasoning(word problem), (e) sentence completion, and (f) Visual analogies. The reliability of the Lochhead-Whimbey Analytical Skills Test is estimated to be .76 for the reading Comprehension subtest, .75 for sentence completion, .76 for arithmetic reasoning and computation, .70 for numerical series, and .56 for verbal synonyms and analogies (NJCB, 1982). The computation of the reliability was undertaken by the New Jersey College Basic Skills Placement Test Board (N=513). The reliability of the New Jersey Test of Reasoning Skills was estimated to be .82 for reading comprehension, .81 for sentence completion, .67 for arithmetic reasoning and computation, .59 for numerical series, and .69 for verbal synonyms and analogies. It must be stressed that these data came from both 10th-12th graders and first year college students in the state of New Jersey. The investigator believes that the population just mentioned shared some characteristics with the population in this study and concluded that the 20-item thinking skills tests were reliable with the participating students.

Each item on the thinking skills tests was scored 0 if incorrect, and 1 if correct. The total score for each student was found by adding the points awarded in all the questions. The maximum possible score was 20.

All the tests (Thinking skills and Physics achievement) were administered during the period of the research. The reliability for each administration of each test was calculated by using the Cronbach Alpha test (Cronbach, 1951), and in all four separate reliability coefficients were calculated. The alpha-coefficients are shown in Table 3.2 below.

Table 3.2. Results using Cronbach Alpha Test

Test	Type	α - coefficient
Thinking Skills	Pretest	.72
	Posttest	.77
Physics Achievement	Pretest	.68
	Posttest	.72

Although one of these alphas was somewhat low, it was considered adequate due to the diversity of test items.

Attitude Questionnaire

It was the belief of the investigator that the intervention with the teachers might have a significant impact on the attitudes, values, and perceptions of students towards their teachers and physics learning. In order to detect these attitudinal changes, the decision was made to develop an instrument designed to assess these attitudes. The following criteria to be met by the attitudinal instruments were identified:

1) Items were selected to assess the differences among the comparison groups.

2) Items selected would relate to form, sequence and necessity treatment variables of skills which were the focus of the research.

3) The number of items must be small and the time required for the students to complete test short.

4) Whereas the main priority for the questionnaire format and item selection derived from the research, that is, to relate academic and emotional attitudes to the treatment variables, it was also desired that the instrument should supply feedback of a practical nature to the teacher.

5) The instrument should be useful to all physics teachers interested in obtaining quick, functional information about the success of their teaching methods and curricula, to enable them to effect possible revision and improvement.

6) The scoring of the instrument should be simple.

Taking into account these factors, a questionnaire was adapted from a standard physics questionnaire (The Birnie-Abraham-Renner Quick Attitude Differential or BAR) published by the Psychological Corporation, New York. Different sections of the original questionnaire address feelings about self-concept, feelings about school, and feelings about physics. To these, items probing about attitudes regarding interactions with teachers, and about the value of physics, were included. Each item on the questionnaire was in the form of a question or statement that invites a response somewhere on a line connecting the two extremes. The final questionnaire contained 20 items and was administered in both the pre-test and post-test.

Students' Interview

To assess students' attention, understanding, and use of the thinking skills, six students from each of the experimental groups were interviewed following the post-tests. The interviews were conducted by the investigator and a colleague. We were unaware of the score of the participating students as well as the class achievement level of the students interviewed. The interviewing of students involved a process known as the "concurrent, think aloud". The interview session moved from open-ended questions about students' physics problem solving and reasoning to more structured questions regarding the specific processes that had been applied. The interview format and the specific questions used were adapted from a methodology used by the Scientific Reasoning Research Institute at the University of Massachusetts/Amherst.

Students' responses to the complete interview were audiotaped and transcribed and used in the analysis where necessary.

CHAPTER 4

TREATMENT AND ANALYSIS OF THE DATA

Introduction

In this chapter the results of the tests that were administered to provide a summative evaluation of the effects of the instructional program are presented. These tests include the thinking skills, physics achievement, and the attitude questionnaire. The results are given here as the primary data.

The study was designed to answer the following evaluation questions:

1) (A) As a result of the intervention, do subjects in the experimental groups exhibit superior thinking and learning skills as measured by the assessment instrument, when compared to subjects in the control groups?

   (B) Did the results of the intervention show that subjects in the experimental groups exhibit better understanding of physics concepts and problem-solving skills than the control groups?

2) Did the effectiveness of the instructional program vary in any significant way across the four experimental classes in terms of sex, and age?

3) Did the intervention initiate any attitudinal change in the subjects towards their physics teachers, and physics learning?

To answer these questions, data were collected by administering a battery of physics and thinking skills tests both before and after the program (as "pre-tests" and "post-tests"). In addition, data were collected on students' attitudes both before and after the intervention since the investigator felt the program might have an impact on the attitudes, values, and perceptions of students towards themselves, their teachers and physics learning.

The data collected were analyzed with two basic goals in mind (corresponding to the evaluation questions above). The first goal sonsisted of determining whether the experimental subjects have more successful outcomes than the control subjects. The second goal consisted of determining whether the experimental treatment was more successful for some students (or groups) than for others within the experimental classes. Class means, performance gains, t-tests, regression analysis, and analysis of variance on the tests were utilized as the basic units of analysis.

All the analyses were performed using BMDP 4V (Bio-medical Data Program, Version 4) on the CDC/Cyber 870 computers at the University of Massachusetts/Amherst.

Pre-Test Performance: Thinking Skills and Physics Tests

The data presented here for each test are based on the students who took both tests, that is, pre-test on thinking skills and pre-test on physics achievement. First, MANOVA was performed with the following factors: treatment (Experimental vs. Control); Class within treatment (4 classes per treatment). The type of tests were thinking and physics (pre- and post-). The MANOVA with the factors listed above showed that there was significant effect of classes within treatment [F(6,155)=4.95, p=.0001]. The significant effect, though not unexpected because of reasons provided earlier, meant that we could not consider the main effect to be treatment. Consequently, the results are reported by pairing experimental and control classes with common characteristics as described in chapter three.

Tables 4.1 to 4.4 represent the pre-test performances of the 4 pairs of experimental and control classes. These tables show the mean scores on the pre-tests and the difference in the means between the experimental and control groups. The numbers of experimental and control students are also listed.

Table 4.1. Pre-test Results:
Thinking Skills and Physics Tests of Paired Class A

	Test Name	
	Thinking Skills	Physics
Number of Questions	20	20
Number of Exp. (Class A)	28	28
Number of Control (Class A)	21	21
Mean in % (Experimental)	48.75	51.43
Mean in % (Control)	47.77	49.65
Difference in means in %	.98	1.78

Table 4.2. Pre-test Results: Thinking Skills and Physics Tests of Paired Class B

	Test Name Thinking Skills	Physics
Number of Questions	20	20
Number of Experimental (Class B)	15	15
Number of Control (Class B)	15	15
Mean in % (Experimental)	46.34	53.00
Mean in % (Control)	50.67	59.50
Difference in means in %	4.33	6.50

Table 4.3. Pre-test Results: Thinking Skills and Physics Tests of Paired Class C

	Test Name Thinking Skills	Physics
Number of Questions	20	20
Number of Experimental (Class C)	23	23
Number of Control (Class C)	20	20
Mean in % (Experimental)	54.13	62.83
Mean in % (Control)	53.75	58.25
Difference in Means in %	.380	4.58

Table 4.4. Pre-test Results:
Thinking Skills and Physics Tests of Paired Class D

	Test Name	
	Thinking Skills	Physics
Number of Questions	20	20
Number of Experimental (Class D)	22	22
Number of Control (Class D)	19	19
Mean in % (Experimental)	49.55	62.73
Mean in % (Control)	52.63	59.74
Difference in means in %	3.08	2.49

Table 4.1 indicates that the experimental class A performed better than the control class A on the thinking skills pre-test by a very small percentage (.98). On the physics pre-tests, the experimental class also performed better than the control class by a small amount (1.78). The difference is statistically significant for the physics achievement pre-tests [$F(1,41)=2.21$, $p < .025$].

A perusal of Table 4.2 indicates that on both thinking skills and physics pre-tests, the control class B performed better than its corresponding experimental class B. The percentage differences in the means are statistically significant [$F(1,30)=2.72$, $p < .001$] for the combined thinking and physics pre-tests.

As can be seen in Table 4.3, students in the experimental class did differ from students in the control group in their pre-test thinking skills and physics mean scores. The difference in the mean score is statistically significant for the physics pretest [F(1,46)=3.11, $p < .002$]. On the thinking skills pre-test, although some differences are detected between the experimental and control class, the difference is statistically insignificant [F(1,46)=3.26, $p < .60$].

Table 4.4 indicates that the experimental class performed better on the physics pre-test by a margin of 2.99%. This difference in the mean scores between the two paired classes is statistically significant [F(1,41)=2.89, $p < .002$]. However, on the thinking skills pre-tests, the control class performed significantly better than the experimental class.

It is immediately apparent that the paired experimental and control classes exhibit significant differences in some of the mean scores on the thinking skills and physics pre-tests. Since the major interest here was a comparison of the experimental and control classes after intervention, the gains made from pre-test to post-test will be considered. The next few sections present data on the relative gains evidenced by both experimental and control classes.

Performance Gains: Thinking Skills and Physics Tests

For convenience, both pre-test and post-test scores and the relative gains are presented in Tables 4.5 to 4.8.

Table 4.5. Performance Gains:
Thinking Skills and Physics Achievement of Paired Class A

	Test Name	
	Thinking	Physics
Number of Questions	20	20
# Experimental Students (Class A)	28	28
Pre-test Score(Exp.) in %	48.75	51.43
Post-test Score(Exp.) in %	65.89	56.09
# Control Students (Class A)	21	21
Pre-test Score(Cont.) in %	47.77	49.65
Post-test Score(Cont.) in %	50.15	53.22
Gain, Experimental Class (%)	17.14	4.66
Gain, Control Class (%)	2.38	3.57

Table 4.6. Performance Gains:
Thinking Skills and Physics Tests of Class B

	Test Name	
	Thinking	Physics
Number of Questions	20	20
# Experimental Students (Class B)	15	15
Pre-test Score(Exp.) in %	46.34	53.00
Post-test Score(Exp.) in %	58.00	60.34
# Control Students (Class B)	15	15
Pre-test Score(Cont.) in %	50.67	59.50
Post-test Score(Cont.) in %	51.01	61.50
Gain, Experimental Class (%)	11.66	7.34
Gain, Control Class (%)	0.34	2.00

Table 4.7. Performance Gains:
Thinking Skills and Physics Tests of Class C

	Test Name Thinking	 Physics
Number of Questions	20	20
# Experimental Students (Class C)	23	23
Pre-test Score(Exp.) in %	54.13	62.83
Post-test Score(Exp.) in %	63.92	66.53
# Control students (Class C)	20	20
Pre-test Score(Exp.) in %	53.75	58.25
Post-test Score(Exp.) in %	56.50	60.35
Gain, Experimental Class (%)	9.79	3.70
Gain, Control Class (%)	2.75	2.1

Table 4.8. Performance Gains:
Thinking Skills and Physics Achievement Tests of Class D

	Test Name Thinking Skills	 Physics Achievement
Number of Questions	20	20
# Experimental Students (Class D)	22	22
Pre-test Score(Exp.) in %	49.55	62.73
Post-test Score(Exp.) in %	57.74	66.41
# Control Students (Class D)	19	19
Pre-test Score(Cont.) in %	52.63	59.74
Post-test Score(Cont.) in %	53.42	60.42
Gain, Experimental Class(%)	8.19	2.27
Gain, Control Class(%)	0.79	3.68

Tables 4.5 to 4.8 show the gains scores on the thinking skills and physics achievement tests. Each table shows data for one of the four pairs of experimental and control classes.

The immediate impression of the data above is of consistently larger gains in the experiment than control classes for the thinking skills test, but not the physics tests.

The gain for the experimental class A was significantly greater than that of the control class A (one tail t-test) for both the thinking skills test [$F(1,42)=3.32$, $p < .001$], and the physics achievement test [$F(1,49)=2.79$, $p < .025$]. Hence, for class A, the intervention had a significant positive effect for both the thinking and physics tests, probably somewhat greater for the thinking test.

Table 4.6 shows the gains for both experimental class B and control class B. The gain for the experimental class B was significantly greater than that of the control class B for both the thinking and physics tests [$F(1,30)=4.88$, $p < .001$]. It is apparent here that the gain made by the experimental class B suggests clearly that the intervention had a positive significant effect for both thinking and physics tests.

In Table 4.7 we observed that although no significant differences (at the $p < .05$ level) were found between the experimental class C and control class C thinking and physics pre-test means, the experimental class C post-tested at a significantly higher level ($p < .002$) on the physics test than the control class C. When post-test gains in thinking and physics tests were tested, the gain by the experimental class C was significantly greater at the .001 level (one tail t-test) than the gains made by the control class C [F(1,30)=4.12, $p < .001$]. Hence, for class C, the intervention had a significant positive effect for both thinking and physics tests.

In Table 4.8 the experimental class is observed to retain the advantage over the control class in terms of gain on the thinking skills. The gain for the experimental class D was significantly greater than that of the control class D (one-tail t-test) for the thinking test [F(1,41)=4.67, $p < .001$] and is quite consistent with the findings thus far. However, contrary to the trend so far observed, the gains on the physics achievement from pre-test to post-test favors the control class over the experimental class. It is important to point out that the fact that in paired class D the control group performed better on the physics test was not surprising since their performance on both thinking and physics pre-tests was high. This apparent anomaly will be discussed later on.

Statistical Significance of Combined Gains

As can be seen from Tables 4.4 to 4.8, the main effect in this study is one of consistently greater gains in the experimental class across the thinking skills test, reaching statistical significance in every instance. On the physics test, the differences between the experimental and control classes are significant for 3 of the 4 pairings. In one case, i.e. the case of paired class D, the significant gain is in favor of the control class. On the whole, however, the experimental classes show gains over the period of the study that are significantly larger than the gains of the control classes on the thinking skills and physics achievement tests that were administered.

The consistency of this outcome across the tests of thinking skills and less clearly but still significantly in the physics answers the major question of our study, that is, whether the instructional strategy treatment was effective. The differences observed between the gains of the experimental and control classes appear large enough to be of practical significance. This answers in the affirmative the first two evaluation questions. The statistical significance of the observed differences in the gains of the experimental and control classes gives the impression that on the whole the intervention did produce consistently positive effects in all the different schools involved in the study. This result is very important because schools with different characteristics were selected with the view of assessing the effect of intervention on them.

Test Performance in Relation to Gender

Gender was a factor that was random in the preceding analyses, but it was decided to consider the issue of gender to assess whether it interacted with the intervention. Equally important, two factors made the issue of gender worth studying. First, historical differences in male and female attitudes toward physics learning can affect students' motivation, readiness, and level of information differentially between the sexes. Secondly, males have tended to score higher than females on measures of physics achievement. For both of these reasons, it was speculated that this intervention might affect males and females differentially.

Since the investigation of gender was exploratory in nature, the four experimental and control classes were combined separately. The experimental classes consisted of 48 males and 40 females (54%, 45%), and the control class consisted of 42 males and 33 females (56%, 44%).

Both the thinking skills and physics achievement tests were analyzed for sex-related differences in performance on the pre-test, post-test, and gains, separately for the experimental and control classes. Three statistically significant differences in the experimental classes were detected. On the thinking skills pre-test, the females performed better than the males. With respect to the gains on the same test, males were found to have greater gain than the females. In the physics post-test the gain was in favor of the males, while the pre-test performance on the same test favors the females. On the whole, no significant differences were found in the control classes.

These results then suggest that there were no substantial differences in the performance of males and females in this study.

Test Performance in Relation to Age

Another factor that was exploratory in nature was that of age. As indicated earlier, students who participated in this study were drawn from grades 10 to 12, with ages ranging from about 15 to 17 years. Thus, it was felt during the course of the research that this relationship should be explored, since the study involved students of different ages, and one might expect a higher test performance for older students. Furthermore, there is empirical evidence to support that different age groups respond differently to learning strategies. The work of developmental theorists (Ginsburg & Opper, 1979; Bruner, 1957; Piaget, 1931) has indicated that readiness for learning is related to an individual's developmental stage, in which age is a factor. For example, during the period from 2 to 4 years children are expected to employ mental symbols, to engage in symbolic play, and to use words. Krumboltz's (1979) social learning theory of decision-making considers learning experiences to be key factor in readiness to respond to treatment; age should be related to the quality of academic-related learning experience an individual has been exposed to. Thus, according to both the developmental and social learning theories, readiness and response to a learning strategy can be expected to vary with age. The potential for differential outcomes was thus targeted for investigation.

Table 4.10 shows correlations between age and the pre-test, post-test, and gain scores for both the experimental and control classes. The data shows the existence of consistent but small negative correlations. On the pre-test, the negative correlations are similar between the experimental and control groups and this suggests that older students tended to have higher initial cognitive skill levels. On the post-test, the control students show very similar correlations, whereas the experimental students show somewhat larger correlations, suggesting that younger students tended to gain more from the program than older students. This interpretation is supported by correlations of age with the gain scores for both experimental and control groups: Though the control group shows approximately zero correlation, suggesting that student gains occurred rather uniformly across age levels, the experimental group shows a moderate correlation, indicating that younger students benefited more from the program, on average, than older students.

Table 4.9. Correlation of Age and Test Performance

Test	Pretest		Posttest		Gain	
	Exper.	Ctrl	Exper.	Ctrl	Exper.	Ctrl
Thinking Skills	-.17	-.17	-.29	-.20	-.26	-.10
	-.13	-.19	-.25	-.27	-.04	-.03
	-.19	-.17	-.30	-.21	-.23	-.01
	-.22	-.20	-.33	-.23	-.24	-.05
Physics Test	-.21	-.23	-.36	-.25	-.27	-.02
	-.20	-.25	-.27	-.23	-.22	-.03
	-.18	-.23	-.32	-.23	-.26	-.06
	-.23	-.20	-.29	-.21	-.29	-.08

Note: The correlations in single figures, -.01 to .08 under GAIN are not significant, the others are significant with $\rho < .01$.

Attitude Questionnaire

Means scores on each of the 20 items in the questionnaire were computed for the four control classes and for the four treatment classes combined. The higher the means of the treatment group in comparison to the control group, the more favorable its attitude was judged to be toward the intervention.

Significant differences between the control and the experimental classes on the questionnaire were tested using t-tests for significance of mean scores. The results of the questionnaire were uninformative. Of the 20 items, the difference between the change evidenced over the period of the study by the experimental and control groups was statistically significant (at the $p= .05$ level) for 10 items, close to the 8 items expected to be significant by chance, and those 10 did not give any coherent picture.

It is the opinion of this investigator that attitudes, values, and perceptions towards physics learning and teachers were probably influenced by the program, and that the questionnaires administered were simply insensitive to this influence. As a mechanical matter, it was noted that the scales to be marked for each item were consistently ordered from positive (on the left) to negative (on the right) and that all students showed a strong leftward trend throughout, leaving little room for desirable change. In short, the questionnaire instrument developed for this study was not up to the task.

CHAPTER 5

SUMMARY, CONCLUSIONS, RECOMMENDATIONS, AND IMPLICATIONS

Summary

The primary objective of this study was to develop a program which encourages students to acquire thinking skills while learning physics. It was believed that to achieve this outcome, teachers' instructional behavior and processes must be changed as a result of training sessions with the investigator.

In accordance with the main objective of the study, it was found that the intervention had a corresponding effect on teachers' instructional behavior, and on the resulting instructional processes of the class. Consequently, students in the experimental classes reported using more thinking skills when solving physics problems. The program also affected students' physics achievement. These effects depended both on the initial physics achievement level of the class and the student. A closer look at the scores of students in the experimental classes indicated that physics/thinking skills instructional strategy had a more positive impact on higher or medium ability students in terms of their physics achievement scores than the lower ability students. However, if one considers the scores on the thinking skills tests, it is apparent that the lower ability students benefited more from the instructional strategy than did the higher ability students.

It was hypothesized that positive effects of physics/thinking skills instruction were more difficult to achieve in lower ability students because, as a group, these students simply had more difficulty in learning. Lower ability students may have needed a longer period of guided high-quality meaningful instruction adapted to their learning needs. Because high ability students began with better learning skills and strategies, they readily benefited from the physics/thinking skills instructional program, even if the teachers' instructional behavior was not always optimal. In conceptualizing the cognitive processes that mediated the effects of students' ability and the physics/thinking skills intervention on students' physics achievement, one could consider how student initial ability in physics might affect the instructional processing and decision-making of the teacher. Teachers might have used their knowledge of students' ability and their perception of the students' understanding to pace and modulate their thinking skills instruction and to provide more or less structure and guided practice as needed. Analyses of the video tapes of the classroom processes suggested that teachers in whose classes low ability students were present did not modify their instruction to meet the needs of the lower ability students. Within a given class, lower ability students were more likely to benefit because the thinking skills program was needed more by these students. That is, lower ability students in the class were less likely to already possess the thinking skills being taught, or some other equally effective way of thinking. Moreover, the amount of time teachers spent teaching the thinking skills might have corresponded better to these students' learning needs, than to the learning needs of the higher ability students. That is, when teachers spent "too much time" teaching thinking skills (from the perspective of the learning needs of higher ability students), they were not introducing new content that higher ability students could have learned and could have used to answer posttest questions. Thus, the physics/thinking skills treatment had a "remediating effect" for lower ability students within the class by providing them with cognitive strategies that they did not initially have although this acquisition of the strategies may not necessarily lead them to outperform the higher or medium ability students.

Likewise, the physics/thinking skills instructional program had a reliable and general impact extended across students of different socio-economic backgrounds (as measured by the school a student attends). It was also observed that the treatment strategy was indifferent to the sex of the student. With respect to age, though, small negative correlations were expected and observed. Statistically, all the participating teachers were uniform in delivering the program, though the observation data (observation from video tapes) suggest otherwise.

Conclusions

In conclusion, the findings of this study are important for four reasons. First, it represents one of the first experimental classroom-based studies aimed at improving the thinking skills and physics understanding of high school students through physics instruction. Many previous thinking skills strategy training studies have lacked ecological validity in the sense that researchers rather than teachers have instructed the students. In this study, the investigator worked with teachers on the skills they taught to their students. Teachers were able to learn the skills and cognitive strategies, as well as how to teach them. In turn, the teachers were able to teach these thinking skills to their students as part of their typical on-going classroom instruction in physics. Thus, this study demonstrated the practical utility of a thinking skills instructional approach in an actual class situation, provided a model for implementation with teachers and students, and documented and described effects of the intervention in a valid situation.

Second, the study demonstrated that to gain a complete understanding of the effects of a classroom-based physics/thinking skills curriculum, researchers need to conceptualize and examine effects at class level and at individual student level. This is important if any new instructional program is to benefit all students in the class. Nearly as important, researchers need to distinguish the unit of statistical analysis from the unit of conceptual analysis. In this study, because students were taught the thinking skills in a whole-physics class situation, effects on students were not independent. Thus, the class was the appropriate unit of statistical analysis. However, the effects were analyzed conceptually both at the class level and at the individual student level. Results showed that the effects of the program depended on the ability level of the class as well as the ability level of the students within a class.

Third, educational researchers have engaged, and still are, in debate and still are about whether higher order thinking is domain-specific, and about "the wisdom of attempting to develop thinking skills outside the context of specific knowledge domains" (Resnick, 1987, p.18). The knowledge and understanding derived from this study may contribute to the current debate on whether and how higher order thinking can be facilitated in the classroom. As researchers continue to consider these questions, they need to keep on mind the complexity of the teaching and learning processes that occur in real classrooms.

Finally, while this study must be viewed as an exploratory one, it has demonstrated that a program such as this can have reliable and substantial effects, at least when assessed on short-term basis.

Recommendations

1. This study lasted a period of 10 weeks, and thus although the evaluation data suggest that the thinking skills of the participating students were enhanced as measured by their performance, it could be argued that the program has only short-term effects. It is against this background that the investigator urges that the study be treated as a beginning on which to build. Consequently, it is recommended that similar studies should be conducted over a longer period. Six to twelve months would provide enough time to assess the long-term effects of the program.

2. It is the belief of this investigator that any educational intervention must bring about change in students' attitudes, values, and perceptions towards teachers, themselves, and the subject. The questionnaires administered in this study failed to measure subtle changes in attitude. It is recommended that the questionnaire be extended and refined for future study.

3. Though the effects of the instructional strategy on lower ability students and higher ability students was explored briefly in this study, it is recommended that an entire study could be designed to focus on the treatment effects on lower ability

students. This will mean the need to examine students' cognitive processes underlying the within-class and between-class ATI effects on students' performance.

4. It is also recommended that the duration of the intervention with teachers be extended. This calls for the development of a new plan for training the teachers.

5. In this study, the schools were selected from both the private and the public sectors. For homogeneity of students and classes, it is suggested that any further study must focus separately on either public schools or private schools.

6. The Teachers' Manual prepared for this study is for a period of only ten weeks. Hence any attempt to extend the duration of the study must be accompanied by a revision of the manual to cover a 12 month period. Suggestions which were made by teachers and noted in the appendix of the manual must be considered.

Implications

This study would be incomplete if we did not address the question of what this study implies for the present and the future.

The present study was probably the first to identify the need to gather data to help explain the processes that mediate the effects of classroom-based thinking skills strategy interventions on teachers' instructional processes and on students' achievement in physics. The results of this study have implications for future research and for educational practice, such as implementing new education programs. The results provided important information to explain the effects of treatment interventions in the classroom. Equally important, the results provided information that was not available and that was not obvious from the examination of students' scores on tests or from teachers' and students' behavioral data gathered through classroom observation. Thus, the data gathered through this study may be useful in developing theories of classroom learning and teaching. The data generated through this study provide insights that researchers on teaching might draw on to develop psychological models of the processes that occur in the classroom and that lead to student achievement.

Similarly important, the findings of this study may provide information that will be useful in designing future interventions with teachers to impart thinking strategies to students in their classrooms. In particular, the observation data provide rich, descriptive, qualitative case studies that might be used with teachers to illustrate how teachers and students respond differently to educational interventions. The findings also provide concrete evidence to illustrate how a thinking skills intervention significantly altered the cognitive processes reported by students in the experimental classes.

The American Association for the Advancement of Sciences has just released a report intended to change the way mathematics and sciences are taught in the schools during the next decades. The report "Science for all Americans," states that literacy in science, mathematics and technology "has emerged as a central goal of Education." (Chronicle of Higher Education, March 5, 1989). Among other recommendations, the report states that students taking science and mathematics should concentrate more on "developing thinking abilities and less on memorizing details." (Chronicle of Higher Education, March 5, 1989).

Finally, as noted earlier, several contemporary experiments in the direct teaching of thinking skills have yielded very positive results. However, most efforts to cultivate thinking skills in students have not focussed on bringing together context-specific knowledge with general thinking skills. Rather, they have taken the form of courses segregated from the conventional subjects matters and made little effort to link up with subject matter (cf. Nickerson et al., 1985; Segal et al., 1985).

In contrast, the approach that seems needed as seen from the American Association for the Advancement of Sciences report cited above calls for the intimate intermingling of thinking skills and context-specificity in instruction. This study has addressed exactly that call. Thus, it is satisfying to note that one important implication of the outcome of this study is that it is possible to teach content subjects in the classroom while at the same time helping students to acquire thinking skills. This investigator believes that this approach in physics education, and perhaps teaching in general, is promising and provocative: It gets beyond educating memories to educating minds, which is what teaching should be about.

APPENDIX A

Written Consent Form

WRITTEN CONSENT FORM

To participants in the study:

I would like to request your cooperation in the teaching of physics instructional materials in the classes you are teaching this year. The study is titled "The Development of Physics Instructional Materials to Enhance Thinking and Learning Skills". This study is part of my doctoral dissertation and is being undertaken to learn more about how physics instruction can be used to enhance thinking skills in students. This information will contribute to research in education, and may be beneficial to future teachers.

If you decide to participate, you will be asked to teach a 7 to 8 week unit of instruction using specially prepared instructional materials. Your students will be pre-tested and post-tested. You will also be required to participate in one thirty minute orientation session with me prior to the beginning of the study.

My goal is to analyze the material gathered in the study for presentation in my doctoral dissertation. I may also use the information in journal articles, workshops for teachers, and possibly a physics textbook. However, I will not under any circumstances use your name or the name of the school affiliated in the study. I will refer to your school as " a public high school in western Massachusetts.

Possible risk factors from your participation are no greater than normal class activity. However, you cannot expect to be compensated for any discomforts or injury as a result of your participation in the experiment described here. The investigator in this study is Isaac Amuah, a doctoral student at University of Massachusetts/Amherst. If you decide to participate, you are completely free to withdraw consent and discontinue at any time during the course of the study. If you have any additional questions, please contact me at the Scientific Reasoning Research Institute, University of Massachusetts, 545-0988 (Daytime) or (413) 549-7536 (Evenings).

Sincerely,

Isaac Amuah

(You may keep the top portion of this form).

I have decided to participate in the study as described above, and will allow my class to be pre-tested and post-tested. My signature indicates that I have read the information above and have decided to participate. I realize that I may withdraw without prejudice at any time after signing this form should I decide to do so.

-- ------------

Signature Date

APPENDIX B

Thinking Skills Pre-Test

THINKING SKILLS PRE-TEST

Name______________________________
Instructor___________________________________
Sex_____________

Instructions:

This inventory consists of 20 questions. circle the answer which you think is correct. Please note that your performance here will not affect your school grade.

1. If Kweku is someone born on Wednesday, then Kofi is someone born on/in/at...

(A) December (B) Midnight (C) Friday
(D) England

2. Laboratory is to scientist as ________ is to _____________:

(A) Death...life (B) Jail...prisoner (C) Dog...bone
(D) Teacher...blackboard

3. If F = ma = 60N and a = 10ms-2, then mass m is:

(A) 5N (B) 10 kgms-2 (C) 10 kg (D) 6 kg

4. Which pair is literally equivalent to Electricity:Resistance?

(A) Motion:Friction (B) Liquid:Density (C) Fluid:Viscosity
(D) Speech:Loud

5. What does the term ut represent in $S = ut+1/2at$?

(A) Velocity (B) Displacement (C) Distance
(D) Acceleration

6. Which two disciplines constitute the physical sciences?

(A) Physics and Botany (B) Chemistry and Physics
(C) Biology and Geology (D) Zoology and Geo-Physics

7. If sodium has 11 protons in the nucleus, then its atomic number is:

(A) 12 (B) 22 (C) 11 (D) 6

8. Light travels in a straight line, but it can diffract too, meaning that it can:

(A) Jump over obstacles (B) Reflect
(C) Bend around obstacles (D) Destroy obstacles

9. Which pair of words fits best in the blanks?

Oven is to bake as _________ is to __________.

(A) Automobile:Carry (B) Dishwasher:Dishes (C) Food:Ice
(D) Vacuum cleaner:Rug

10. Ten full crates of walnuts weigh 410 lbs, while an empty create weighs 10 lb. How much do the walnuts alone weigh?

(A) 400 lb. (B) 300 lb. (C) 310 lb. (D) 320 lb.
(E) 420 lb.

11. One number in the series below is incorrect. What should that number be?

3 4 6 9 13 18 24 33

(A) 33 (B) 7 (C) 24 (D) 31 (E) 32

12. BDF is to GEC as JLN is to_

(A) KMN (B) KMO (C) MKI (D) OKI (E) OMK

13. Which pair of words best fits the meaning of this sentence:

____________the dog was big, he was ______________heavy.

(A) Since--not (B) Although--very (C) Although--not
(D) Because--nevertheless

14. Write the 2 numbers which should appear next in the series:

3 9 5 15 11 33 29 ____ ____

15. An orthopedist is a _________ specialist.

(A) Brain (B) Heart (C) Ear and Throat (D) Lung
(E) Bone

16. An equivocal statement is ____________________.

(A) Relevant (B) Equivalent (C) Credible
(D) Somewhat Loud (E) Ambiguous

17. Three empty cereal boxes weigh 9 oz and each bowl holds 11 oz of cereal. How much do 2 full boxes of cereal weigh together?

(A) 20 oz (B) 40 oz (C) 14 oz (D) 28 oz (E) 15 oz

18. Cross out the letter in the word pardon which is in the same position in the word as it is in the alphabet.

(A) P (B) A (C) R (D) D (E) O

19. A journey always involves a ______________________.

(A) Person (B) Destination (C) Distance (D) Vehicle
(E) Preparation

20. In how many days of the week does the third letter of the day's name immediately follow the first letter of the day's name in the alphabet?

(A) 1 (B) 2 (C) 3 (D) 4 (E) 5

APPENDIX C

Thinking Skills Post-Test

THINKING SKILLS POST-TEST

Name______________________________
Instructor______________________________
Sex________

Instructions:

This inventory consists of 20 questions. Circle the answer which you think is correct. Please note that your performance here will not affect your school grade.

1. The words pair and dozen are examples of characteristics of the dimension called ____________?

(A) Color (B) Richness (C) Number (D) Weight

2. Here are some dimensions referring to the nations of the world. Which is not orderable?

(A) Number of inhabitants (population)
(B) Kilometers of coastline
(C) Official Language
(D) Amount of rainfall

3. Snake is to hiss as saw is to

(A) Whine (B) hammer (C) cut (D) board

4. Which of the following words does not belong with the rest?

HORSE PIG ROOSTER COW LAMB

(A) Horse (B) Pig (C) Rooster (D) Lamb

5. River is to running and flag is to waving as ___________ is to __________?

(A) grass is to seed
(B) car is to wheels
(C) rain is to fall
(D) landscape is to wind

6. According to which principle does a rubber band hold objects together?

(A) Adhesion (B) Penetration (C) Pressure
(D) Hooking

7. Which is one of the functions of an automobile?

(A) Keep people comfortable when travelling
(B) Consume gasoline
(C) Have a glass windshield
(D) Have a steering wheel

8. An engineer wants to build a bridge over a deep and wide river. Which would be the least problematic aspect of his design?

(A) How to build the central support that holds the bridge up.

(B) How to make the bridge as high as possible so that ships can pass under.

(C) How to build a sufficiently light structure so that the supporting elements do not collapse.

(D) How to paint the lines dividing the lanes on the bridge surface.

9. Which pair of words is different from the other three pairs?

(A) Walk -- slowly
(B) Speak-Loud
(C) Read-Book
(D) Lift-Quickly

10. If X is both north of Y and Z, Y is north of W, and W is north of Z, then which of the relationships is also true?

A. W is north of X. B. X is south of W. C. Y is south of Z.
D. Z is north of Y. E. None of the above.

11. Which number is repeated first in the following series?

5 9 4 8 2 3 6 1 7 4 7 6 7 8 9 1 5 2 3 5 8 9 5 3 5 4 3 7 1

A. 7 b. 8 C. 6 D. 4 E. 5

12. Which pair of words fits best in the blanks?

Oven is to Bake as ________ is to __________

(A) Automobile: Carry (B) Dishwasher: Dishes
(C) Food: Ice (D) Vacuum cleaner: Rug

13. Write the 3 letters which should come next in this series:

B A A C E E D I I E M M F ___ ___ ___

14. One-Third is to 9 as 2 is to ________

A. 6 B. 18 C. 36 D. 54 E. 99

15. Elephant is to small as ____________ is to ______________

(A) Large: Little B. Hippopotamus: Mouse
(C) Turtle: Slow D. Lion: Timid

16. Which word means the opposite of demise?

A. hasty B. Birth C. Accept D. Embrace

17. Which set of letters is different from the other three sets:

a. HRTG b. NONP c. XACW d. LDFK

18. Hospital is to sickness as _________ is to __________

A. patient: disease B. jail: prisoner
C. doctor:patient D. school:ignorance
E. nurse: illness

19. A train travels 50 miles while a car travels 40 miles. How many miles will the train travel when the car travels 60 miles?

A. 60 B. 50 C. 70 D. 75 E. 80

20. Heretic is to religious as ________ is to __________

A. disbelief: faith B. adversary: cooperative
C. sinner: punishment D. disrespectful: pious

APPENDIX D

Physics Pre-Test

PHYSICS PRE-TEST

Physics Achievement

Name____________________________________
Instructor______________________
Sex______

Instructions:

This tests consist of 20 questions. for each multiple-choice question, circle the answer which you think is correct. Please note your performance here will not affect your school grade.

1. Which one of the following is a vector quantity?

   A. Electrical Energy
   B. Electrical Resistance
   C. Electrical Field
   D. Charge

2. A lift of 50 kg is suspended by a cable. If the tension in the cable is 400N, the lift is moving...

   A. Upward with constant speed
   B. With constant upward acceleration
   C. Downward with constant speed
   D. None of the above.

3. A bell falls freely under gravity. If air resistance is ignored, it falls with constant...

   A. Velocity
   B. Kinetic energy
   C. Momentum
   D. Acceleration

4. During an elastic collision:

   A. Only momentum is conserved
   B. Only energy is conserved
   C. Both momentum and energy are conserved
   D. Heat is dissipated

5. Thermionic emission is the emission of:

   A. protons from a heated metal
   B. Electrons from a heated metal
   C. Neutrons from a heated metal
   D. Atoms from a heated metal

6. The phenomenon observed when light bends around a barrier is called...

   A. Reflection
   B. Refraction
   C. Polarization
   D. Diffraction

7. A cricket ball is thrown vertically upward. Assume that there is no air friction. At the highest point in it, kinetic energy...

   A. is at its greatest, and potential energy is zero.
   B. is zero, and potential energy is at its greatest.
   C. and potential energy are both at their greatest
   D. and potential energy are both at their smallest.

8. Which one of the following is a unit for force?

   A. Watt
   B. N
   C. J.C-1
   D. V.m-1

9. Which one of the following is always found in the atomic nucleus of every element?

A. electron
B. neutron
C. proton
D. alpha

10. A 2 resistor and a 4 ohms resistor are connected in series and a potential difference of 12V is applied across the combination. Which of the following is true?

A. The potential difference across the 2 ohms resistor is 6V.
B. The current in the 2 ohms resistor is 2A.
C. The current in the 4 ohms resistor is 3/t.
D. The potential difference across the 4 ohms resistor is 4V.

11. A physics student talks about a measurement made in newtons. She is most likely to be discussing

A. Force
B. Weight
C. Acceleration
D. Quantity of matter

12. A smooth object falling from a great height will reach its terminal velocity when .... is zero.

A. Gravitational acceleration
B. Upward force of friction
C. Resultant Acceleration
D. Gravitational Constant
E. Downward force of gravity

13. Which statement is not true? In metals, the conduction electrons...

    A. are not attached to specific atoms
    B. move only in the direction of an applied electric field
    C. Can carry a current
    D. Have random velocities

14. Which is the largest energy?

    A. 1J   B. 1 Cal   C. 109 GeV   D. 3 Volt-Coulombs

15. The force due to gravity on a 50-kg mass is:

    A. 4.9 N   B. 4.9 x 103 N   C. 490 N   D. 50N

16. Which of the following is the largest?

    A. 1 x 105   B. 1002   C. 100x102   D. 1/10-6

17. What does the term vt represent in S = vt+1/2at2?

    A. Velocity
    B. Displacement
    C. Distance
    D. Acceleration

18. Which is incorrect?

    A. 1 millisecond = 106 seconds
    B. 1 millimeter = 10 centimeters
    C. 1 megavolt = 109 millivolt
    D. 1 centimeter = 10-5 kilometer

19. The quantity pAvE, where p = density, A = area, v = velocity, and t = time, has the units of...

    A. Mass
    B. Density
    C. Mass x Time x Length
    D. Volume

20. Which is larger?

    A. sin 45o
    B. cos 45o
    C. tan 45o
    D. tan 90o

APPENDIX E

Physics Post-Test

PHYSICS POST-TEST

Physics Achievement

Name______________________________
Instructor______________________
Sex______

Instructions:

For each of the multiple-choice questions, circle the answer which you think is correct. Please note the outcome of this test will not affect your school grades.

1. Which one of the following physical quantities is not completely specified?

   A. A velocity of 20 m.s-1, due N
   B. A mass of 14.5 kg
   C. A displacement of 10m, due E.
   D. A momentum of 25 kg ms.s-1

2. On the earth, an object has a mass of 5 kg. the approximate weight of the object on the earth is:

   A. 10N
   B. 50N
   C. 100N
   D. 300N

3. Motorists are urged to wear seat belts in automobiles. The advantage of wearing a seatbelt given by physicists would be

   A. To hold up the driver's pants
   B. To increase the deceleration of the car
   C. To counteract the inertia of the driver
   D. To increase the mass of the car

4. Which one of the following represents the magnitude and a unit vector quantity?

   A. 10J
   B. 20 N.C-1
   C. 5W
   D. 3V

5. The coulomb force of repulsion between positively charged objects A and B can be increased by:

   A. halving the charge on B
   B. Doubling the distance apart
   C. Halving the charge on A
   D. Doubling the charge on A

6. A man walks from A to B to C to D to A around a rectangular street block. Where does be experience his maximum displacement?

   A. at B
   B. at D
   C. at A
   D. at C

7. Which one of the following statements with regard to force is false?

   A. Force sometimes causes distortion of an object.
   B. Force always acts in a specific direction
   C. Force will always cause acceleration
   D. Force sometimes causes change in direction of motion

8. Which one of the following pairs contains two vector quantities?

   A. Force and speed
   B. Impulse and momentum
   C. Mass and weight
   D. Electrical field strength and force

9. The formation of a spectrum by white light passing through a glass prism is due to:

   A. reflection
   B. diffraction
   C. interference
   D. refraction

10. The famous scientist who stated the Law of Universal Gravitation was

    A. Einstein
    B. Newton
    C. Galileo
    D. Aristotle

11. The property of inertia is found in a body's

    A. friction
    B. momentum
    C. mass
    D. velocity

12. The number and kind of molecules in an object determines the quantity of matter in an object. This quantity is called

    A. Force
    B. Density
    C. Mass
    D. center of mass

13. Which of the following is not always true?

- A. $F = (mv/ t)$
- B. $F = ma$
- C. $F(t2-t1) = P2-P1$
- D. $T = L/ t$

14. A car travels 100km at a speed of 30km/hr for one part of a trip and at 50 km/hr for the remainder. It takes two hours to make the trip. What is the average speed?

- A. 40 km/hr
- B. 45 km/hr
- C. 50 km/hr
- D. It cannot be determined

15. When a ball is thrown straight up, the acceleration at the maximum height is:

- A. zero
- B. decreasing
- C. increasing
- D. 9

16. If a velocity-time graph is a straight line with an upward slope, which of the following is not true:

- A. The velocity is constant
- B. The acceleration is a constant
- C. The velocity is changing
- D. The distance is changing

17. Which of the following is the largest speed?

- A. 60 mi/hr
- B. 100 km/hr
- C. 100 ft/s
- D. 2.5x103 cm/s

18. Which of the following is not one of the fundamental quantities of physics?

    A. time
    B. length
    C. weight
    D. mass

19. The smallest mass known to exist in nature is that of

    A. an atom
    B. a proton
    C. a neutron
    D. an electron

20. On the moon the quantity of matter in an object

    A. Is the same as it is on the earth
    B. Is greater than it is on earth
    C. Is less than it is on earth
    D. Is six times larger than it is on earth

APPENDIX F

Attitudinal Questionnaire, Pre-Test

ATTITUDINAL QUESTIONNAIRE, PRE-TEST

Do not write your name on this questionnaire. It is being administered for research purposes only and will in no way affect your grade.

1. Sex: male_____ female_____

2. I am: an only child_____ an oldest child_____
a youngest child_____

3. The next older child is: a boy_____ girl_____,
_____ years older than myself

4. The next youngest child is: a boy_____ girl_____,
_____ years younger than myself.

5. I am currently in grade (please circle one):
9 10 11 12

6. Do you plan to go to college? yes_____ no_____
If yes, what type of institution? 2 year college____
4 year college____

What do you expect to be your major field of study?__________________

The following statements were made by students who had recently completed a physics course. We are anxious to find out what you think about their statements. Please indicate your reactions by circling A if you agree with a statement and D if you disagree with it.

	Agree	Disagree
7. Most of the labs were not that informative for the amount of time spent on them.	A	D
8. Last year I was hesitant to take physics because so may people told me how tough it was.	A	D
9. I think this physics course is designed in such a way that even those who have little background in mathematics can gain very much from the course.	A	D
10. This course has made physics interesting to me.	A	D
11. The text is written well.	A	D
12. I don't think I have a good enough math background for this class.	A	D
13. This course has not been the drag that I expected physics to be.	A	D
14. The labs are fun.	A	D
15. I think learning about the men and women who made physics grown helped to make the course more interesting.	A	D
16. This physics course is one of the most interesting courses I have taken in high school.	A	D
17. I would recommend this physics to my friends.	A	D
18. The book was really enjoyable to read.	A	D

19. Primarily as a result of this course, I plan to take another physics course in college. A D

20. Physics is one of the most difficult courses I have taken in high school. A D

APPENDIX G

Attitudinal Questionnaire, Post-Test

ATTITUDINAL QUESTIONNAIRE, POST-TEST

The next two pages contain pairs of words that you will use to describe your image of the heading at the top of each page. Each pair of words will be on a scale which looks like this:

CHEMISTRY

QUICK SLOW

Please make a check in the box which best represents how the word pair describes the heading at the top of the page. For example, if you feel that "CHEMISTRY" is only somewhat connected with "QUICK," you would check the scale as shown. If you feel that "CHEMISTRY" is somewhat connected with "SLOW" or very closely connected with "SLOW," you would check one of the boxes nearer to "SLOW."

Look at the heading at the top of the page; get an impression of it in your mind and then quickly work down the page checking the scales. We are interested in your first impressions, so work rapidly and do not go back and change any marks.

Please check each scale and make only one check per scale.

1. Science and technology cannot possibly solve the problems of the environmental crisis.
   A B C D E

2. Public funds should not be spent on scientific research while millions live in poverty.
   A B C D E

3. The study of science is not necessary for successful living.
   A B C D E

4. Spending tax dollars on scientific research is good for the country in the long run.
   A B C D E

5. Science offers extensive career opportunities.

A B C D E

6. More nuclear power plants should be built now to prevent a critical power shortage in the future.

A B C D E

7. Our economic well-being depends on the unimpeded growth of science and technology.

A B C D E

8. The study of physics is devoid of emotional involvement.

A B C D E

9. Scientific policy questions should be left to those with the scientific training to understand them.

A B C D E

10. In the near future it will not be easy to find jobs in science.

A B C D E

11. Students should be required to study more science.

A B C D E

12. Problems of air pollution will be solved by the continuing efforts of scientists.

A B C D E

13. Medical science is not keeping pace with the increase in health problems.

A B C D E

14. Science and technology create more problems than they solve.

A B C D E

15. I would definitely not recommend my high school physics course to someone I like.

A B C D E

16. Information on any scientific research project should be freely available to the public.

A B C D E

17. Nuclear power plants are inherently dangerous and should not be operated.

A B C D E

18. Intellectual involvement in physics is highly rewarding.

A B C D E

19. Potentially dangerous scientific knowledge must be kept from the unscrupulous and irresponsible.

A B C D E

20. Medical science is advancing at a rapid rate.

A B C D E

APPENDIX H

Teachers' Manual

TEACHER'S MANUAL

STRATEGIES FOR TEACHING THINKING SKILLS IN THE PHYSICS CLASSROOM

Developed by

Isaac Amuah

This manual contains the following information:

(i) Descriptions and discussions of thinking operations which have been found to enhance thinking.

(ii) Examples on how to use a particular skill in developing a lesson.

(iii) Instructional procedures and techniques.

(iv) Development of a Unit

(v) Samples of lesson plans

(vi) Lesson plan guidelines

OVERVIEW

Let us consider some strategies that you can use to test the assumptions about thinking as previously discussed. The strategies here represent several examples of procedures you can following (and/or improve on) to help students in your class engage in various intellectual operations. These strategies give you a starting point for incorporating thinking skills in your instructional efforts and in planning learning activity sequences. Some of them require convergent thinking, some divergent, some more than one of the forms of thinking we have talked about during the training session. The list should not be viewed in any way as final or absolute. The strategies are also not mutually exclusive, since many of the operations involved in one strategy overlap or are parts of other strategies. Nor is the list a hierarchy of any sort, with the operations at the top of the list considered prerequisite to those listed at the bottom. Please note that the primary purpose of the list is to suggest some dimensions to the global concept THINKING that you emphasize in order to bring about an increase in the thinking "behaviors" of your students. The operations to be discussed include:

Observing
Describing
Comparing and Contrasting
Developing concepts
Differentiating
Defining
Generalizing
Predicting
Explaining
Hypothesizing
Offering alternatives
Summarizing

In all, 7 units of lessons will be prepared to be used for the duration of the study. The units will be prepared by the teacher in consultation with the investigator. Each unit is divided into 2 or more sub-units. Each of the sub-units is comprised of an introduction and a set of lessons. The introduction to the unit explains how the lessons that follow relate to each other and to the course as a whole.

The Lessons

Each unit is composed of a set of lessons. A lesson is a prescription for a 40-45 minute classroom session devoted to a specific set of instructional objectives. Each of the lessons is prepared with certain design goals in mind, and each addresses a specific instructional objective.

Lesson design goals

The intent in developing these materials is that the following assertions are true for each lesson:

* It has at least one clear objective
* That objective, if realized, will further the overall goal of enhancing thinking skills in a general way.
* The teaching method is practical and implementable by a teacher without extensive special training.
* The materials are meaningful and intrinsically interesting to the students.
* The activities are intellectually stimulating
* The lesson challenges the students to use what is being learned, and provides some guidance regarding how to do so.
* There is a practical way to determine whether [or the extent to which] the objectives of the unit have been attained.

ORGANIZATION OF THE TEACHER LESSON PLAN FOR STUDY PERIOD

LESSON SERIES 1 OBSERVING AND DESCRIBING

Unit 1: Representing Directions/ Observation and Classification
Unit 2: Path length and Displacement/ Ordering
Unit 3: Vectors and Scalars/ Hierarchical Classification
Unit 4: Speed and Velocity/ Analogies: Discovering Relationships
Unit 5: Forces, forces of equilibrium/ Spatial Reasoning and Strategies

LESSON SERIES 2 COMPARING AND CONTRASTING

Unit 1: Definition of Momentum/ Word Relations
Unit 2: Momentum from the Second Law/ The structure of Language
Unit 3: Applications of Momentum/ Reading for meaning
Unit 4: Conservation of Momentum/ Arguments
Unit 5: Elastic and Inelastic Collisions/ Assertions

LESSON SERIES 3 DEFINING AND DEVELOPING GROUPS

Unit 1: Representing Directions/ linear Representations
Unit 2: Path Length and Displacement/ Tabular Representations
Unit 3: Vectors and Scalars/ Systematic Trial and Error
Unit 4: Speed and Velocity/ Thinking Out the Implications
Unit 5: Forces of Equilibrium/ Representations by Simulation

LESSON SERIES 4 SUMMARIZING/GENERALIZING

Unit 1: Work, Energy and Power/ Introduction to Decision Making
Unit 2: Work,Energy and Power/Gathering and evaluating information

Unit 3: Relationship Between Energy and Work/ Analyzing Complex Decision Situations
Unit 4: Mechanical Energy and Conservation of Mechanical Energy/ Design
Unit 5: Momentum and Kinetic Energy/ Procedures and Designs

The individual lessons will be constructed in accordance with a particular format which addresses the following topics:

* Title
* Rationale
* Lesson objectives
* Target abilities
* Products
* Materials
* Classroom procedure

Development of Instructional Procedure

In order for the teachers to implement the program, they were trained to use specific teaching procedures and techniques. Among the instructional procedures and techniques emphasized during the training sessions were:

1) Cognitive modeling of the skill or strategy by "thinking aloud" (Palinesar & Brown, 1984).

2) Presenting the skills of self-questions.

3) Telling the learner explicitly that use of the strategy will improve performance in physics

4) Providing explicit instruction on when to apply the skill or strategy

5) Providing practice in use of the skills with diverse types of physics problems and content.

LESSON FORMAT

The description of each lesson follows a standardized format, which addresses the following topics:

Rationale: An explanation of why the lesson is part of the materials.

Objectives of the lesson: A specification of what the lesson is intended to accomplish. The following are examples of lesson objectives:

* To increase skills in concept formation.
* To make students aware of the powers of a strategic approach to problem solving in physics
* To teach a general strategy for analyzing problems
* To introduce a systematic procedure for distinguishing physical quantities.

Target Abilities: A list of things the student should be able to do after completing the lesson. The following are examples of target abilities:

* To use a diagram to help figure out the meaning of a physical statement.
* To interpret a phenomenon using different principles
* To identify pairs of scientific assertions in which one assertion implies the other.
* To analyze a decision situation to determine what decision alternatives exist.
* To evaluate a procedure.

Products: Tangible things the students are required to produce.

Materials: Materials needed by the teacher or students.

The Need for Feedback: I request that you document your experience in using the recommendations and materials in this manual. Impressions from you, as a user of the materials, will be very useful in any attempts that may be made to improve the effectiveness of the materials in the future. In particular, I would like to know the following from your experience in using the materials:

- Are there places where it is unclear?
- Did some of the recommendations prove to be especially effective?
- Did some of the recommendations prove to be ineffective?
- Are there ways in which the materials can be made more interesting to the students?

Attitudes toward Student: Inasmuch as the purpose of the materials is to motivate students to think while acquiring content knowledge, it is important that efforts to think are encouraged and reinforced at every opportunity. In this regard, teachers must learn to evaluate students not so much on the basis of the specific answers they provide, but on the ways in which they derive these answers.

General Recommendations: Remember that this material emphasizes exploration and discovery by students. The challenge to you, the teacher, is to facilitate this exploration and discovery. You may have to do some exploring yourself in order to answer how best to help your students in this regard, but here are some hints:

- Do not lecture.
- Resist the temptation to provide answers to questions before giving the students a chance to come up with answers of their own.
- Help students reject the idea that every question has one and only one answer.
- Find and emphasize the thoughtful elements of incorrect answers.

- Try to foster an atmosphere that the students find non-threatening and supportive, in which they feel free to try to question, to express their ideas, and are not terrified by the fear of failure.

- Make clear to students that you are willing to explore ideas and concepts, and that you get satisfaction from discovering new principles and relationships.

- Be willing to admit when you do not know something, when you have made a mistake, or when the meaning of a concept is not clear to you.

- Encourage the students to ask questions, both of themselves and of each other, as well as try to answer them.

- Keep actively and productively engaged. Evidence shows that the degree to which students learn is determined to a large extent by the amount of time they spend effectively working together.

OBSERVING

INSTRUCTIONAL OBJECTIVE: Given an array of physics information, students can identify various quantities included in this array on the basis of certain objective characteristics which they possess.

Observing is a necessary prerequisite to all intellectual operations that involve thinking. Students must be brought into contact--that is engaged with the data before they can do anything with it. It is imperative, therefore, that you provide opportunities for students to read/view/taste/hear/feel/smell/touch/participate-- in short, become involved in as many different kinds of experiences as possible. Equally important here is the necessity for you not to structure or determine ahead of time what students are expected to observe, apart from perhaps providing a focus. (For example, in a topic like friction, students might be asked to examine the surfaces of the objects involved). Your task here is essentially one of providing and engaging students in different experiences so that they can come in contact with many kinds of ideas, events, or objects, and their differing characteristics.

DESCRIBING

INSTRUCTIONAL OBJECTIVE: Given various quantities and phenomena, students can identify the particular characteristics which the quantities possess that caused them to be noticed in the first place.

Observing is only a beginning. Once students have been motivated to engage in an experience--to view, smell, or touch the world, they must be encouraged to describe as fully as possible the characteristics of that which they have observed. Your task in this regard, therefore, is to go beyond involving students in a variety of experiences--it is to ask them to report back (through asking an open-ended question such as " What did you notice in this experiment?" what it was that they actually did observe (i.e. touched, felt, saw, or read) in their experience. By asking open-ended questions such as " What can you tell about these data?," you can encourage students to describe their observations.

Again, care must be taken to ensure that students report their own, rather than perceptions.

COMPARING AND CONTRASTING

INSTRUCTIONAL OBJECTIVE: Given two or more different items, students can correctly state many of the similarities and different which exist among the items.

Comparing and contrasting is an important part of thinking. Students cannot understand individuals, phenomena, objects, events, or characteristics clearly unless they can compare and contrast these phenomena in terms of their similarities and differences. You can help students to compare and contrast by asking them to study similar aspects of previously unrelated content, and then ask identical questions about this content. For example, suppose you wanted students to consider why it is impossible to live on planet Mars. You might ask them to read a number of scientific accounts and then ask certain questions about each of the literature they have read in relations to the factors which makes Earth habitable.

* What happens if you live on Mars?
* Why do you suppose it happened as it does?
* In what ways are the descriptions you have read similar?
* In what ways are the description you have read different?
* How will you explain the similarities and differences, if any?

Notice that the same questions are to be asked of each account, and that they are arranged in definite order. (See Table below). This order is intentional. It is based on the assumption that students must understand what is occurring in each instance before they will be able to explain why it is occurring. They must decide on how two or more instances are similar or different before they will be able to explain why they are similar or different.

COMPARING AND CONTRASTING

Teacher asks	Students	Teacher Follow-through
What happened?	Summarizes facts of incident	Checks for accuracy and completeness. Writes facts for all to see.
Why?	Infers reasons for things happening as they did.	Encourages responses. Writes on chalkboard or transparency.
In what ways are the descriptions you have read(seen, heard, etc.) similar? Different?	identifies similarities and differences	Encourages many replies. Puts on chalkboard, or transparency.
How would you explain these similarities and differences	Infers reasons for similarities and differences identified	Encourages replies; clarifies meaning
What does this suggest to you about items (incidents, etc.) like this in general? What conclusions can you draw about items (incidents, etc.) like these?	State an inference or a conclusion which applies to both (all) items under discussion or consideration	Places on chalkboard or transparency. Encourages discussion as to how conclusions might be verified.

DEVELOPING CONCEPTS

INSTRUCTIONAL OBJECTIVE: Given an array of data, students can identify certain characteristics which various quantities, included in the array have in common, group the quantities on the basis of these characteristics, and then assign logically defensible and abstract labels to these groups.

Students form concepts when they begin to sort different objects (ideas, events, etc.) that they have observed or identified into a meaningful set of categories so as to make some sense of order or pattern out of diversity. Your task is to get them to respond to questions which require them to (a) observe a situation (the motion of a cart on a rough surface); (b) describe that which they have observed (list items or phenomena); (c) find a basis for grouping those listed items which are similar in some respect; (d) identify the common characteristics of the items in a group; (e) label the groups they have formed; (f) subsume additional items that they have listed under those labels; (g) recombine items to form new groups and to create even larger and more inclusive groups.

When a large number of items have been reported and made accessible to the entire class, students can be asked to group together various items which they perceive as similar in some way, and then to attach a label or "name" to the groups which they have formed. As part of this process, they must differentiate in some way or another the various items before them, and then decide on the basis of the groups which they have formed what the labels for these are to be.

Let us consider an example. Suppose that a teacher wished to assess his/her class familiarity with the Aristotelian theory of MOTION. First, information on the nature of motion and contributing factors needs to be obtained from various sources__ books, experiments, lectures etc. Students then must be asked to identify as many of the suggested factors as they can (describing). Possible class responses might include the fact that motion always involve forces, the greater the force the greater the motion, an object may remain at rest, an object may move uniformly in a straight line, speed up during straight-line motion, and slow down during straight-line motion. These responses may be written on the chalkboard or a transparency for all to see.

When the list is fairly extensive, the class can be asked: "Looking at the list of responses on the board, do you see any responses which might be placed or grouped together?" Students are thus encouraged to note similarities and differences as they try to place the various responses with similar characteristics in the same group and perhaps even combine some group into larger groups. Possible supportive questions at this point to get them thinking about similarities include " Why do you think these responses might be grouped together?" How the students group, however, is not as important as their learning to increase their capability to identify common characteristics of otherwise quite dissimilar responses.

When the class seems to have exhausted the possibilities for grouping or classifying, they can then be asked: " What names can be given to these groups or classification that you have formed?" It is important to emphasize here that you should accept the kind of relationships which the students suggest through their labels as long as the students have fairly clear reasons for them. This does not preclude your suggesting or encouraging students to reconsider their labels in terms of a particular topic being focused on. But the essential point of strategy is to get the students to formulate their own concepts rather than to accept the concepts of somebody else. What is most important is that the students performs the operations for themselves, that they see the relationships among responses or phenomena, that they recognize a basis on which to group responses or items, and then they label the groups that they have formed. You should not do these things for the students.

DEVELOPING CONCEPTS (LISTING, GROUPING, AND LABELING)

Teacher Asks	Student	Teacher Follow-through
What do you see, here? (Listing)	Gives items	Makes sure items are accessible to each student.For example: chalkboard; transparency; individual list; pictures; etc.
Do any of these items seem to belong together?	Finds some similarity basis for grouping items	Communicates grouping For example:underlines in colored chalk, marks with symbols
Why would you group them together?	Identifies and verbalizes the common characteristics of items in a group	Seeks clarification responses when necessary
What would you call these groups you have formed? (labeling)	Verbalizes a label (perhaps more than one word) that appropriately encompasses all items	Records
Why? (Explaining)	Gives explanation	Seek clarification if necessary
Could some of these belong in more than one group? (Recombining - seeking multiple groups for some items)	States different relationships	Records
Can we put these same items in different groups?	States additional relationships	Communicates grouping
Can any groups be combined? (subsuming)	States additional different relationships	Communicates grouping

DIFFERENTIATING AND DEFINING

INSTRUCTIONAL OBJECTIVES: Given a number of examples and non-examples of a certain concept, students can state which examples and which are not examples, and tell why.

Having examined a number of examples and non-examples of a given concept, students can state a definition in which the essential attributes(characteristics) of the concept are presented.

During one classroom discussion on FORCE, this researcher observed a student offered the following remark with which the rest of the class agreed: "Force is the rate of change of momentum." Upon questioning the class further, however, it became quickly evidence that many students did not really understand what a "rate of change" was. Before a teacher can get students to investigate further the relationship between force and momentum, he had to ensure that all the class understood (and hopefully could agree) the meaning of "rate of change" and the concept of momentum in the first place. How could this be done?

The teaching of a concept like FORCE can proceed in one of two ways, one inductive, the other deductive. Let us consider the inductive example first:

1) You must first research and form for yourself an adequate understanding of the concept in order to determine its most important attributes. In this regard resort is often made to scientific definition of the term.

2) When a satisfactory definition has thus been obtained or developed, identify the larger class of which the concept is a part (e.g., in this case, the term FORCE is a part of the larger class of MOTION) and then determine the most important attributes (in other words, the defining criteria).

3) Present alternatively a variety of situations that illustrate examples of FORCE for student to determine.

4) As the class looks at the examples and non-examples that you have presented, point out which ones are forces by saying " This is a force in action" and asking students to determine how they differ from the non-examples. This, in effect, requires students to look for and identify essential attributes which all of the examples of FORCE possess in common, but which the non-example lack.

5) Have the class state the major attributes which the examples all possess.

6) Have the class state a definition of the concept by making a declarative statement which contains all of the major attributes.

It is important that you not neglect step 6. It points up the difference between an intentional and an extensional meaning of a concept. " The extension of a word is the set of things to which it is applied, according to a rule, the intent is the set of characteristics the things must have in order for the word to apply correctly to them. The extension of FORCE is Static force, particular force, gravitational force etc. The intent of FORCE is the characteristic of each name being referred to different and independent meaning. Thus intentional meaning refers to the definition of a concept; extensional meaning to examples of the concept. Though it is surely true that individuals can possess a concept without being able to verbalize it, the ability to explain what one means when one uses a word is extremely valuable. Many inarticulate students experience considerable difficulty and frustration in attempting to communicate with their fellow students because they possess few concepts and even fewer word-labels for the concepts they possess.

7) Present more examples and non examples of the concept and ask students to identify which are FORCES and which are not, telling why in each case.

8) Have the students on their own find and identify new examples. Notice that the essence of this strategy involves the identification of essential attributes through distinguishing between examples and non-examples of the concept in question. As students make such distinctions, they inductively realize what essential attributes are. The strategy is summarized in the Table below.

ATTAINING CONCEPTS (Differentiating and Defining)

Teacher	Student	Teacher Follow-through
Say the word after me (stating the concept)	Repeats word	Make sure word is pronounced correctly
This is an... This is also an... (Gives examples)	Look at object or listen to description given, or reads statement which illustrates the concept.	Checks for any students who may not be able to see or hear.
This is not an... (Gives non- examples) object	Looks, listen to, or which is not an example of concept but is similar to concept	Checks again reads about new
What characteristics does an...possess that enable you to recognize it?	States major attributes which all examples possess	Ensure that all attributes are given
Tell me what you think an... (Ask for definition)	States the definition of the concept	Have students written down their definition?
Which of these describes an... or is this an... (Ask for identification)	Selects from one or more objects or descriptions	Shows additional objects or gives fresh descriptions to test
Show me an...(Asks for original examples	Brings in new examples	Verify correctness of examples

A deductive alternative to the preceding approach is as follows: Once a satisfactory definition of the concept has been obtained form a physics text or developed, list the definition on the chalkboard or a transparency so that all students can see it. If possible, illustrate it if you can or perhaps compare it with other concepts the students already know. Again present a variety of examples and non-examples of FORCES (giving mostly examples at first), only now ask the class to examine them in the light of the criteria that are before them on the board. Inform the class that if a given phenomenon meets all the criteria listed on the board, then it is a FORCE. If all of the criteria do not apply to a given phenomenon, it is not a FORCE.

A final word about teaching concepts. When categorizing concepts for instruction, you need to consider the level of abstraction. The more abstract a concept is, the less its distinguishing characteristics can be reduced to variations in physical dimensions, such as length, width, size, or color. This is simply another way of saying that more abstract concepts are more difficulty for students to "see" than are those that are concrete. Hence concepts like VELOCITY or DISPLACEMENT are easier for students to learn than concepts like FRICTION or WORK, while concepts like PRESSURE is the most difficult of all. Furthermore, the more abstract a concept, the more important a part language plays in learning it. The chief task for you in this respect is to find a varied number of concrete examples which illustrate the abstraction. To help students learn an abstract concept like FRICTION, therefore, you need to present them with a different examples of objects all of which the surface are different.

EVALUATING STUDENT MASTERY OF A CONCEPT

The degree to which a student learns or, to use Brondy (1961)'s term, " masters" a concept can vary considerably. Each of the following examples of concept learning, it would appear, might be considered as representing greater "mastery" of concept.

1. Students can state a textbook definition of the concept verbatim form memory.
2. Students can restate a textbook definition in their own words.
3. Students can state from memory(or identify) common examples of the concept.
4. Students can suggest their own examples of the concept.
5. Students can identify (or suggest on their own) unusual examples of the concept.
6. Students can explain (or tell why) various common and unusual items or instances are examples of the concept.
7. Students can relate (tell how) the concept to other concepts or ideas and explain how (tell why) the concept is related.

GENERALIZING

INSTRUCTIONAL OBJECTIVES: Given a detailed list of items (objects, concepts, phenomena), students can state valid generalizations (that have not been given previously) and, when asked, can provide the resources and limitations of the generalizations which they have formed.

If students are to use effectively the data which they acquire, they must be encouraged to establish connections and relationships among otherwise unrelated pieces of information. The ability to establish valid relationships (i.e., statements supported by evidence) is essentially one of the forming, using, and validating generalizations.

Getting students to make generalizations involves essentially three steps:

1. They must look at two or more different samples of content with the same questions in mind. For example, what are the reasons that an object with the same mass will have different weight at different places on the surface of the earth.?
2. They must then explain the data they have obtained. For example citing the reasons why an object could have different weights and explaining why is the case.
3. They must then offer a generalization by inferring what are the common factors and differences involved in a number of situations.

The sequence of questions to be pursued to bring about generalizing is illustrated in the Table below:

GENERALIZING

Teacher Asks	Student	Teacher Follow-up
What did you find? What differences did you notice (with reference to a particular question)?	Gives items	Make sure items are accessible, for example: chalkboard transparency posters
What do you think this happened? Or how do you account for these differences?	Gives explanation which may be based on factual information and/or inferences	Accepts explanation. Seeks clarification if necessary
What does this tell you about...?	Gives generalization	Encourages variety of generalization and seeks clarification when necessary.

This pattern of inviting reasons to account for observed phenomena and generalizing beyond the data is repeated and expanded to include more and more aspects of the data and to reach more abstract generalizations.

PREDICTING AND EXPLAINING

INSTRUCTIONAL OBJECTIVES: Given a generalization previously developed or acquired and given a new situation, problem, or question to which the generalization applies, students can make a statement or take action that represents a defensible use of the generalization in analyzing or coping with the situation, in solving the problem, or in answering the question.

Given a set of events occurring (one of which is identified as the event to be explained) in an experimental setting, students can give a plausible and logically sound explanation of the chains of cause-and-effect relationships that resulted in the occurrence of the event.

Helping students to form generalizations is only part of what needs to be done if you are to encourage and assist student thinking. Students should also be encouraged to try out or apply the generalizations they have formed in one situation to another situation new and different. Such application allows students to demonstrate how well they understand the essence of a concept they have developed or formed by determining its applicability in another situation that is somewhat similar in form yet different in particulars from the one which the concept originated.

In brief, then, the process of applying generalizations involves asking students to (a) make inferences based on their application of a concept they have previously formed as to what might happen in a new situation (i.e., what consequences might follow from certain already known conditions); (b) explain why this will happen; (c) identify what facts would necessarily have to exist for the inference offered in (a) to indeed be true; and (d) to make further inferences as to what might then follow. The sequence of questions the teacher pursues in order to encourage the above is illustrated in the Table below.

It is obvious to you that students must acquired a body of information and developed some generalizations (at least implicitly) if they are to apply them. For example, if students understand that an object in a linear motion will continue to do unless acted upon by an external force, then they can predict what might happen if a car with passengers is suddenly brought to rest. If they understand how certain scientific inventions have changed man's life, then they can make inferences of any new inventions. In short, students are encouraged to use what they already know in order to predict in a conditional form the consequences that might occur in a new situation.

Let us consider an example. Suppose students have considering the concept of GRAVITY and have previously drawn a conclusions about this concept. Reviewing the procedure outlined in the Table below, the first step is to encourage students to make inferences based on the ideas they have previously formed. Thus you might ask: What might happen to life on earth if there is no gravity on earth?

APPLYING GENERALIZATIONS (Predicting and Explaining)

Teacher Asks	Student	Teacher Follow-through
(Focusing question) Suppose that a particular event occurred given certain conditions, what would happen?	Make inferences	Encourages additional inferences. Selects inference(s) to develop.
What makes you think that would happen?	States explanation; identifies relationships	Accepts explanation and seeks clarification if necessary
What would be needed for that to happen?	Identifies facts necessary to a particular inference	Decides whether these facts are sufficient and could be assumed to be present in the given situation
(Encouraging divergency) Can someone give a different idea about what would happen?	States new inferences that differ in some respects from preceding ones	Encourage alternative inferences, requests explanations and and necessary conditions. Seeks clarification where necessary
If, as one of you predicted, what do you think happen after that?	Makes inferences related to the given inference	Encourages additional inferences and selects those to pursue further

The pattern of inviting inferences, requiring explanations, identifying necessary conditions, and encouraging divergent views is continued until the teacher decides to terminate the activity.

The second step is to get students to explain and support the inference(s) they have made. For example, a student might infer that we could easily walk above the earth surface and life in general will be difficult. You need to help the student make explicit the chain of casual links that leads from the elimination of gravity to the implications of life on earth so that the class as a whole may perceive the connection and thereby build on it to make further connections.

The third step is one of identifying conditions that would be necessary to make the inference plausible. Why would it be difficult to eat or drink in absence of gravity? Encouraging students to apply previously formed generalizations is an exercise in divergent thinking. It allows students to use information in an original way rather simply encouraging its passive absorption.

You must take care, however, to be aware of the variety of possible predictions that you may obtain. Otherwise it would be easy for you to limit the discussion to only the most obvious or likely possibilities. This would suppress any incipient creative or unusual kinds of connections that the students might perceive, and once again imply that you really want only what you consider to be "right" answers. The danger is particularly likely when students students branch out into areas of content that are unfamiliar to the teacher. On the other hand, divergent predictions can be carried to the point of sheer fantasy, with little, if any, link to what most of us perceive as reality. It is important, therefore, for you not only to see that students are challenged to produce factual and logical support for their ideas but also to be alert that certain examples may have considerable potential to develop in depth, and to encourage students to pursue an idea as far as they are able.

HYPOTHESIZING

INSTRUCTIONAL OBJECTIVE: Given relevant facts about a phenomenon, experiment, or event, student can state one or more logically sound but informally worded hypothesis (that they have not been given previously) about that phenomenon, experiment, or event today, in the past or in the future.

A hypothesis is a prediction offered in order to provide a basis for further investigation. Hypothesizing is a key ingredient in the development of insights, and thus occupies a basic role in Gestalt-field theory. It is central to the process of reflective thinking. Hypotheses give give order and direction to an investigation. Hypothesis formation and validation involve the following steps:

* Identifying a problem to investigate.
* Defining more precisely the particular aspects of the problem to be investigated (i.e. stating a question to consider);
* Formulating a hypothesis (i.e., making a logical statement, usually in an "if-then" form as to what might exist or happen if such-and-such exists or happen);
* Gathering data (from reading, discussing, interviewing, observing, experimenting, etc.);
* Organizing and evaluating the data (i.e., eliminating irrelevant material, categorizing the data which is relevant to the problem under consideration, checking the reliability and validity of sources);

- Testing the hypothesis against the data (i.e., did such-and-such actually exist or happen as predicted?);
- Drawing a conclusion (i.e., stating a generalization).

A sequence of questions designed to achieve these steps is shown in the Table below.

HYPOTHESIZING

Teacher Asks	Students	Teacher Follow-up
What makes it impossible to sustain oneself in the space?	Names the problem	Clarifies responses
What kinds of factors make it impossible?		
Why is that a problem? - or - Why are you concerned about...? - or - What about...might we investigate?	Identifies and states a precise question or aspect of the problem	Helps get the question stated clearly
What causes...? - or - If...continues, then what might occur?	Formulate hypothesis to investigate	Helps get hypothesis stated and available for all to see. Clarifies terms.
Where can we obtain data that might help us to some conclusions about...?	Locate sources. Gather data.	Suggests additional sources to consult
How can we organize the data we've collected?	Organizes data into relevant categories.	Suggests additional categories to consider Helps students place data into appropriate categories
- or -		
How might we group or categories this data? etc	Regroups data into sub-and subordinate categories	
What data can we use? Why?	Evaluate data as to relevance, accuracy, etc.	Helps determine appropriate criteria by which to judge usefulness of data

What evidence is there to support our hypothesis? refute it? To what extent is it supported or refuted?	Considers degree to which hypothesis is supported or refuted. Cites supportive or refuting evidence	Asks for evidence. probes for inconsistencies. Places evidense so all can see
Should we change our hypothesis in any way? If so, how? Why?	Modifies hypothesis if necessary. Gives reasons	Clarifies terms
What can we say about...(the problem) in light of conclusion is the evidence we have basis obtained?	States generalization (conclusions)	Clarifies terms. Asks for estimate of degree to which warranted, and on of what evidence.

The difference between the above steps and the previous strategy for applying generalizations is that in this case a generalization has not yet been made by students. In the previous strategy, we were interested in applying generalizations, that is, in having students see how far they can carry the implications which they believe would follow from a warranted generalization. In this strategy, we are making a prediction that we hope will eventually lead to a warranted generalization. The previous strategy is used primarily after a generalizing exercise or strategy has been completed; the present strategy is used to initiate or get students started in investigating a problem in which they are interested.

Let us consider an example. Suppose that a number of students were in interested in investigating how electricity is generated. They might be asked to read widely in a variety of sources on how electricity is generated from different sources. They could then be asked to investigate in detail. Suppose they wish to know more about what produce electricity, a focusing question, to serve as the key to their investigation, can be formulated: " What do you think(hypothesize) at this time, based on your preliminary reading, generates electricity?" Various reading matter can now be identified and assigned. Personal interviews with electrical engineers and physicists can be conducted. Field trips for observation purposes can be undertaken. The data they collect can be organized and evaluated as to adequacy, reliability, accuracy, relevance, etc., and their hypotheses "checked" against the data that they have collected and evaluated. What evidence is there to support their hypothesis? To refute it? To what extent is it supported or refuted? Should it be modified? If so, in what way(s), in light of the data they have obtained, should it be changed? The students can then be asked what qualification(s) have to be placed on the conclusion(s).

Actual investigation of a hypothesis may require that several of these steps be repeated since they are interactive in nature. For instance, as data becomes organized, it may become apparent that more information is needed, and thus necessitate further data-gathering; testing the hypothesis against the data may suggest new ways of organizing the acquired information. You can help students bring order to their investigations by continually asking them to define their problems as precisely as possible, to state hypotheses, to organize data into categories, to evaluate, to check hypotheses against the data that they have acquired as a result of their investigation, and then to state generalizations which they they can support with evidence.

OFFERING ALTERNATIVES

INSTRUCTIONAL OBJECTIVE: Given a discussion or other information in which generalizations, explanations, or hypotheses, are developed, students occasionally suggest that additional evidence or a different line of reasoning might lead to changes in or more of the generalizations, explanations, or hypotheses.

Implicit in many of the foregoing strategies has been the need for you to suggest, but also to encourage students to seek out and offer alternative suggestions, viewpoints, and possibilities. To bring this about, you must continually ask students to consider additional and different ways of thinking, and perceiving. For example, as students report the details of their observations, they can be asked questions such as " What else did you notice?" Students can be regularly encouraged to suggest additional hypotheses and explanations. As they compare and contrast data, question such as "In what other ways are they different?" or " What other similarities do you notice?" suggest themselves. When they generalize, alternative possibilities can be encouraged through such queries as " What other conclusions can you draw?" or " What else can you suggest?" Alternative predictions can be fostered by asking "What else might have happened if such-and-such occurred?"

The examination of alternatives is essential if you expect students to do something that uncritically accepts the views of others. If students are to be helped to make their own minds on scientific phenomena, they must be encouraged to seek out and consider a variety of explanation as a matter of course. The active pursuit, presentation, and discussion of alternative ways of thinking, believing, feeling, and acting as a regular feature of classroom life can help to bring about the development of critical minds.

PLANNING OF TEACHING UNITS

Objectives, subject matter, learning activities, teaching strategies, diagnostics and other evaluative measures must be organized in some fashion or another to encourage effective instruction. Thus the need for planning. Thus far, we have discussed the operations for enhancing thinking during instruction. We now need to consider how these operations for thinking can be organized and interrelated in order to further effective teaching and to encourage student to think and learn--in short, how to plan instructional efforts for this study. To gain some ideas in this regard, therefore, we shall take a look at an example of what is frequently referred to as a teaching-learning unit, and then I shall suggest guidelines you can use to help write the units for the purposes of this study. We shall also consider the notion of lesson planning, lessons being the pieces or parts which, taken together, make a complete unit.

DEVELOPMENT OF A UNIT

Main Idea: The teaching of Momentum and its Conservation

Notes to the Teacher	Learning Activities
Diagnosis	Opener
	Have students write half a page on the topic:
The purpose of the opener is to introduce the concept of momentum and its conservation to the students. We will return to these responses later as we begin to develop the concept in greater detail.	What do you think the momentum is important? Why? This is could be an oral assignment if you prefer.
Developing Concepts	On the chalkboard, list enough of the responses to practice grouping and categorizing.

Demonstrations and Discussions

The demonstrations and the discussions should help students begin to realize that objects may differ in momentum in terms of their masses and velocity. Because this unit as a whole is concerned with momentum and conservation of momentum, learning activities dealing with these should be stressed.

Then discuss with your class:

Which of the physical quantities on the list are more important in defining momentum

The essence of the activities 1-4 attempt to introduce formally the concept of momentum and to get students thinking about what they mean when they say " I understand momentum". These activities also introduce the idea that momentum is always conserved.

Development

1. Let students write all the physical quantities that comes into action when an object is motion.

From the responses, select several to show the differences that can be found.

Time
Mass
Velocity
Speed
Acceleration
Force

Be sure to avoid making any judgement. Otherwise students will tell you what they think you want to hear rather give their own opinions.

Explain

This would be a likely spot to help students realize the the difference between responses and inference

Asks:

Students to combine mass with the rest of quantities individually

Ask for volunteers who would be willing to have their answers read to the class.

Then:

Read the responses that the volunteers wrote in the Opener.

Asks:

Do you notice any connection between the two responses?

What do we describe the product of mass and acceleration?

Does the product of mass and time (m*t) sound familiar?

What about the following:

force times time
mass time velocity
mass times speed

3. Duplicate the list that follows or reproduce it on a transparency and let students, working in pairs decide in writing which of these quantities stand for. You might wish to work orally on one or two to help them discover which is scientifically correct. List on the board

The question of how one decides what one combination of quantities is important and is well worth discussing with students when the opportunity permits, because it raise the whole question of " quantity of motion", Impulse . You might start your students thinking about Newton's second Law of motion and momentum.

what combination of quantities the class suggest as appropriate. Then asks:

What conclusions can we draw from the fact that some products of mass with some quantities represent unique quantities.

Then discuss:

Which of the quantities discovered in this exercise are important?

Are some of these quantities more important than others?

4. Discuss:
How difficult is it to stop a moving object?
What force is required?
It is impossible to answer these question unless you know
(a) the mass of the object concerned, and
(b) how fast it is travelling.

The major thing for students to realize is the relationship between mass and velocity of a moving object.

P= m*v

Formulating Hypotheses

Evaluation of responses to either or both of these questions could be made on the basis of variety, on the numbers of relevant and plausible Explanations given, and on the numbers of spontaneous comparisons.

5. In the lab., have students perform series of experiments with mass and velocity changing and calculating momentum using

What effect does changes in mass and velocity have upon the value of momentum?

What other factors might contributed to the value of momentum.

6. Have students do the following in their worked books:

Mass	Velocity	Momentum
50kg	10m/s/s	?
100kg	?	50kgm/s/s
?	20m/s/s	20kgm/s/s

Suggested References:

The Project Physics Course, by James Rutherford, and Gerald Holton (New York: Holt Rinehart, 1970), p. 84-90.

LESSONS AND LESSON PLANS GUIDELINES

I wish to point out that the preceding unit guidelines suggest an organization of subject matter and learning activities to encourage student investigation and formulation of relationships (ideas). How many "lessons" or "periods" are necessary to develop and help students investigate the ideas, and to involve them in any particular unit will vary depending on the nature and abilities of the students and teacher involved.

However, in this particular study I suggest the following five essentials which should guide your lesson planning (most suggested by participating teachers):

1. A clear idea of what you wish to accomplish by the end of the lesson (i.e., clear purpose or objective). This can range from an objective as specific as being able to solve physics problems using the Newton's Laws of Motion Equations to one as general as Motion.

2. A clear idea of procedures and activities you will to use to help students attain the objectives you have in mind. Will you have students read? write? answer questions? discuss? do experiment in the lab. It is important for you to ask yourself whether you have laid the necessary groundwork so that students will be able to participate effectively in whatever you have planned. For example, if you intend for students to discuss how WORK is defined in physics, prior exposure to various misconceptions with respect to WORK could be explored.

3. A clear idea of the order in which you will proceed to have students use the materials and activities. One recommendation here is to consider the idea of rotational activity sequences (Details to be given during training session). The important thing is that you know where you are going and how you plan to get there, using whatever sources. Here is one example of a teacher's plan that illustrates a carefully ordered lesson.

The teacher's intention is to encourage students to arrive at a definition of WORK.

1. Tell them that we are going to try to evolve a satisfactory definition of WORK. Demonstrate that students often have misconception with the physics conception of WORK.
2. Have them suggest meaning of WORK and write them on the board.
3. Have them describe and criticize each of the definition written on the board.
4. Have them sort out the definitions that are common and list them on the board.
5. Have students at their desks work out a common definition of WORK.
6. Single out the best of these and put up on the board for approval. Get two or three and have the class tell which definition they like best and why?

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