

EXPLICITLY STRUCTURED PHYSICS INSTRUCTION

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Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Physics

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March 1984

Blacksburg, Virginia

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(ABSTRACT)

In an introductory physics course, problem solving skills are not traditionally taught. The instructor explains the physical theory and works example problems. Many students, however, are not able to develop the ability to solve problems implicitly.

The program of Explicitly Structured Physics Instruction (ESPI) was developed to teach problem solving skills explicitly. It is designed to help students organize their work, increase their accuracy, eliminate initial panic or lack of direction in approaching a problem, increase confidence in problem solving, promote understanding instead of rote memory, and improve the students' ability to communicate with the instructor and other students. It provides not only an explicit strategy for problem solving, but also a structure for examining formulas called the formula fact sheet, and an opportunity for practice and feedback in a problem solving session which involves the use of out loud thinking.

The program of ESPI was developed over five academic quarters of testing. A statistical analysis was performed on the data obtained, but the qualitative data obtained from student interviews and questionnaires, as well as the instructor reaction to the program, provided the main source of input in the development of the program and the measurement of its success.

Reaction to the program in its final revised form was very positive. Over 90% said that they would use the strategy even if it were not required, and that the formula fact sheet had been very helpful. Over 75% said that the problem solving session was very helpful. Final grades of those who used the strategy were significantly higher than those who did not. Retention of students in the course was raised from 70% to 86%.

The study indicates that a well integrated program built around the use of a problem solving strategy can help students focus on understanding physics and the problem solving process.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation for all those who contributed support, understanding, guidance and assistance in the preparation of this dissertation.

I am especially grateful to Dr. Clayton Williams, who patiently guided this project from its inception. He gave much encouragement as well as knowledgeable advice.

Dr. Samuel Bowen, Dr. David Roper, Dr. Dale Long, Dr. David Jenkins, and Dr. Thomas Teates each added significant insight in the development of this dissertation.

It was through assistance of Dr. _____, President of Tidewater Community College, and Dr. _____, Provost of the Virginia Beach Campus, that it was possible to obtain Education Leave of Absence and Educational Aid.

_____ and Dr. _____, Division Chairmen at Tidewater Community College, were able to help me avoid conflicts between my studies and teaching responsibilities.

I am grateful to the Franklin Institute Press for their permission to use questions from their book, Problem Solving and Comprehension, Second Edition, in the development of an out loud thinking test.

, Associate Professor of Chemistry, Virginia Beach Campus, Tidewater Community College, provided a listening ear in addition to a lot of advice and encouragement.

Most importantly, I want to acknowledge the support of my wife and children who gave up their husband and father for many hours in the preparation of this dissertation and also acted as a sounding board for my ideas. I shared many frustrations with them, and they were always able to boost my morale.

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CHAPTER ONE

Introduction

The major thrust of introductory physics courses is too often misdirected. Students memorize equations and long procedures with little understanding of what they are doing. They plug numbers into equations and produce answers. They are expected to mimic the actions of their professors in solving problems without comprehending the structure of what is being done. They leave the course with a bundle of facts, but without developing a personal problem solving strategy. If they have failed, their failure is too often interpreted as their own laziness and inability to apply themselves.

The basic question in physics instruction should not be whether it is better to have lecture or group discussion, or whether to give multiple choice or essay type tests, but how to stress the process and not the product of problem solving. Too often success is synonymous with higher exam scores. As Bloom and Broder¹ have said,

In spite of this emphasis on the products of thought, educators usually agree that good habits (or processes) of thought are the important and significant outcomes of education. Also they would probably agree that the

particular solutions or answers given to school room problems are of little consequence except insofar as they serve to indicate the quality of thinking.

Unfortunately, the usual system of instruction is presently designed to stress the end product. Courses are listed in terms of the topics covered. Linn² has pointed out that teachers have some vague notion of conveying an understanding of physics and reasoning skills, but the students are more concerned with passing tests and turning in correct homework assignments.

It is important to state exactly what skills students should be learning and demonstrating in their introductory physics course. Such skills as how to tackle word problems in an organized fashion and how to interpret and understand formulas should be explicitly taught, not just a hoped-for outcome.

Deciding which skills need to be taught is quite a challenge, but developing a process for teaching these skills is perhaps even more of a struggle. How much is understood about how people think and how they can be taught to reason? In an attempt to answer this question, several approaches have been taken. They all fall under the umbrella of what is called cognitive process instruction. According to Lochhead and Clement³, "cognitive process instruction is an approach to teaching which emphasizes understanding, learning and reasoning skills as opposed to

emphasizing rote memorization of factual information." Cognitive process instruction includes such fields as developmental psychology, information processing and artificial intelligence, thought vocalization, knowledge development, and heuristics.

The objective of this study was to put together a comprehensive package for Explicitly Structured Physics Instruction (ESPI) which specifies skills to be learned and processes for teaching these skills. In order to develop this package, each of the fields of cognitive process instruction was investigated, and ideas were extracted which appeared to complement the overall plan.

The hypothesis of the study was that when problem solving skills are appropriately addressed and explicitly taught, students will be able to acquire more confidence in problem solving, develop better organization and gain greater satisfaction with physics.

In order to test this hypothesis, the plan was implemented and revised over a period of five academic quarters. Revisions were based on feedback from both students and the teacher. The success of the plan was not to be based on the final grades of the students or some comparison to a control group, but would be based upon the students' and teacher's evaluation of how the plan met its

goals. The basic criteria would be the effectiveness of the program in helping students develop a personal problem solving strategy.

Each of the individual theories upon which this study is based has been intensively probed in the past, but little work has been done with the actual implementation of a comprehensive program for teaching problem solving skills that incorporates aspects from several research areas. This study further proposes not only to show that the ESPI system is an effective means of teaching problem solving, but also to illustrate in detail exactly how the system may be implemented.

CHAPTER TWO

Literature Review

The purpose of this literature review is to outline what work has been done in the fields of cognitive process instruction and evaluation, but even more importantly to lay the theoretical groundwork for the plan of Explicitly Structured Physics Instruction (ESPI) proposed in this study. Each field will be reviewed with the goal of outlining its distinguishing features and explaining its origins.

Developmental Psychology

Developmental psychology, with Piaget as one of its chief spokesmen, emphasizes mental structure and stages of intellectual development. Most college students fall into either the formal or concrete reasoning stage of development. As contrasted in Figure 1, formal students can reason deductively and deal with concepts, symbols and abstract properties, whereas concrete students need reference to familiar objects and actions and require step-by-step instruction in order to solve any lengthy problem.⁴ Piaget assumed that by the late teens almost all students

A concrete reasoning person:

1. Needs reference to familiar actions, objects and observable properties;
2. Uses classification, conservation, serial ordering and one-to-one correspondence in relation to concrete items above;
3. Needs step-by-step instructions in a lengthy procedure, and
4. Is not aware of his own reasoning, inconsistencies among various statements or contradictions with other known facts.

A formal reasoning person:

1. Can reason with concepts, relationships, abstract properties, axioms and theories;
2. Uses symbols to express ideas;
3. Applies combinatorial, classification, conservation, serial ordering and proportional reasoning in these abstract modes of thought;
4. Can plan a lengthy procedure to attain given overall goals and resources, and
5. Is aware of and critical of his own reasoning, and actively checks on the validity of his conclusions by appealing to other information.

Figure 1

CONCRETE VERSUS FORMAL REASONING^a

^a Robert G. Fuller, Robert Karplus and Anton E. Lawson, Physics Today 30(2), 23(1977).

would be formal, but recent data seems to show that less than 50% of college age students qualify as formal thinkers.⁵

In order to move from concrete to formal thought, Piaget proposed a process called self-regulation. Fuller⁶ described this as

a self-regulating process in which one's experience of nature through sensory input is compared with one's interior understanding of nature through one's use of mental structures. When our experience does not match our understanding, disequilibrium occurs. Piaget argued that human beings are made uneasy by disequilibrium. Humans are naturally led to seek additional experiences or reorganize their understanding. We mentally evolve to a state of equilibrium in which our concepts are adequate to understand the things that previously confused us.

A weak link in this scheme is describing why some students self-regulate and others do not when faced with similar circumstances. The way to help students initiate and successfully complete the process of self-regulation and thus advance toward formal thinking is vague in Piaget's scheme.

Hestenes⁷ has said that "formal operations are obviously essential for understanding science. Yet available evidence shows that science courses do little if anything to help students acquire them. Rather, science courses tacitly select the formal thinkers and discourage the concrete thinkers by continually confronting them with information which cannot be processed without formal

operations." When students have difficulty with such concepts they are then labeled as slow or lazy, when in reality they might be working really hard but not achieving the desired self-regulation.

Several approaches have been made to this problem of how to promote self-regulation. Karplus⁸ has developed a teaching technique entitled the "learning cycle". As used in the ADAPT program at the University of Nebraska, it follows a three-step process in which students first "explore" by having a set of concrete experiences (presented by the instructor). In the second phase a new concept is introduced. This step, entitled "invention", asks students to construct all or part of the appropriate relationship between the experiences by themselves, with only encouragement and guidance from the instructor. Lastly, "application" allows the student to find applications for the invented concept.

Lawson and Renner⁹ suggest an outline of activities to promote self-regulation in the classroom as well as the laboratory. They suggest that the instructor begin with concrete ideas through demonstrations and example and move toward the formal ideas. He should plan lab experiences before classroom discussion. Students need to be challenged to predict outcomes or ask questions about demonstrations of phenomena in the classroom or outside. Students need to be

encouraged to interact with each other and serve as role models for each other. Students should be asked to justify their conclusions and be receptive to the process and not just the answer. Students are encouraged to reason out loud and the instructor is to model the behavior that he expects students to develop.

In a 1975 Workshop on Physics Teaching and the Development of Reasoning¹⁰ similar steps were suggested to encourage self-regulation:

You can make a presentation more concrete by:

1. Beginning with concrete situations.
2. Illustrating the arguments with specific examples.
3. Providing "action models" or procedures that enable the student to work out an answer or verify a conclusion through concrete actions rather than through deductive or algebraic reasoning.
4. Providing a clear overview of a complicated explanation in advance, indicating the purpose of the principal steps.
5. Making clear references to formal operations when these are used:
 - a. Identify variables that are held fixed while others change.
 - b. State assumptions that are made.
 - c. Paraphrase equations in words.
 - d. Use diagrams to illustrate steps of the reasoning.
 - e. Enumerate some specific instances.
6. Proceeding directly from known or previously explained ideas to new ones.
7. Providing pictures of apparatus that is referred to.

When ideas have been taught concretely, this allows the students an opportunity to grasp the concepts as beginning points in the process of self-regulation.

The emphasis is on taking students where they are and not where they should be. The lesson is one of starting out as concretely as possible and then gently pushing the students to struggle and develop the higher reasoning skills.

Information Processing

Information processing research attempts to form models of thinking. Hestenes¹¹ models the general structure of a human information processing system as consisting of a short term memory (STM) or consciousness and a long term memory (LTM) or unconscious memory. The STM which is fed input from the senses has a capacity of from five to seven "chunks". The chunks may be letters, words, or conceptual units. These chunks may be transferred to the LTM, but the transfer is slow. If the STM becomes overloaded as old chunks are replaced by new ones, information is lost. The LTM has "programs" that determine how input to the system is processed. In Greeno's¹² model the extra element of a "working" memory is introduced. It is here that "information from the STM and LTM interact and a solution is generated and tested."

Two essential features emerge from this model. The first is a need for some kind of external memory to avoid overloading the STM. Hestenes¹³ suggests that, "Students

need to learn how to use paper and pencil to control their thinking as well as to express their thoughts. And teachers need to learn how to teach them to do it." Larkin¹⁴ has also written about the need to provide an extension of the problem solver's working memory capacity by the use of pencil and paper. She states that this takes extra time, but it is quicker than trying to memorize the information (transfer to LTM) and makes the information readily available.

The second significant feature is that of chunking. Chunking refers to how information is perceived and stored in the memory. The STM allows for only about six chunks, but a chunk may be a single item or familiar pattern of many items. Experts recognize patterns, which then evoke actions. Experts store information in what is called a production. Productions include not only the action to be taken but the condition which must first be satisfied to cue the action.¹⁵

Reif¹⁶ talks about "schemata" which are chunks of all "the knowledge needed to solve routinely a particular class of commonly occurring problems....Observations indicate that novice students tend to store their knowledge in terms of memorized formulas, with little ancillary information."

Simon and Newell¹⁷ have said that because of the similarities of human thinking to processes utilized by

computers, it is possible to test information processing theories by formulating them as computer programs.

Many computer models have been devised to test theories of performance that contrast expert and novice problem solvers. As an illustration of this, Chi¹⁸ and others discovered by the use of "protocols" (transcripts of people solving problems out loud) that

the important distinction between the expert and the novice is that the expert uses a working-forward strategy, whereas the novice uses a working-backward strategy. The expert's strategy is simply to work from the variables given in the problem, successively generating the equations that can be solved from the given information. The novice on the other hand starts with an equation containing the unknown of the problem. If it contains a variable that is not among the givens then the novice selects another equation to solve for it and so on.

Larkin¹⁹ and others have written computer programs that model these two schemes and demonstrate how the computer can learn through practice. Such computer models as Ph100, Ph632 and ABLE are compared to protocols of experts and novices working the same problems.

By examining what is necessary to make the computer model conform to features of experts such as forward thinking, chunking of items and qualitative analysis, conclusions can be drawn about the basic structure of thinking.

Thought Vocalization

Larkin²⁰ has said that in order for us to help students learn how to solve problems, we must "1. Observe in detail what experts do in solving problems; 2. Abstract from these observations the processes which seem most helpful; 3. Teach these processes explicitly to students." This is what Krutetski²¹ and Kantowski²² did in their research. They were studying the thinking processes of students doing mathematical problems. In order to observe carefully these processes they chose a process called out loud thinking or thought vocalization.

As Whimbey²³ explains, in order to teach properly, "the skill is explained and demonstrated to the student. The student practices the skill with guidance and feedback." He then illustrates this by explaining how a golf pro will demonstrate the fundamentals of the game to his pupil, but then the pro will have the pupil practice as he observes his techniques and critiques them.

In education, however, the only way to observe the thought process of experts or for instructors to be able to give correct feedback is for both teacher and student to think out loud. Thinking is a covert activity, hence, if thoughts are not vocalized, only guesswork will supply any clues to what is happening.

Not only does out loud thinking allow students and instructors to observe the thinking of each other and to give appropriate feedback, but it is the "safest way to insure that you do not skip steps in your reasoning, nor miss facts in drawing conclusions. In other words, you will find that vocalizing your thoughts will force you to be more careful and thorough in analyzing your thoughts."²⁴

In order to implement the process of thought vocalization or out loud thinking, Whimbey²⁵ has the students work in groups of two or larger. One solves the problem and the others serve as listeners. The listener checks the accuracy of the process and asks the problem solver questions if he discovers a discrepancy. It is also his responsibility to demand constant vocalization of the problem solver. It is easy to skip steps without vocalizing them, but this makes it impossible for a listener to make sure he understands what is happening, and the practice will pay off in more complicated problems. As a result of this process, both problem solver and listener learn from each other. They both become more aware of their thought processes and are developing them by practice.

Bloom and Broder²⁶ conducted their research on problem solving using out loud thinking. They found "some students were almost entirely unable to reveal the processes they

employed in the attack on problems.... The majority of students, however, were able to report a good deal of their method."

These techniques of thought vocalization could be applied to modes of studying together such as that of Alexander. Stonewater²⁷ reports that in Alexander's "learning cell" theory,

Students are paired so that they can study a particular instructional package with each other.... Once in class the instructor could present a lecture over the strategy and then break up the class into learning cells for practice in applying the theory to actual problem solutions. Alexander reports that when using a learning-cell approach to instruction, students learn more than when studying individually. They learn to analyze, synthesize and apply their knowledge, and their feelings of isolation/alienation and test anxiety are decreased. He attributes these positive outcomes of the learning cell to the active practice involved, to the immediate feedback between peers in the cell, and to the responsibility participants develop not only for their own learning, but also for the learning of a valued partner.

The exact reason as to why out loud thinking gives such positive results is not known. Lochhead²⁸ says that it appears obvious that speaking with colleagues increases our understanding and clarifies our thoughts, but we really do not know the reason that vocalization proves to be so important. He states that educational theory not only ignores the impact of thinking out loud, but usually discourages it. We as students are too frequently told to do things in our head and not to use scratch paper or talk

to ourselves. But, it's a common experience of physics instructors to feel that they do not really understand most areas of physics until they try to teach them.

There has not been any research which has attempted to find what percentage of students could benefit from this process of out loud thinking. There are perhaps many who are just too self-conscious or for some other reason would not be able to express their thinking processes to others.

Knowledge Structure

Recent studies indicate that even more important than the quantity of knowledge gained, is it's organization. Reif²⁹ states that "knowledge is often viewed and taught as a valuable collection of facts, principles, rules and logical relationships. Such a static view of knowledge is of very restricted utility in science and for other contexts of more than routine complexity." He describes a process called successive refinement, whereby the students decompose the problem into subproblems. This structure requires that the student have a successful search technique and that the student's knowledge base is carefully organized into a heirarchical order. The knowledge is stored as chunks or problem schemata and not just as isolated formulas.

Eylon³⁰ carried out a study to test the hypothesis that effective organization of knowledge is crucial to problem

solving. His results indicated (unsurprisingly) that those who use hierarchical organization did significantly better in recall and problem solving tasks.

Chi³¹ discusses the differences between novice and expert knowledge bases:

(A novice's) knowledge is organized around dominant objects (such as an inclined plane), and physics concepts (such as friction) mentioned explicitly in the problem statement. Experts, on the other hand, organize their knowledge around fundamental principles of physics (such as conservation of energy) that derive from tacit knowledge not apparent in the problem statement.... Expert schemas contain a great deal of procedural knowledge, with explicit conditions for applicability.... Our hypothesis is that the problem solving difficulties of novices can be attributed mainly to inadequacies of their knowledge base, and not to limitations in either the architecture of their cognitive systems or processing capabilities.

Byron and Clement³² indicate that many students are formula centered and demonstrate little understanding of the concepts, even though they show an ability to solve problems in special cases. Through interviews they found that students could perform calculations with a formula, but when asked to give a coherent verbal description of the situation, widespread misconception suddenly appeared. The source of these qualitative misunderstandings can often be traced to deep seated preconceptions held by the students which make the comprehension of new concepts in the classroom very difficult.

Many studies are currently being done to try to identify those concepts with which students have problems. Trowbridge and McDermott³³ investigated the misunderstanding of the concepts of velocity in one dimension. Fredette and Clement³⁴ investigated misconceptions of an electrical circuit and suggested a well-conducted effort to overcome misconceptions by developing laboratories which tie qualitative principles to a variety of real world situations.

Examining Relations

In addition to structuring basic physics knowledge, it appears that structuring the way that students look at formulas or relations can also be beneficial.

Larkin³⁵ proposed a series of abilities that students should have in order to "understand" a relation. She examined a procedure using programmed learning to give explicitly structured practice that required the student actively to investigate each relation with respect to a list of abilities (See Figure 2). She later investigated the use of this list as a checklist for going over an equation for understanding, but found this to be cumbersome. She had better success with having this list converted into a template. The students then filled in a series of blanks on a matrix like a crossword puzzle. She reported that "such a

A. Statement and Example

State the relation and give an example of its use

B. Quantities in the Relation

1. Properties (list basic properties: number or vector, possible signs, units, typical magnitudes)
2. Interpretation (symbolic representations: words, graphs, numbers, formulas)
3. Conditions specifying meaning
4. Comparison of quantities (similarities and differences)

C. The Relation Itself

1. Conditions of applicability (recognize situations in which the relation can or cannot be used)
2. Comparison of relations (compare to a similar relation)
3. Relating quantities (find an expression or value for any quantity in the relation)
4. Dependence (for two different values of one quantity compare the corresponding values of another quantity)

D. Organization of Relations

In a physical situation, identify those relations which are applicable and use them without confusion

Figure 2

ABILITIES ENCOMPASSED BY "UNDERSTANDING"
A RELATION^a

^a F. Reif, Jill H. Larkin and George C. Brackett, American Journal of Physics 44(3), 212(1976).

template constitutes an easily visualized data structure for organizing the information pertinent to any relation. More important, the templates seem to be sufficiently appealing that students use them spontaneously. The templates serve students as explicit reminders of what aspects of a relation need to be examined to gain an understanding of the relation.

With whatever form of examination is used, there are several important issues that must be addressed. Students need to understand that each relation falls into a general framework. As Hudson and Nelson³⁶ report:

What makes physics hard for some beginning students is usually not the mathematics. Instead difficulty stems from not catching on soon enough to the "physicist approach" namely, viewing phenomena in terms of just a few general principles. For example, most of this volume deals with the mechanics of linear and angular motion, yet basically we use only three methods to solve mechanics problems.

Another aspect of understanding relations is teaching the conditions under which the equation should be used. As explained by Simon³⁷:

It is a rule of algebra that you may subtract the same expression from both sides of an equation. The rule gives no hint of the circumstances under which a problem solver should avail himself of that privilege.... If you will examine some typical algebra textbooks you will find that all of them make the rule of addition completely explicit, but you will almost surely find also that the conditional rule which tells when the operation is appropriately applied is only implicit, or if mentioned, is not much emphasized or elaborated.... Hence, if the student mainly memorizes, learns by rote, the laws stated in the textbook, he or she will acquire little or no problem solving ability.

Any investigation of relations should include a reference to when it is appropriate to use the relation.

The use of diagrams and explanations of terms is emphasized by Aarons.³⁸ He says that until students are able to draw the diagrams correctly and redefine the technical terms in their own words, they really do not understand the relations. We cannot assume that if students get the answer that they understand the physics. These two steps are often bypassed, because it is easier just to plug in the numbers as opposed to understanding the relation.

Finally, when examining relations, it is important to look at them from many different points of view. Some students prefer to examine relations from a visual approach. They draw diagrams and imagine physical setups. Others prefer to look at the relations as a mathematical equation: they will, when faced with a problem, immediately define symbols and set up the equation. Still others relate to a definition in words.³⁹ The relation should be examined in such detail as to reach all these kinds of people.

Heuristics

A heuristic has been defined as "a general suggestion or strategy, independent of subject matter, that helps problem solvers approach, understand, or efficiently marshal their resources in solving problems."⁴⁰

Just how important is it to have a general strategy for attacking problems? Woods⁴¹ came to the following conclusions from his research and observations:

Students do not have an organized method of defining or thinking about problem solving. They just "do their own thing". To many this meant starting to solve a problem with whatever came into their head first. To others this meant that they tried to locate a worked out example problem. Still others found they just did not have confidence to do anything; getting started on solving any problem was just a traumatic experience. When they got "stuck" on solving a problem, few could describe where they were, what was causing the difficulty and what obstacle they were trying to overcome.

Schoenfeld⁴² refers to the great similarities in the approaches of experts in problem solving. He proposes that a "global strategy" could be developed, based upon these similarities and also upon input from the systematic techniques of artificial intelligence. This strategy could then serve as a model for novice problem solvers and could greatly shorten the time and effort required to develop a personal problem solving strategy. He also says that "the likelihood of students picking up the strategies from their experience is small. Thus, if we expect students to learn to use such strategies we should label them explicitly and explicate their use in much the same way we would teach any other mathematical strategies or techniques.

In examining student protocols, Larkin⁴³ found that "many students in an introductory physics course approach

problems in very haphazard and ineffective ways.... Thus even when students know all of the relevant facts and principles necessary for the solution of a problem, they may be unable to solve it because they lack any systematic strategy for guiding them to apply such facts and principles." To help solve this dilemma, she outlined a four-step strategy for solving problems. This consists of the following:

DESCRIPTION: List explicitly the given and desired information. Draw a diagram of the situation. (The result of this step should be a clear formulation of the problem.)

PLANNING: Select the basic relations pertinent for the solving of the problem and outline how they are to be used. (The result of this step should be a specific plan for finding the solution.)

IMPLEMENTATION: Execute the preceding plan by doing all necessary calculations. (The result of this step should be a solution of the problem.)

CHECKING: Check that each of the preceding steps was valid and that the final answer makes sense. (The result of this step should be a trustworthy solution of the problem.)

This plan is very similar to that of many others. A compilation of eight plans is provided in Appendix A . Woods⁴⁴ lists criteria for choosing a strategy to use. He notes of course that instructors can either develop their own, use one that has been developed by someone else, or

else take one from the literature and modify it to meet the needs of the user. He lists seven reasons why a strategy of whatever origin should be used:

1. It provides a consistent methodology that can be used for all problems.
2. Its application shows the generality of problem solving as an activity.
3. It is an excellent means by which problem solvers can overcome the initial panic of "how can I ever solve that?"
4. It slows the process down; usually this helps make the problem solver be more accurate and methodical.
5. It provides a starting structure for identifying the parts of the problem.
6. It is an essential component for group problem solving.
7. It makes a dramatic difference in (the instructors) problem solving ability.

Part of the problem rests in deciding how much skill a student must have to be able to use a particular strategy. These prerequisite skills must somehow be discovered and sometimes also taught, since even a particularly well thought out strategy will fail if the students lack the ability to do simple algebra or draw diagrams.

The rest of the problem lies in finding a way to help the students internalize the strategy so that it becomes a part of their personal problem solving arsenal. Larkin's⁴⁵ strategy for teaching her four-step method was that of "explaining the strategy to students, then demonstrating it

in the case of a few problems, and afterwards providing students with practice and feedback on a variety of physics problems of the kind encountered in an introductory course."

Aubel⁴⁶ says that in order to help students master the system they must be given plenty of encouragement with patience. They must have the opportunity to practice the skills on simple problems, so that they will have the confidence to use these skills on more difficult problems.

One of the most involved programs for implementing a strategy was at Twente in the Netherlands.⁴⁷ Those involved with the program commented that "offering a few random heuristics here and there is not sufficient; the heuristics offered should form a system of heuristics." The implementation of the heuristic at Twente involved an orientation to the strategy. It was then illustrated through example problems worked in class and then students were guided through problems. The students were given worksheets to use. They were required to do all work in strict accordance with the heuristics. The students did most of the work on their own or in small groups, with guidance from the instructor when needed.

Linn⁴⁸ addressed the issue of convincing the students to use a strategy or heuristic. He says that too often students have been able to get by with shoddy techniques for solving problems in the past. This attitude is reinforced

because, for many college physics problems, a strategy is simply too involved for the level of the problem. The only way to get students to use the heuristics on the easier problems so that they will have the skills necessary to tackle the more difficult ones is simply to require that they use it and make it a part of their grade. The students realize that their grade is based not only on the product or answer, but also on the process.

The importance of making the strategy a real part of the physics program is emphasized by Woods:⁴⁹

Use it as a framework about which to develop the case problems and examples you work in class.

Plaster the walls with the strategy; display it; repeat it as a logo on assignment sheets. Talk about it.

Require others to use it and show that they have used it.

Ask others to recall the strategy and components of it.

Develop examination or evaluation procedures that will help you and your students see how well they understand the strategy.

If a strategy can be implemented, there are many benefits to both the instructor and the student. One of these is increased ease in tutoring. Marples⁵⁰ says that when a student comes in to talk to the professor, the professor may take one of two tacks. He can demonstrate the problem to the student or he can attempt to ask the student a series of questions to discover just where the student's

difficulty lies. But, if he elects to ask questions, they are usually so open that the student does not know what he is aiming at, or so precise that he has done the student's work for him. If, however, both the professor and student are familiar with the same strategy, the professor has at his command a series of questions and a direction to which the student will be able to relate.

It is also readily apparent that the same advantage would be found in lecture, since the student would be in tune with the procedures of the professor, and since the problems would be worked out in the same way each time.

Another advantage of the heuristic or strategy is that it keeps the student closer to the physics of the problem. Most strategies require that the student make a physical representation of the problem (sketch, diagram, etc.). As suggested by Simon and Simon⁵¹,

The physical representation provides a basis for generating the physics equation.

Second, the physical representation provides a situation that can be used to check one's errors.

Third, the physical representation provides a concise and global description of the problem and its important features.

And finally, we conjecture that the physical representation permits direct inferences to be drawn about certain features and their relations that are not explicit in the problem statement, but can be deduced once a representation is constructed.

Another feature which the typical strategy uses to keep students closer to the physics of the problem, is a ban on starting calculations too early. Kramers-pals⁵² says that "often students start calculations before they have a good overall picture of the problem situation. The resulting new numbers make the students lose sight of this picture even more." The omission of units is also a regular practice among students but is usually strictly forbidden by the strategy.

How successful have programs utilizing such a heuristic been? Schoenfeld⁵³ says that, "when problem solving strategies are identified and taught, and when students think to use them, the impact on the students' problem solving performance is substantial." Lucas⁵⁴ states that "the strongest evidence of this study indicated that college students who received training in heuristic processes exhibited superior overall performance in approaching problems, devising workable plans, and obtaining accurate results."

In the Twente project success was judged not only on the examination scores but also on the ability to complete all the phases of the strategy, the time keeping of time spent on the given course at reasonable levels, and the

satisfaction of both the students and the faculty. They report that they were successful on all four of these measures.⁵⁵

Larkin⁵⁶ reported that:

Students who received such instruction exhibit... a greater use of diagrams and also a more intelligent use of algebra before cranking out numbers.

Show more extensive planning, and also greater success in attaining solutions.

Even when the students... do not attain the correct solution of a moderately complex problem, they do tend to use reasoning and steps relevant to the solution.

Several introductory physics textbooks apply this approach of teaching students a general strategy for solving problems. The eight-step strategy of Ewen and Heaten⁵⁷ from their book Physics for Technical Education is listed in detail in Appendix A. The book works all of its example problems according to the strategy and encourages students to use it in solving all of the problems in the text. Wall⁵⁸, the author of a preparatory physics text entitled Introductory Physics: A Problem Solving Approach, tells the instructor that he must "insist the students solve problems in a suitable format." The example problems in the text include such elements as a discussion of the physical situation of the problem, listing of the givens and the "to find" of the problem, and symbolic solutions followed with insertion of the numbers with appropriate units.

Ward's⁵⁹ book, Solving Physics Problems, is written as a supplementary text. He lists as his basic strong points such things as a "five step approach to solving problems (which) aids the student in assessing his/her weak points relevant to specific problems" and the fact that "90% of the problems contain art work and line drawings."

Evaluation

It appears that physics provides an excellent avenue for investigating cognitive process instruction. Hestenes⁶⁰ said,

Physics is ideal for studying reasoning and learning strategies because the subject matter is well defined and the concepts involved vary widely in kind and complexity. It would be most difficult for a psychologist to acquire the scientific insight needed for a deep study of scientific thinking. It is easier for a scientist to learn the relevant results and methods of psychology with the natural sciences.

But how should this investigation be carried on?

Kilpatrick,⁶¹ in an article about the variables and methodologies in research on problem solving, said,

Rather than comparing methods, researchers interested in instruction in heuristics should put their energies into devising the best instructional program they can and then demonstrating in detail how the program functions and how effective it is in the classroom. The creation, tryout and revision of program components and instruments for measuring effectiveness are research activities of far greater potential than the comparison of methods.

Arguing that cognitive process instruction is tied closely to observation, Lochhead⁶² says that research should be more "concerned with contextual validity of the situation than the extent to which factors can be controlled."

Eisner⁶³ says that techniques used by ethnographers (descriptive anthropology) are more appropriate for educational research than the traditional approach of testing and measurement. An ethnographer does not impose artificial conditions upon the study for the sake of controlling factors. The ethnographer makes his observations "where the action is" and remains there for a significant period of time. He "describes what has occurred in discursive terms. It is not a method that assigns a central position to measurement, although appropriate measurement is sometimes used."

The need for a new paradigm of evaluation is stressed by Parlett.⁶⁴ He calls this new model "illuminative evaluation". It does not require objective numerical data in order to permit statistical analysis based upon a treatment and a control group. He says that the old technique required either very large samples or extremely strict control, allowed for no change during the process of the study and imposed restriction on the scope of the study to satisfy the research requirements. Parlett says:

The model described here, illuminative evaluation, takes account of the wider contexts in which educational programs function. Its primary concern is with description and interpretation rather than measurement and prediction. It stands unambiguously within the alternative anthropological paradigm. The aims of illuminative evaluation are to study the innovatory program; how it operates; how it is influenced by the various school situations in which it is applied; what those directly concerned regard as its advantages and disadvantages; and how students' intellectual tasks and academic experiences are most affected.

The observation phase occupies a central place in illuminative evaluation. The investigator builds up a continuous record of ongoing events, transactions and informal remarks... Discovering the views of participants is crucial to assessing the impact of an innovation. Instructors and students are asked about their experiences and also to comment on the use and value of the innovation.

While concentrating on observation and interviews, the illuminative evaluator does not eschew paper and pencil techniques. Their advantage in larger scale illuminative studies is especially evident. Also survey type questionnaires used late in a study can sustain or qualify earlier tentative findings.

It appears that the most reasonable approach to evaluation of any program for increasing the ability of students to solve problems, cannot be based simply on comparison of examination scores, but also must include such issues as student and faculty perception of the program, reasoning ability as determined by actual observation of individual work, and the overall effectiveness of the program.

CHAPTER THREE

Rationale and Methodology

After examining the various subfields of cognitive process instruction, whose design is to promote thinking and understanding as opposed to rote memory, it became apparent that there is much in common among these subfields.

Developmental psychology stresses the need to promote student interaction and out loud thinking. This is exactly the major thrust of thought vocalization. This idea of active practice with feedback and learning from each other is complemented by the use of heuristics. Heuristics serve as guides in helping students to communicate with each other in a group because they are all using the same general strategy.

Information processing systems stress the importance of external or pencil-and-paper memory for extending the short term memory of the problem solver. Heuristics are based on the principle of attention to detail and writing everything down, including the knowns and unknowns, diagrams, intermediate steps, etc.

Information processing systems also point out the importance of chunking or recording information in the memory as action-condition pairs (schemata) so that it can be referenced as a complete thought instead of scattered bits of information. The study of how to examine relations emphasizes paying attention to all of the auxiliary information that goes along with the equations, rather than memorizing them. Heuristics include the ideas of understanding the physics of the problem and knowing when to use what equation as opposed to just equation manipulation. Knowledge structure also encourages categorizing equations in terms of procedural knowledge and fundamental principles.

Diagrams are essential to examining relations as well as to the use of heuristics. Developmental psychology encourages their use, because they tend to make the problem more concrete.

One of the major purposes of thought vocalization is to promote accuracy. This is also one of the major thrusts of heuristics.

The fields of study described above are organized in the present study into a comprehensive program in which each can serve to complement the others. The major components of this package, entitled Explicitly Structured Physics Instruction, are the WISE strategy, the formula fact sheet, the problem solving session, and the use of classroom time.

This chapter will investigate the rationale behind this system and its components, its goals, and the methods which have been used to evaluate and revise the system.

Explicitly Structured Physics Instruction

The purpose of Explicitly Structured Physics Instruction (ESPI) is to structure not only how the physics is taught, but also how the problems are to be solved by the students. "Explicitly" refers to the fact that that which a student is required to know is spelled out in detail. Both the problem solving process and the requisite skills needed to use the process are supposed to be taught. In ESPI the student is not expected to develop a problem solving strategy simply by watching a professor and then trying to infer a general procedure for solving problems. The strategy is taught step-by-step. Problem solutions presented in class always follow the same format. The structure for the examination of formulas is taught along with the formulas. Problem sessions are also structured and the students are taught how to work together in pairs. Thus under the ESPI system the full structure is taught explicitly or in an "externally visible"⁶⁵ format as opposed to being partially implied.

The goal of the program is not necessarily to increase the final exam scores, though of course one hopes this will be a natural byproduct of the program. Its immediate goals are to help students organize their work, increase their accuracy, eliminate initial panic or lack of direction in approaching a problem, increase confidence in problem solving, and improve the student's ability to communicate with the instructor and other students. It is designed to help the students focus on the process of problem solving instead of the end product or answer.

The ESPI program as presented here has been developed and refined over the past two years, largely through the process of using and analyzing successive versions of it throughout five academic quarters (AY 1982-83 and Summer and Fall 1983) of mostly non-calculus physics courses taught by the author at Tidewater Community College and Virginia Wesleyan College. These applications and analysis of ESPI are described in detail in Chapters Four and Five.

The WISE Strategy

The WISE strategy for problem solving (see Figure 3) was developed to promote organization, accuracy and understanding in problem solving. It is based on research on heuristics. Heuristics appear to be at the pinnacle of

WHAT'S HAPPENING

Physical Principle

Identify the basic physical principles involved in the problem.

Diagram

Draw a sketch or diagram.

Knowns and Unknowns

Identify and label what is given and what is required, using appropriate units.

ISOLATE THE UNKNOWN

Select an Equation

Identify an equation that will enable you to solve for the unknown.

Solve Symbolically

Using only the symbols, solve for the unknown.

Search Systematically

If one equation is not enough, then use the basic physical principle to identify other equations to solve simultaneously.

SUBSTITUTE

Plug in both the numbers and the units.

EVALUATE

Are the sign, magnitude, and units correct? Compare with your diagram, intuition, and knowledge. If you like your answer, place a check mark beside it.

Figure 3

A WISE Strategy for Problem Solving

cognitive process instruction (CPI) since the other fields of CPI seem to be involved in the construction and effective use of heuristics.

The first step of the strategy, entitled *Whats happening*, asks the students to list the knowns and unknowns of the problem, draw a suitable diagram and identify the basic physical principles in the problem. Then in the second step the student is asked to *Isolate the unknown*. This is to be done by selecting an equation and solving it symbolically for the unknown, using the physical principles involved in the problem to select other equations if one is not sufficient. In the third step, *Substitute*, the student plugs in both the numbers and units into the solved equation, and finally with *Evaluation*, the student checks the signs, units, and the magnitude of the answer.

Accuracy. One of the basic purposes of the WISE strategy is to promote accuracy. The need for this was indicated in an investigation carried out over a period of four academic quarters by the author of this study. In the course of this investigation over 1300 mistakes made by students on tests and final exams were categorized in one of three types: careless mistakes, conceptual mistakes, and algebra and trigonometry mistakes. Careless mistakes included drawing sloppy diagrams, overlooking information, answering the wrong question, miscopying material, leaving

out a variable, arithmetic mistakes and sign mistakes. Conceptual mistakes included using the wrong equation, adding vectors like scalars, confusing initial and final velocity, and getting lost in the problem. Algebra and trigonometry errors referred to such mistakes as mixing up sine and cosine, and subtracting to isolate one factor of a term in an equation.

It was found that out of a total of 1337 mistakes made (with each mistake counted even if the same mistake was made by someone else), 620(46%) were careless errors, 614(46%) were conceptual problems and only 103(8%) were algebra and trigonometry mistakes. Of course there was some ambiguity in deciding on the category for each mistake. Some mistakes which appear to be the result of fuzzy thinking may simply be caused by working too quickly, or an algebra mistake may be the mask of general confusion in the problem. There were, however, enough mistakes analyzed so that category misplacements would tend to cancel out each other. Also, the exact percentages were not crucial for showing basic trends.

The high percentage of careless errors signals in particular that some way is needed to slow down the student and make him more accurate. The WISE strategy has been designed to do this. For example a check on the magnitude or direction of the answer can alert the student to a

mistake earlier in the problem. Properly drawn diagrams can eliminate many sign errors. Symbolic solutions and carefully labeled knowns and unknowns can eliminate many other careless errors. And of course algebra mistakes, many of which are simply careless, can usually be caught by a units check at the end of the problem (as almost any science instructor knows).

This investigation points out that it is not just mathematical and conceptual errors that burden students. By proper use of the strategy, the student should be able to eliminate many of the careless errors and build a framework to catch the more fundamental mistakes as well.

Self Regulation. According to the theories of developmental psychology, the development of self-regulation is enhanced by emphasis on the process and not just on the product in problem solving.⁶⁶ The WISE strategy is designed specifically to generate this kind of emphasis on this process. Throughout most the author's five-quarter applications of the WISE strategy the student was graded on his process, or on his use of the strategy as well as the answer. Also, asking the student to draw diagrams and identify the basic principles involved should make the situation more concrete, and thus easier for many students to handle.

External Memory. Information processing perspectives urge the use of pencil and paper to expand the short term memory. Many students try to get by with writing as little as possible and with doing as much as possible of the work of problem solving in their head. The WISE strategy should clearly mitigate against the tendency and prove helpful in getting them to use this very valuable resource.

Tutoring and Group Work. The activities of tutoring and group problem solving are greatly enhanced by faithful use of the WISE strategy. This is because both the student and teacher (or both students) use the same general approach. As Marples⁶⁷ pointed out, the tutor has at his command a list of questions that he can ask and to which the student can relate. The student is thus enabled to be guided by gentle clues, because he is aware of the directions from which the tutor is coming. In a group of students the same will be true, because students that are using the same approach will be able to communicate better.

Understanding. The use of symbolic solutions should help students think in terms of the physics of the problem instead of a jungle of numbers. Also the structure of the WISE strategy has been designed to promote understanding of the physical principles of the situation and to discourage

"fishing" for equations that work. The students are asked to deal with general procedures and structures as opposed to simply memorizing a sequence of steps for each type of problem. The use of representations such as diagrams helps to isolate the physical principles of the problem and act as a bridge between the real world and the equation.⁶⁸

Organization. Because each problem is attacked in the same manner, and because students are asked to pose the same kinds of questions each time they attack a problem, the students' initial panic can be overcome when they have learned to use the WISE strategy. The fact that problems are always solved in the same organized fashion models for the student explicitly how problems should be solved. The WISE strategy captures the essence of many of the usefully systematic ways of solving problems, and allows the students the flexibility to develop their own personal problem solving strategy within its framework.

Formula Fact Sheet

The formula fact sheet (see Figure 4) has been designed to be utilized in the classroom to structure the investigation of equations. The class as a group is supposed to fill in the indicated information about the equation in question, such as whether it is a scalar or vector equation, what units are used, what a typical diagram

.....

When/what:

Scalar _____

Vector _____

Diagram

Component _____

Magnitude only _____

Direction _____

Requires A and A_0 _____

Symbol	Name	Units (Derived)	Basic & Notes
.....
.....
.....
.....

Notes: Hints/Constraints

Companion Equations

Figure 4
 Formula Fact Sheet

would look like, how to state the equation in words, when it is to be used, and what hazards to watch out for. Students are also asked to list other equations that are frequently used in conjunction with the one in question.

The purpose of the formula fact sheet is to impress upon students that there is more to understanding an equation than just memorizing it. They are thus taught to recognize condition-action pairs, or what motivates the use of the equation. Students are thereby encouraged to learn all the auxiliary information about the equation along with the equation so that it may be stored in the memory as basic procedures or schemata as opposed to isolated facts.

The WISE strategy complements the formula fact sheet since the strategy asks the student to pick an equation based on the physical principles, and the fact sheet asks the student to concentrate on those physical situations that require the use of the equation. The related or companion equations that are indicated on the sheet should help to put the equation into the context of the basic structure of physics.

The fact sheet has also been designed to help those students who approach the understanding of equations with different perspectives. Those who relate to the equation

itself, those who understand verbal descriptions of it, and those who like to see a physical model should all be satisfied.⁶⁹

Problem Solving Session

Through most of the five quarters of the author's development of the ESPI program in his courses, a problem solving session was held weekly during the first hour of the laboratory period associated with the course. The session emphasized interaction between students and out loud thinking. Students were given immediate feedback as they worked in pairs. This process was designed to enhance the accuracy of the problem solving process and to encourage self regulation. Students were taught to work together and think out loud by the use of exercises that have been developed by Whimbey⁷⁰ and allow the student to learn the working together process without having to worry about the physics of the problem. (See Appendix B for a copy of the exercise.)

Classroom Time

The author's classroom time was also organized to encourage development from concrete to formal thought by the use of demonstrations and practical examples. The WISE

strategy was taught along with other explicit skills needed to do physics problems, such as certain strategies for solving algebra problems.

Original Program

Several items discussed above are explained in terms of their final format. In the beginning of the study, for example, the formula fact sheet was not used. It was first implemented the second time the physics sequence was begun (Spring Quarter 1983).

The WISE strategy was also in a much different form in the beginning. Chapter Four will outline the reasons behind the changes in the strategy. The original strategy was labelled the general heuristic. The complete general heuristic along with the guidesheet that came with it and a sheet explaining the "working backwards" technique are contained in Appendix B. The general heuristic utilized all of the basic principles involved in the WISE strategy, but in addition it involved asking the student to restate the problem, draw a physical sketch along with the diagram and estimate his answer in the first step. In step two the student was also asked to outline his procedure in detail first before proceeding with the actual solution of the problem, to write down all equations that might be useful in solving the problem and to solve by working backwards. The

fourth step involved asking about how solving the problem provided insight into other problems and if there was a way to solve the problem more efficiently.

Method of Evaluation

A reasonably long term evaluation period was picked to test the success of the ESPI program. Because of the very large number of variables involved in the program and the nature of its purpose, it was decided at the outset to forego attempts at the traditional experimental-control group procedure and to follow essentially the guidelines of illuminative evaluation.⁷¹ This latter procedure allowed for revision in the midst of the project and also emphasized the developmental aspects of the project. The goal of this project was not to prove that this method was better than some other method, but to develop a system of instruction based upon recent developments in cognitive process instruction and to evaluate its effectiveness.⁷²

The ESPI program was implemented in the Fall of 1982 at two colleges: Tidewater Community College (TCC) and Virginia Wesleyan College (VWC). A total of two sections of General College Physics 201 (using algebra and trigonometry) and one section of University Physics 221 (using elementary calculus) were involved at TCC and one section of General College Physics 211 was taught at VWC. Revisions of the

program were based upon feedback from the students in the form of questionnaires and interviews and instructor evaluation. All sections were taught by the author of this study.

The students in these Fall Quarter 1983 classes were tracked until they completed the three quarter physics sequence, and their reactions to the system were gathered at the end of each academic session. Physics 201 was then taught using the revised and "improved" program three times (Spring, Summer, and Fall of 1983). Physics 202 was also taught during Fall Quarter of 1983 to students who had taken Physics 201 either in the Spring or Summer quarters. The success of the program was measured by student interviews and questionnaires, by faculty evaluation, and also by a supplementary statistical evaluation of grades, attitudes and other variables. The answers to the following questions were crucial to the study: Did the students (and faculty) have a positive reaction to it? Were students able to adapt to it? Did they feel that it helped them organize themselves and develop a problem solving strategy?

The outcome of this study was planned to be a list of practical ideas about how to implement a program like ESPI, an indication of both what worked well and what did not, and a mapping of possible directions for future research and development.

CHAPTER FOUR

Preliminary trials

The system of instruction, Explicitly Structured Physics Instruction, was implemented three times on a trial basis and modified on the basis of the feedback from the students and instructor evaluation. This chapter lays the groundwork for the establishment of the final form of ESPI which form was implemented for the first time in the Summer of 1983.

Trial One

The program was first implemented in the Fall of 1982 with three classes of (non-calculus) General College Physics and one class of (calculus-based) University Physics. All of the classes were at Tidewater Community College (PHYS 201 and PHYS 221) except for one class of General College Physics at Virginia Wesleyan College (PHYS 211). The author of this study taught all four classes.

The principle instrument of the program was the general heuristic (See Appendix B). To help students to utilize the heuristic, a guide sheet was provided which had a block for filling in each step of the heuristic. The basic plan

included following the heuristic in detail when performing the problem solutions in class and requiring the students to use it when doing homework or answering test questions. Several problems were done on guide sheets and displayed on the overhead projector. A large fraction of class time was spent on working problems based on the heuristic and allowing the students to work problems in conjunction with the instructor or alone while the instructor roamed around and gave advice. The instructor utilized the principles of out loud thinking as prescribed by Whimbey⁷³ so that the students could follow his reasoning. The students were informed that failure to use the heuristic would result in penalty points. The lecture was supported by a problem solving session during the first hour of the course's weekly laboratory. During this session the students worked problems in pairs using out loud thinking. The instructor walked around the room and gave help to those who were stuck.

All students in two of the classes were interviewed orally to investigate their thought processes and their progress with solving problems. These interviews were conducted three times during the academic session and were recorded for later analysis. At the end of the term, questionnaires were distributed in which all students were asked to evaluate the effectiveness of the heuristic and

the coherence of its presentation. They were asked to comment on the problem solving session in lab and also on the organization of the lecture.

Analysis

The first trial met with mixed response. The engineering (calculus physics) students seemed to be somewhat insulted that someone was trying to tell them how to solve problems. Many of the other students felt like they were being harrassed. They complained that the system was just too awkward and unwieldy. Several students were able to mobilize student opinion against the program. The negative comments about the system seemed to outweigh the positive.

Seventy-nine students (TCC and VWC) filled out the end-of-term questionnaire, although all students did not answer all questions (See Table 1). When asked about whether the heuristic was a help or a headache, 44% said that it was a headache, 36% said that it was helpful, and 19% said that it was somewhat helpful. When asked if they used it on their homework, 62% said that they either did not use it or did their homework their own way first and then filled in the heuristic form.

Typical comments included:

It was a good idea, but steps must be cut down.

I'm scared of forgetting some step or bit of information.

Drop the heuristic.

Too many steps. Lets plug and chug.

My problem solving ability has increased because my work is better organized.

It sort of takes you by the hand and leads you through the problem.

The students were also asked which steps of the general heuristic that they would use if it were not required. 75-100% of them said that they would write down the knowns and unknowns, draw a diagram and (of course) execute the calculations. 50-75% of them said that they would solve symbolically and write down the key relations (equations). 25-50% said that they would restate the problem and check their answer. Less than 25% said that they would estimate their answer and outline their work before beginning the calculations. The students had been graded on a 0 to 3 scale based upon their adherence to the general heuristic on homework, quizzes and tests. An average heuristic score was compiled for each student over the course of the academic session. The average score by the General College Physics students was 1.7 out of 3 signifying that they had completed either four or five steps of the eight-step heuristic (restatement, sketch/diagram, knowns/unknowns, estimation, outline, key relations, symbolic solutions,

Table 1

Fall 1982 Questionnaire Summary
 PHYS 201,221 (TCC) and PHYS 211 (VWC)
 n=79

Question	Responses
1. Which of the following steps would you use if the heuristic were not required?	
Restatement of the Problem	25
Sketch	56
Diagram	64
Key Relations	40
Knowns and Unknowns	67
Estimate	7
Outline Procedure in words	10
Solving Symbolically	45
Execute(Plugging numbers into equations)	72
Check	26
2. I found the heuristic to be:	
A headache	35
Helpful	29
Somewhat helpful	15
3. How should problems using the heuristic be presented in class?	
On the blackboard	16
On an overhead transparency with printed sheet	26
Either the blackboard or transparency	8
Neither	4

Table 1 (continued)

Question	Responses
4. I found the problem solving session to be:	
Helpful	27
Sometimes helpful	9
Not helpful	15
5. Did you find the process of working backwards helpful?	
Yes	29
No	45
6. Did you find the heuristic guidesheet helpful?	
Yes	26
No	35
7. Did you use the heuristic in the homework?	
I used the heuristic	28
I did not use the heuristic	14
I did the problem my own way and then put it into the heuristic form	31
8. Did you read your textbook carefully	
Yes	49
No	25
9. Would you come to an optional small group study session?	
Yes	49
No	21

check). The average heuristic score for the University physics class was 2.25, which indicates that these students completed one more step than the other students. Obviously there was a problem with the system. Either the students were just unwilling to use all of it, or it was simply too long.

The questionnaire also indicated that the students did not like the working backwards technique. Only 40% of the students indicated that they liked the idea. Only half of the students indicated that the use of the guide sheets in class was useful. When asked about the problem solving sessions in lab, 53% said that they were helpful, and 18% said that they were sometimes helpful. Comments included:

Working with a partner during the problem solving session and thinking out loud gave me the opportunity to hear myself aloud work the problem through, giving me a better understanding of the problem.

A lot of the time it bothers me to work with someone. But I have to admit it has helped some.

Very helpful. Mistakes can be corrected while in progress.

Frustrating, mostly because I don't like to verbalize what I am doing.

Conclusions from the First Trial

The overall impression of the instructor was that the general heuristic had been too mechanistic and that students were so concerned with the mechanics of fulfilling the heuristic that they lost track of the purpose of it. Based

on the questionnaires it was decided to eliminate restatement, sketch, estimation, outline and key relations from the procedure.

It was also observed that part of the problem lay in putting too much emphasis on the heuristic. There were fewer demonstrations in class. Also the students were asked to work problems before they had actually been properly introduced to the relevant theory and formulas. The confidence of the instructor was also part of the problem. Since the instructor had never used the system or anything like it before, he was unable to convey very forcefully to the students that the system is really beneficial. Many students felt that they were being used as guinea pigs for an untested system. However, even though there had been something of an avalanche of negative thought, there were enough positive comments to warrant the continuance of the program with some revisions.

Two sections of the students had been given oral tests during the first quarter to help measure their progress. The use of this oral exam was discontinued due to lack of time. It did provide some useful information but not in proportion to the time that it took. Such oral interviews may prove helpful if the aim of the research is to take the

protocols of interviews and analyze them to determine the development of thought processes. For this study, however, they proved to be simply too unwieldy.

The engineering students presented a unique problem. Many of them had already had engineering courses that parallel the information in this physics course and had already been taught an explicit problem solving strategy in their engineering courses. Therefore they felt that the general heuristic was unnecessary for them, and attitude became a real problem. It was the conclusion of the instructor that the use of the ESPI program would not prove quite as useful for these students. Perhaps the best way to handle the situation with these students in the future would be to offer ESPI early in the term and leave it optional.

Second Trial

The general heuristic was drastically cut back and renamed the "basic game plan" for the 1983 Winter Quarter classes (See Appendix B). The new version was taught at the beginning, but the students were informed that the new strategy would not be required, but only strongly suggested. The problem solving sessions were continued in the lab. The lecture time was re-apportioned to include more demonstrations and theory. At the end of this academic term, each student in the Tidewater Community College

classes was brought in for a fifteen- minute interview with the instructor. Questions were asked about the student's impressions of the course and its elements.

Sixty-one students were interviewed, but they were not all asked the same questions since the interviews were conducted in a very open format. The responses were categorized, and the tabulation of these responses can be found in Table 2. Not only were there many more positive comments than in the fall, but the indication seemed to be that a solid majority of the students actually liked the ESPI program. Some of the comments gave particular insight into why the program was making a better showing than it had in the first quarter:

Game Plan organized my work.

Game plan forces you to think about the problem before jumping in. I felt pressured last quarter. The class had a negative attitude.

The game plan allows you to concentrate more on the problems and less on the structure. All the details help me, I don't just do it for you. I used to make silly errors because I didn't write down the information. You have converted me to the fact that it is more important to understand the problem than just to get the answer.

It helped to solve problems algebraically first. I hated it at first. I would get confused. It works better now working algebraically. I make fewer math errors. I enjoy class this quarter. Last quarter I dragged myself out of bed. We spent too much time solving problems and not enough with the theory.

Table 2

Winter 1983 Interview Summary
 PHYS 202,221 Tidewater Community College

Comments grouped into categories		Responses
Classroom	I don't like solving problems in class	2
	I do like solving problems in class	16
	Homework should be due daily	11
	Demonstrations were helpful	8
	Talk about concepts in class not problems	4
Heuristic	Heuristic has helped	29
	I don't like the heuristic	4
	It is too much work for easy problems	3
	Important for everyone to follow the same game plan	1
	It helps to find mistakes	1
	I have my own way of solving problems	1
	We wanted flexibility in the second quarter with the heuristic	1
Problem Solving Session	I liked group work in the session	19
	I liked individuals not pairs	6
	I don't like the session	8
	Session is sometimes good	5
	If I don't understand it I like to work in a group	1

It is important for everyone to follow the same game plan. If you need help, then everyone has the same game plan. I don't think we would have made it through physics very well without the heuristic.

If I hadn't had the game plan I would not know how to attack a physics problem.

Even though the second trial could not be labeled an unqualified success, it was a definite improvement over the first trial. Some of the biggest difficulties lay in simply convincing the students to try the ESPI system. Reactions from the students about the problem solving session were still mixed, as is noted in Table 2. The change that made the biggest difference in the second trial was the simplifying of the general heuristic. Also of importance was the revision of the lecture format to include more theory and practical applications.

Third Trial-End of Sequence

Some of the comments by the 1983 Winter Quarter students regarding the game plan seemed to indicate that they would like the freedom to choose their own plan of attacking a problem. Many felt that after two quarters of being taught a problem-solving structure they should be allowed to use that model which they had developed themselves. In response to this, the game plan (now slightly modified and renamed the general problem solving strategy) was used in class during the Spring Quarter by

end-of-sequence students, but not stressed or required. (See Appendix B.) The problem solving session was also eliminated except before tests. This latter change took place in response to the volume of negative feedback about the session from the second quarter classes. There had also been much positive reaction to the session, but the instructor decided to hold individual problem sessions with those desiring them. The formula fact sheet was introduced for the first time, but it was emphatically rejected by the class, so it was discontinued. The class was simply tired of innovation in this third trial, and they just wanted to get on with the business of finishing the physics sequence.

On their final exam, the students were asked what they felt about the elimination of the problem solving sessions in the lab and de-emphasis of the game plan. Nineteen of twenty-two responded that they regretted the demise of the problem solvings session. Five expressed regret that the heuristic was not emphasized, while nineteen felt that it was appropriate to allow them the choice. They were also asked if they felt that the beginning physics group should be taught the heuristic or strategy. Nine of ten responding said yes.

In spite of the small number of students that wanted more emphasis on the heuristic, many did say that they did not need more emphasis because they were currently using most of its features habitually. Some of the comments received were unexpected:

I missed the problem solving sessions, because I felt that they helped my test score.

The heuristic was helpful in understanding the material in the chapters. Although it required more time to complete homework, I feel I could have understood the material better had the heuristics been used.

I favor the problem solving sessions and the heuristics. I think it would be a good idea to continue the plan. It helped me a great deal. When I was in 201(First session), I felt more confident when we used the heuristics.

In the previous quarter the game plan was stressed and utilized by me, and it was a tremendous help. As this quarter progressed, I slowly moved away from the more logical methods and therefore my understanding of the problems decreased.

I enjoyed a break from the mandatory heuristic form, but I still incorporated the basic format of solving symbolically.

As for the problem solving session, I hated it at the time, but maybe we should have done this more often this quarter.

By the third quarter of physics I think a student should use the style that works best for them. For myself "my style" was developed from heuristic game plan.

The end-of-sequence class at Virginia Wesleyan College during the Spring Semester of 1983 was considerably smaller than those at Tidewater Community College. The structure

used there was very similar, however. They filled out a questionnaire at the end of their second semester. Since there were only seven students in the class, excerpts from each will be included to give a good cross section of comments:

I used the whole plan, if not on paper, at least in my head. It really helped a lot.

I strongly recommend the heuristic method.

I used the most important parts most of the time. It became a natural thing to do after a while. Although your students will rebel, it should probably be required for homework to get them used to using it.

I used it. It helped somewhat.

I used it some. The parts I did use helped a great deal.

Using the heuristic/game plan was basically helpful. Writing the knowns and unknowns, diagram, plug and chug helped us to understand the problem and redefine it for ourselves, so we were able to solve them.

I used heuristics on tests and homework problems. It helped me do problems better. If it helped me, it will definitely help others understand more of their work.

One conclusion reached after the third trial was that the problem solving session should be held regardless of some negative feedback. No one ever stayed for an optional problem solving session. Whether or not to require the strategy in the third session is unclear. Many students have progressed to the point of developing their own strategy, while others still need the push.

Third Trial-Beginning of Sequence

In the 1983 Spring Quarter at Tidewater Community College the General College Physics sequence was begun again, and it became the stage for the dress rehearsal of the ESPI system. The general problem solving strategy was used in this class also. This was the same strategy used by the end-of-the sequence class in the Spring quarter. This strategy was required and homework and tests were graded not only with respect to the answers but also on the use of the strategy. The problem solving session was again held regularly at the beginning of the laboratory period. The formula fact sheet was introduced and used throughout the quarter.

This beginning-of-sequence class seemed to proceed much more smoothly than the previous classes. Students seemed to enjoy the work that they were doing. At the end of the quarter all of the students were interviewed.

When asked about the effectiveness of the general problem solving strategy, eight said that it was very helpful, three said that it was somewhat helpful and three said that it was not helpful. However, all three who said it was not helpful to them also commented that they felt it was helpful to others and the class should continue to use it. Nine said that the problem solving session was usually helpful, three said that it was sometimes helpful, and only

one said that it was never helpful. Eleven of thirteen said they felt that the formula fact sheet was usually helpful, and the other two said it was sometimes helpful. When quizzed about their preference for pair problem solving vs individual problem solving, six said that they preferred pairs, and one said that solving individually was best in the lab.

Four students said that they would continue to use the general problem solving strategy, even if it were not required. The class was split on the question of having homework required, but almost all of them liked the idea of doing problems in class in order to get some feedback.

Comments from the students included:

For people that don't have a clue about what is going on the strategy is really good.

I would still use the general problem solving strategy even if it weren't required. It got everything all organized. I tried to understand it as opposed to filling in numbers in the formulas.

General problem solving strategy is good. I like it. At first I didn't like it because I didn't like to solve symbolically, but you get used to it. It keeps me organized. If it hadn't been required, I wouldn't have done it. I would still do it if you stopped requiring it right now. It helps me understand the problems instead of just getting the answers.

I wouldn't have gotten through it without the general problem solving strategy.

Summary

The trial runs seemed to indicate the following points:

1. The general problem solving strategy is an effective way to help students learn to solve problems. It must be easy to use and must be required.
2. The problem solving session should be conducted regularly. Pair problem solving is an effective way of conducting this session.
3. The formula fact sheet can enhance the use of the strategy.
4. Classroom time should be used to teach principles as concretely as possible, discuss theory and give practice with problem solving.

More work, however, was required to substantiate these points and detail more precisely what factors determined how students will react to and learn from the system. Chapter Five details the trials of the final form and its analysis.

CHAPTER FIVE

Analysis

In the Summer and Fall Quarters of 1983 the final revised form of the Explicitly Structured Physics Instruction program was tested. It involved the use of the general problem solving strategy or the WISE strategy, a problem solving session in lab based on out loud thinking, the formula fact sheet, and classroom activities based on concrete learning experience, theory and practice with problem solving solving. This chapter will analyze the student and instructor reaction to the presentation of the ESPI program and describe student performance.

Summer Quarter

Two sections of General College Physics(PHYS 201) were taught at Tidewater Community College in the 1983 Summer Quarter. At the conclusion of the quarter, a questionnaire was filled out by all of the students in one section and the students in the other section were personally interviewed by the instructor utilizing the same questions used on the questionnaire (See Table 3). Data was gathered at the beginning of the quarter about the attitude of the students,

Table 3
 Summer 1983 Questionnaire
 PHYS 201 Tidewater Community College
 n=32

Statement	Responses
Did you find the General Problem Solving Strategy helpful?	
Very Helpful	24
Somewhat Helpful	7
Not Helpful	1
If it were not required, would you use it?	
Yes	29
No	2
Should the General Problem Solving Strategy be taught and required of future groups of Physics 201 students?	
Yes	32
No	0
Did you find the Problem Solving Sessions useful?	
Usually	23
Sometimes	8
Never	1
Do you prefer to work in pairs or individually?	
Pairs	22
Individually	6
Should the problem Solving Session in Lab be continued next quarter?	
Yes	29
No	0

Table 3 (Continued)

Statement	Responses
Did the General Skills Test help to make you comfortable with thinking outloud and working in a group?	
Yes	21
No	4
Was the Formula Fact Sheet Helpful?	
Usually	29
Sometimes	2
Never	0
Should we continue to use it next quarter?	
Yes	27
No	0
Should the sheet be preprinted or a group effort?	
Preprinted	7
Group effort	18
Should homework be collected daily?	
Yes	23
No	1
Has your confidence in Problem Solving increased?	
Yes	26
No	1

and at the end of the quarter about the performance of the students. Table 4 summarizes all of the information gathered about the students.

Reaction to the program was positive. Of thirty-two students only one said that the general problem solving strategy was not helpful, and only three said that they wouldn't use it if it was not required. Everyone felt that it should be used again the next quarter. Comments included:

I began to understand things better once I started using the system.

Excellent system for those who are weak in math and logic.

Solving symbolically makes it easier. I used to think that it was easier to put numbers in at first. I've changed my mind. If strategy was optional in the beginning, I would have done it my own way.

You would have chaos if you let them do what they wanted. You have to make them do it. I don't see how they would learn it otherwise. They wouldn't understand the physical principles otherwise.

Students also seemed pleased with the problem solving session. Only one felt that it was not helpful and all twenty-nine respondents said that it should be continued. They said:

I prefer to work individually, but I started to get used to working in a group towards the end of the quarter.

I like thinking aloud, it will force students to think logically.

Table 4

Listing of Variables
for Data gathered Summer and Fall 1983

Name	Description	Numbers Assigned	Mean
MSSD	Lectures missed	% of missed classes	6.3%
MATH ^a	Math background	1 High School Math 2 Some College Math 3 Complete College Sequence	2.8
PHYS ^a	Physics background	0 No previous physics 1 High School or College	0.39
SCIENCE ^a	Science background	0 No previous science 1 High School 2 College 3 College(2 courses)	1.6
ATTI ^a	Attitude toward course	1 Scared 2. Neutral 3 Confident	1.9
TIME ^a	Time requirement for course	1 Less than usual 2 Average 3. More	2.3
PS ^a	How developed is your problem solving ability?	1 Weak 2 Adequate 3 Well Developed	1.9
PATT ^a	Attitude toward physics	1 Dislike 2 Neutral 3 Excited	2.3
WS ^a	Attitude toward learning a problem solving strategy	1 I already have one 2 Neutral 3 I would like to	2.6
PRMA ^a	Pre-math test	Test Score(Maximum of 16)	9.7
POMA ^b	Post-math test	Test Score(Maximum of 16)	12.5

^a Questionnaire or test given at beginning of quarter

^b Questionnaire or test given at the end of the quarter

Table 4 (continued)

Name	Description	Numbers Assigned	Mean
PRPHY ^a	Pre-physics test	Test Score(Maximum of 7)	.6
POPHY ^b	Post-physics test	Test Score(Maximum of 7)	5.2
REAS ^a	Reasoning test	Test Score(Maximum of 19)	12.4
GPSSHW	Use of strategy on homework	% of time strategy used	62.8%
GPSST	Use of strategy on tests	% of time strategy used	70.9%
FEXA	Final exam	% Score	74.4%
FGRA	Final grade	% Score	81.7%
HW	Homework	% of homework completed	75.6%
Test	Test	% Score on tests	82.7%
GPSSOK ^b	Strategy was:	0 Not helpful 1 Somewhat helpful 2 Very helpful	1.7
USE ^b	Would you use the strategy if not required?	0 No 1 Yes	0.93
PSSOK ^b	Problem solving session was	0 Not helpful 1 Somewhat helpful 2 Very helpful	1.8
FFSOK ^b	Formula fact sheet was	0 Not helpful 1 Somewhat helpful 2 Very helpful	1.9
PSCON ^b	Is your problem solving confidence improved?	0 No 1 Somewhat 2 Very much improved	1.6

^a Questionnaire or test given at beginning of quarter

^b Questionnaire or test given at the end of the quarter

Table 4 (continued)

Name	Description	Numbers Assigned	Mean
OFFHOUR ^C	How often did you come during office hours	0 Never 1 Seldom 2 Sometimes 3 Often	1.1
PATTFIN ^C	Attitude toward physics now	1 Worse 2 Same 3 Better	2.8
PSLABASS ^C	Did you come to optional problem solving sessions?	0 Never 1 Seldom 2 Sometimes 3 Often	0.6
OUTLD ^C	Do you like out loud thinking?	0 No 1 Yes	0.7

^C This question asked only of Fall Quarter students

My preference is pairs, because we can exchange our knowledge.

All twenty-seven students answering a question about the formula fact sheet said that it should be continued in the next quarter. All but two said that it was usually helpful, and those two said that it was sometimes helpful. One student summarized the overall general positive reaction by saying, "It took the vague, vast principles and placed them in an understandable, concise format."

The increased confidence expressed by twenty-two of twenty-seven students was typified by the expression of one student who said, "I feel more confident in problem solving than before, because I know there is a step-by-step method to solve a problem, even when it looks impossible to solve."

Fall Quarter

The system implemented in the 1983 Fall Quarter was almost identical to that of the Summer Quarter, except that the strategy was slightly modified and labeled the WISE strategy (See Figure 3 or Appendix B).

In addition to what had been done before, student lab assistants who were enrolled in the second quarter of the sequence (PHYS 202) held optional problem solving sessions several times a week for the PHYS 201 students.

Two sections of PHYS 201 were taught along with one section of PHYS 202 (made up of students who had taken PHYS 201 in one of the two previous quarters). At the end of the quarter, all students completed a questionnaire, and in addition those students who had taken physics before were interviewed. The student assistants were also interviewed. The same information was gathered on these students as had been gathered in the Summer Quarter (See Table 4).

The response to the WISE strategy was quite positive. (See Table 5 for complete data.) Of fifty-two respondents, forty-eight said they would use the strategy if it were not required and fifty said it should be taught and required of future PHYS 201 groups. Thirty-five commented that it was very helpful, seventeen said it was somewhat helpful, and no one said it was not helpful. The students comments included:

It puts more emphasis on the theory of the problem rather than its tedious calculations.

It makes problem solving standardized which makes the info of the problem easier to communicate to others.

It reduced my errors greatly. The strategy made me be very careful in my work.

The WISE strategy if used properly will enable any student to solve any problem, assuming they have the right math background.

Table 5
Fall 1983 Questionnaire
Tidewater Community College

Statement	Responses	
	PHYS 201 n=52	PHYS 202 n=18
Did you find the WISE Strategy Helpful?		
Very Helpful	35	7
Somewhat Helpful	17	11
Not Helpful	0	0
If it were not required any more, would you use it?		
Yes	48	17
No	4	0
Should the WISE strategy be taught and required of future groups of Physics 201 students?		
Yes	50	12
No	2	6
Did you find the Problem Solving Session useful?		
Usually	33	10
Sometimes	12	7
Never	0	1
Describe how you usually worked in the Problem Solving Session.		
Pairs with outloud thinking	20	2
Pairs without outloud thinking	11	8
Individually	7	3
Group of three or more with outloud thinking	2	1
Group of three without outloud thinking	12	10

Table 5 (continued)

Statement	Responses	
	Phys 201	Phys 202
How would you like to work in the Problem Session?		
Pairs with out loud thinking	22	2
Pairs without out loud thinking	17	10
Individually	3	2
Groups of three with out loud thining	3	0
Groups of three without out loud thinking	11	8
Should the Problem Solving Session be continued next quarter?		
Yes	47	16
No	0	2
Did the General Skills test help you to feel more comfortable with thinking out loud and working in a group?		
It succeeded	29	-
Partial success	16	-
Waste of time	0	-
Did you find the use of outloud thinking helpful?		
Yes	32	6
No	12	5
Was the formula fact sheet helpful?		
Very helpful	49	14
Sometimes helpful	3	4
Never helpful	0	0

Table 5 (continued)

Statement	Responses	
	Phys 201	Phys 202
Should we use the formula fact sheet next quarter		
Yes	51	18
No	0	0
Should the sheet be preprinted or a group effort		
Preprinted	21	4
Group effort	26	13
Describe your feelings about your Problem Solving Abilities.		
More confident	29	11
Slightly more confident	18	1
About the same as before	3	4
Homework should be		
Turned in almost every day as it is now	35	16
Never turned in	2	1
Turned in less often	14	1
What is your attitude towards physics now		
I like it better than I thought I would	39	7
I feel the same as when I came in	7	8
I dislike it more than I did previously	0	2
How many times did you come to the office hours		
Often(7 or more times)	4	2
Sometimes(3-6 times)	11	6
Seldom	20	4
Never	15	6

Table 5 (continued)

Statement	Responses	
	Phys 201	Phys 202
Which steps of the lecture would you eliminate or spend less time on		
Discussion of physical principles with demonstrations	0	2
Discussion of formulas with formula fact sheet	0	0
Professor works problems on the board	0	2
Professor asks class members questions while solving problems	12	1
Students solve problems individually while professor checks work	8	2
Which steps of the lecture would like to see us spend more time on		
Discussion of physical principles with demonstrations	10	2
Discussion of formulas with formula fact sheet	15	4
Professor works problems on the board	19	6
Professor asks class members questions while solving problems	7	1
Students solve problems individually while professor checks work	15	5

The problem solving session was found usually helpful by thirty-three of forty-five, and no one found it not helpful. Overwhelming support was found for some kind of pair or group problem solving, with fifty-three of fifty-six preferring this to working by themselves. Thirty-two of forty-four stated that they felt out loud thinking was useful. All forty-seven responding to the question said that the problem solving session should be continued next quarter. Comments included:

Having each person talk out loud the steps of the problem brought up "dumb" mistakes that may not have been caught if working alone and gave insight into different ways to work a problem.

Good idea, because it serves two purposes: Students get better acquainted with each other and what one student sees in a problem another may not, and they can exchange viewpoints.

It helped us find our trouble areas under instructor's supervision.

The formula fact sheet was found very helpful by forty-nine of fifty-two students, and no one said that it should not be continued the next quarter. The students said:

It helped make things clearer on how and when and what equations to use and what to look for to find the equation.

I wish all teachers who teach courses in math, physics and electronics would adopt this method.

Made formulas easy to follow and apply to problems.

I was constantly referring back to them.

Most of the students (47 of 50) reported being at least slightly more confident in their problem solving ability, and that they felt better about physics than they thought they would.

I don't hate word problems anymore. That is a miracle.

I feel more confident than 10 weeks ago. I have learned to go slow and think.

The class has helped me to think in a more logical manner.

I feel better able to organize myself and define the problem, which in turn makes it easier to choose the proper equation.

The PHYS 202 class was also positive about the WISE strategy (7 very helpful, 11 somewhat helpful, 0 not helpful) and said they would all use it if it were not required (See Table 5). Most found the problem solving sessions useful (17 of 18) and liked the formula fact sheets (14 Very helpful, 4 Sometimes helpful).

However PHYS 202 seemed to be slightly more negative toward the system than the other groups. Several thought that the WISE strategy should not be required. One student stated that he felt that the WISE strategy should not be required, and then explained it by saying, "It works. If

you don't want to use it, that would seem to be a personal problem." On the whole, those who felt that it should not be required did say that it should be recommended.

Out loud thinking was also viewed more negatively by the 202 students than by the other groups. They said:

I did not like it because I found it hard to concentrate.

It was hard for me, but listening to someone else think out loud helped me to follow them.

It never helped. I think much better and perform much better when I think problems out inside.

However, they did feel that the problem solving sessions were helpful, and not all disliked the outloud thinking:

I could find where I was weak.

You could find someone else's mistake and they could find yours.

It was useful, because I tend to concentrate more on what I say.

There were also many 202 students who had a positive reaction to the WISE strategy:

I believe most people would just work the problems without understanding the processes involved (without the strategy).

I found using the strategy helpful. I don't completely understand physics, but what I do figure out is due to the WISE strategy.

I think each and every instructor should have this technique, if they already do not. Also it should be published as a guide or book for students and instructors. "The WISE Strategy Method of Physics."

Student Interviews

All students in PHYS 201 who had had college physics previously were interviewed to determine the reactions to this "new" technique of teaching.

One student who received a D in the course saw no difference in the approach of this instructor to teaching physics. He had not, however, used the strategy to any great extent on tests or on the homework. Another D student said that she had understood physics better in her previous attempt, but she had to work 40 to 50 hours a week this time and just did not have an opportunity to study.

Two students had had the author of this study in a class previous to the introduction of ESPI. One said that it was easier to follow the instructor this time. He felt that the course was better with the WISE strategy and that he could see the structure of problem solving better this time since each problem was always attacked in the same way. The other student stated that the approach was completely different and easier to understand. She said that the WISE strategy was the main thing that helped her through the course this time. The fact sheets and problem solving sessions were also cited as important factors. She said it was easier to follow the instructor's work and ask questions about problems now.

One student had taken physics at another college. She said she had spent many hours on homework in her previous work in physics, but without benefit, and without understanding what was happening. She said she was doing much better this time, and the main reason for that was the WISE strategy. She said that after three weeks of adjusting to it, it helped her understand the problems and helped her to focus on the physics instead of math manipulations. She said:

Before it was like big numbers chomping me up.... My first time through, I got the impression that, these are the equations and these are the numbers. Do it. Don't try to understand.... I don't panic on problems like I used to The WISE strategy gets me organized in the beginning. I do not think I could have done as well without it.

Student Assistant Reaction

The student assistants held problem solving sessions and graded homework papers on a regular basis during the quarter. The student assistants were above average students who were currently enrolled in PHYS 202 and were working with students in PHYS 201. In an interview one said,

It is much easier to grade homework papers when they use the strategy, because I know if they do a problem in a way I'm not used to seeing it done, and they use the strategy, then I can see what they've got and what they are looking for. Even though I'm not used to the way they are doing it, I can see that they are doing it right, because they have the formula down and they solve it symbolically and I'm not looking for where the next step is, because they've got it right there.

If they do use the strategy and make a mistake then it is really simple to show them where their mistake was, because you can find the missing piece. If they make a mistake and don't use the strategy, that's when I come to you (the instructor) and say, what did they do here. Do they have the right idea?

The other assistant said that when conducting tutoring sessions, the ones who followed the strategy would eventually understand the problems. She said that those who didn't use the strategy never seemed to be able to make sense of the problem. She mentioned that the tutoring sessions were most effective when she was able to take the students step-by-step through the strategy, by asking them questions.

Instructor Reaction

The instructor found that it was very easy to help students find mistakes and correctly understand what was happening in a problem if they used the strategy. In either tutoring or correcting tests, the strategy was found to simplify greatly the instructor's task of being able to understand the student's work and his reasoning.

The benefit of the strategy became very obvious when the instructor tried to help students who were not aware of the strategy. It was like becoming involved in a mass of numbers and missing steps.

Computer Analysis

Data were collected about student attitudes, prerequisite skills, use of the problem solving system, and grades, for students who took PHYS 201 in the Summer and Fall of 1983 at Tidewater Community College (a total of 83 students). These data were then analyzed by statistical means. This was done to supplement other information gained about the effectiveness of the system. The number of students involved in the sample is relatively small, but although the results therefore may not be conclusive, they might be able to indicate whether future investigation to verify the results is warranted. The Statistical Package for the Social Sciences (SPSS-X)⁷⁴ computer package was used to analyze the data. Many statistical tests were conducted, included Pearson's correlation coefficients, multiple regression, t-tests, frequencies, and chi-square analysis. Only those tests which show particular insight into the implementation of the system of ESPI were included in this study.

Variables

Standard measures of success were included in the data accumulated for each student. These included final exam scores, final grades, homework scores, and test averages. Information from the questionnaire was also included about

whether they liked the problem solving strategy and would use it, and about their attitudes to the formula fact sheet and the problem solving sessions.

Each student took a pre-math and a post-math test, a pre-physics and post-physics test, and a reasoning skills test. The pre and post tests were identical to each other. The use of the strategy on the test and homework was also recorded.

The students were asked to fill out a survey at the beginning of the course in which they indicated their previous math, physics, and science background. They also indicated their attitudes about physics and their levels of confidence in problem solving. Their willingness to learn a problem solving strategy was also assessed. Several other attitude questions were asked and a record of their absences was kept. (See Table 4 for a complete listing of variables.)

Class Profile

After the completion of the 1983 Fall Quarter all of the data were compiled and a class profile was developed on the basis of frequencies of responses. The class had little physics background. Only 39% of the students had had physics before. 88% got a zero or one out of seven on the physics pretest. Although 81% had completed a full year of college math, 70% got a 12 or less of 16 on the math pretest, and 26% got less than 6. 31% confessed to being

scared coming into the course, whereas 24% were confident. 28% considered their problem solving abilities weak and 14% well developed. After the completion of the course, most were satisfied with their experience. 71% felt that the problem solving strategy had been very helpful, with 29% saying that it had been somewhat helpful and no one saying that it had been not helpful. 93% said that they would now use the strategy even if it were not required. 77% felt that the problem solving session had been very helpful, 23% said that it had been somewhat helpful, and no one said that it had been not helpful. 94% felt that the formula fact sheet had been very helpful. 84% felt that their attitudes had improved and 64% felt that their problem solving confidence was improved.

The post-tests indicated improvement. On the post math test only 40% got less than 12 of 16 and one third of the students got 15 or 16. On the post-physics test over 50% of the students got 6 or 7 out of 7.

T-Test

T-tests⁷⁵ were run to investigate the significance of differences in the means between groups in the class. A t-ratio is,⁷⁶

the ratio of the variability between two groups of measurements... to the variability expected within the population(s) from which the groups were selected. The t-ratio provides a method by which measured differences between groups may be compared to those expected as a result of chance.

The class was divided into groups based upon either their pre-math scores, previous physics experience, use of the problem solving strategy, or preference for out loud thinking. (See Table 6.) It was decided that the null hypothesis, that there is no significant difference between means, could be rejected if the probability of insignificance was less than or equal to 0.01. (This would indicate that there was less than one chance in one hundred that the differences in means could have been caused by sampling error, hence the differences in means would not be insignificant.) The magnitude of the t-ratio necessary to show significance depends on the number of independent variables (also known as degrees of freedom) involved in the calculation.

Physics experience was found to be not very significant in affecting the final grade. Out loud thinking appeared to be used mostly by those with poorer grades. When the class was divided into groups based on their pre-math scores (11 and above out of 16 being placed in one group and below 11 in the other), those in the upper pre-math group had final grades that were nine points higher on the average. Those who used the problem solving strategy more than 70% of the time on tests and homework had final grades that averaged 13% higher. Those who used the strategy less than 35% of the time had final grades 17% lower than those who used it.

Table 6

T-Tests
Summer and Fall 1983-Phys201 and 202

Grouping	# of students	Final Grade	T-Ratio	Probability ^a	df ^b
WISE ^c ≥ 140	45	87.4	5.110	0.000	79
WISE < 140	36	74.6			
WISE ≥ 70	67	84.8	4.390	0.001	79
WISE < 70	14	67.1			
OUTLD ^d ≥ 1	29	76.6	-3.08	0.004	41
OUTLD < 1	14	88.1			
PRMA ^e ≥ 11	43	85.6	3.27	0.002	77
PRMA < 11	36	76.9			
PHYS ^f ≥ 1	31	84.4	1.6	0.113	77
PHYS < 1	48	80.3			

^a Probability that difference between means is due to sampling error.

^b Degrees of freedom for unrelated T-test = $n_1 + n_2 - 2$
for related T-test = $n - 1$

^c WISE = % use of strategy on homework plus % use on tests

^d OUTLD 0 Disliked outloud thinking 1 Liked it

^e PRMA Total of 16 points possible; POMA test identical

^f PHYS 0 No previous physics 1 HS or College phys before

Table 6 (continued)

	Test Score	T-Ratio	Probability	dF
PRMA	9.6	-8.7	0.000	76
POMA	12.5			
PRPHY ^g	.6	-25.4	0.000	77
POPHY	5.3			

^g PRPHY Total of 7 points possible; POPHY test identical.

The t-tests indicated that the jumps on the physics and math pre/post tests were significant. The physics test jumped from .58 to 5.3 out of 7, while the math test average jumped from 9.6 to 12.4 out of 16.

Pearson Correlation Coefficients

Pearson's correlation coefficients⁷⁷ indicate "a mathematical measure of the degree of relatedness between two common sets of measurements."⁷⁸ A correlation of +1 indicates that if a graph was produced of one variable versus the other, all of the points on the graph would lie on the same straight line with positive slope. A coefficient of -1 indicates that the slope of the line is negative. A zero correlation indicates that there is no relationship between variables. A high correlation does not necessarily mean that there is a causal relationship between variables, because each of the two variables may be a function of a third variable. As with t-ratios, the value of correlation required for significance depends on the sample size.

Each item of data was paired with every other item to investigate correlations (see Table 7). A list of correlations of the final grade with the other variables indicates that the pre-math test, reasoning tests, homework and the use of the strategy were all highly related to the final grade. It also appears that the final grade had

Table 7

Pearson's Correlation Coefficients
Summer and Fall 1983-Phys 201 and 202

Comparison	Correlation	n	Probability ^a
Final grade with premath FGRA PRMA	0.5372	79	0.000
Final grade with reasoning test FGRA REAS	0.4926	71	0.000
Final grade with homework % FGRA HW	0.6941	82	0.000
Final grade with use of strategy FGRA GPSSHW	0.5073	81	0.000
Final grade with math background FGRA MATH	-0.0803	78	0.242
Final grade with previous science FGRA SCIE	-0.0527	68	0.335
Final grade with previous physics FGRA PHYS	0.1647	79	0.073
Final grade with outloud thinking FGRA OUTLD	-0.3777	43	0.006
Use of strategy with liking it GPSSHW GPSSOK	0.4570	68	0.000
Use of strategy with % homework GPSSHW HW	0.6417	81	0.000
Test strategy with HW strategy GPSST GPSSHW	0.5940	82	0.000
Premath with liking the strategy PRMA GPSSOK	0.0176	65	0.445
Premath with non-required use PRMA USE	0.1203	64	0.172

^a Probability that the correlation is due to sampling error

little to do with how many math and science courses the student had taken and whether or not he had taken a physics course before. There was a negative correlation between the final grade and the student's preference for out loud thinking, which perhaps indicates that those who had developed problem solving skills do not feel that slowing down or working with others is beneficial to them.

It appears that those who used the strategy also did their homework and enjoyed using the strategy. If they used it on their homework, they also seemed to use it on tests. Pre-math scores did not seem to give much indication of who enjoyed the strategy or found it useful.

Variable Means within Grade Ranges

As previously mentioned, several factors seem to have had an influence on the final grade: prerequisite skills and attitudes, use of the strategy and willingness to complete the homework. To investigate such influence the class was split into groups on the basis of final grades to see how each of these groups did with respect to the above mentioned variables. Each of the variables seem to show considerable variance amongst the chosen groups (see Table 8). Types of questions that still need investigation include whether doing the homework helped to develop reasoning and physics skills, or whether those with already developed skills were the ones to do the homework.

Table 8

Average Scores within Grade Ranges
1983 Summer and Fall-Phys 201 and 202^a

Variable	Average Score within Grade Range		
	0-69	70-84	85-100

Factors that varied appreciably between ranges

Premath score (PRMA)	4.9	9.5	11.4
Reasoning test score (REAS)	7.7	12.7	14.0
% Strategy on homework (GPSSHW)	42.0	58.0	73.3
% Strategy on tests (GPSST)	36.0	62.0	91.5
% homework completed (HW)	54.0	69.0	88.5
Problem Solving Confidence (PS)	1.3	1.8	2.1

Factors that showed little variance

Previous math courses (MATH)	2.9	2.7	2.7
Willingness to learn strategy (WS)	2.9	2.6	2.6
Liking the strategy (GPSSOK)	1.6	1.7	1.7
Non-required use of strategy (USE)	1.0	.9	.9
Liking the problem solving (PSSOK)	1.6	1.8	1.8
Liking the formulafact sheet (FFSOK)	1.9	2.0	1.9
Attitude towards physics (PATT)	2.9	2.9	2.8

^a n is greater than 60 and less than 85 for all factors.

Indicators of Failure

Those students indicating on the questionnaire that they had weak problem solving skills were less successful in the course (see Table 8). In order to follow up on this, a comparison of individual final grades was made. From this comparison of final grades it was determined that one third of those confessing weak problem solving skills got D's and F's in the course, whereas no one who reported having developed problem solving skills got a D or an F. Those failing the course had a maximum of 4 out of 16 on the math pre-test. In fact, of all students receiving 5 or less on the math pre-test, 7 of 14 got D's and F's, compared to a class total of 10 out of 82. This seems to indicate that minimal math skills and confidence are essential to avoid failure in the course.

Analysis of Variance and Covariance

Analysis of variance is a procedure used to see if there is a statistically significant difference between means of two or more variables. Analysis of covariance is a procedure to statistically control an uncontrolled variable in this process. The variable to be controlled or "covariate" and the main effect or "variate" must both exhibit large F-ratios⁷⁹ (i.e. the probability of insignificance must be less than 0.01) if the null hypothesis is to be rejected. If the covariate is not

significant (i.e. probability is much greater than 0.01) then it is possible that a great deal of the variation in the means can be attributed to the uncontrolled variable.⁸⁰

This study was to determine whether the final grade was a function of the use of the strategy. In order to obtain a valid test, the influence of previously developed math skills had to be eliminated. To accomplish the latter, the pre-math test scores were used as a covariate and the use of the WISE strategy was designated as the main effect upon the final grade.

The F value of the main effect was 7.324 with a probability of insignificance of less than .001. The pre-math covariate had an F value of 41.23 which was also had a probability of insignificance of less than .001. This seems to indicate very strongly that the use of the strategy did have a relationship to the final grade, independent of the math skills of the students. Unfortunately, it was not possible to conclusively determine that there were no other effective covariates.

Chi-Square Analysis

In an effort to determine the relationship between using the strategy, premath tests scores, homework scores, and the final grade, a chi-square analysis was performed (see Table 9). Chi-square⁸¹ is⁸²

a mathematical distribution presented in table form that can be used to determine whether a set of observed frequencies differs sufficiently from a set of hypothesized expected frequencies that the conclusion can be made that the difference is not due to chance or random selection of the sample being studied.

The class was divided approximately in half relative to the pre-math scores. The upper half achieved scores greater than or equal to 11. Once again it was decided that the null hypothesis would be rejected if the probability of insignificance, p , of the chi-square value was less than or equal to 0.01. When examining the upper half, it is apparent that those who had math skills and used the strategy did very well on the final grade. Those who used the strategy less than 35% of the time did very poorly in the class even though they had high math skills. Those with poor math skills were also able to do well with the use of the strategy, but not as dramatically as those with better math skills. In the middle ground (use of the strategy between 35 and 70% of the time), those with high math skills were able to do well while those without the math skills did not do well. This may indicate that those with good math skills were benefitted by some exposure to the strategy, while those with poor math experience required a greater involvement with the strategy.

Table 9

Chi Square Analysis
Summer and Fall-Phys 201 and 202

		Matrix	Chi square p^a	
I Final Grade vs Use of the Strategy (controlling for pre-math scores)				
A. Pre-math scores <11			11.64	0.003
		WISE ^b Strategy		
		W<70	70≤W<140	W≥140
Final Grade	G<80	8	6	3
	G≥80	2	3	14
B. Pre-math scores ≥11			11.48	0.003
		WISE Strategy		
		W<70	70≤W<140	W≥140
Final Grade	G<80	3	2	2
	G≥80	1	9	25

^a Probability that the difference between the observed and expected frequencies is due to sampling error

^b W=% use of strategy on homework plus % use on tests

Table 9 (continued)

		Matrix	Chi Square	p
II Final Grade vs Use of the Strategy			23.25	0.000
WISE Strategy				
		W<70	70≤W<140	W≥140
Final Grade	G<70	6	3	2
	70≤G<85	8	11	15
	G≥85	0	8	28
III Homework vs Final Grade (controlling for use of the strategy)				
A. W<140			7.42	0.006
Homework %				
		H<70	H≥70	
Final Grade	G<80	14	3	
	G≥80	6	13	
B. W≥140			6.54	0.01
Homework %				
		H<70	H≥70	
Final Grade	G<80	3	3	
	G≥80	2	37	

When the entire class was kept together in comparison and the grades were split into three categories (less than 70, greater than 85, and in between), the data indicated that those who were involved with the strategy did extremely well in the course. Of those who did not use the strategy at least 35% of the time, no one scored higher than 85%. A moderate use of the strategy improved the grade somewhat, but not as dramatically as a heavy use.

Finally, a comparison was made between those who did or did not do homework and their final grade. This was once again done for two groups, those who did and did not use the strategy. If the strategy was not used, the grade seemed to rely pretty heavily on the homework. Little work brought no reward and vice versa. But, if the strategy was used, almost everyone who did the work got a high grade. If they did not do the homework, there was a 50-50 chance of a high grade.

Retention of Students

In an attempt to factor out the influence of the instructor on the overall program, a study of retention of students was made. The author of this project taught all sections of physics using the ESPI system. The author had also taught at the same institution for eight years prior to the introduction of the system. Records of the three quarters in which ESPI was taught were compared to the

previous 10 quarters that introductory physics had been taught by the author in a regular session. Fall of 1982 was not included in this study, because the courses taught that quarter used a modified version of ESPI and therefore did not really fit into either of the two indicated categories. A student was counted as being retained if he took the first test of the quarter and completed the quarter with a grade of D or better.

The three quarters in which the ESPI program was implemented had retention rates of 88,86, and 85%. The previous 10 quarters had rates of 61,77,74,65,69,65,72,79,74,60 (in chronological order). A t-test was performed to see if the average retention rate(86%) of the ESPI sections was significantly higher than the average retention rate(70%) of the traditionally taught groups. The t-ratio obtained of 7.33, has a probability of insignificance far below 0.01.

It is apparent that some appreciable differences can exist in a mode of presentation that includes a strategy. However, simply teaching with a strategy will not guarantee success. In the Fall of 1982 the class was taught with a modified form of ESPI that lacked many of the essential features of the present program. The retention rate for that quarter was only 69%.

CHAPTER SIX

Summary

The Explicitly structured Physics Instruction program was positively received by both instructors and students, especially in its final versions. Statistical measures as well as qualitative data seem to indicate that the program was successful. But, what were the main elements that produced the principle positive results and what should be avoided if the program is to be implemented elsewhere? In this chapter these questions as well as possible directions for future research will be explored.

Main Elements

Probably the most important feature of ESPI is the WISE strategy. It was designed to be easy to learn and use, and yet be meaningful. But, the strategy cannot stand by itself. It should be supported by the formula fact sheet and by the feedback and practice such as produced in the problem solving session.

Classroom instruction should center on the principles of physics and their practical applications, as well as on problem solving skills. All of these features are crucial

to the system, but of equal importance is the attitude of the instructor. He must be enthusiastic about not only the physics itself, but also the system. The system must be continually used and promoted.

Pitfalls and Cautions.

Detailed steps necessary to implement the ESPI program are contained in Appendix C, but several important points need to be emphasized. Difficulties will arise if the instructor attempts to adopt any system that is too foreign to his style. In the 1982 Fall Quarter this was attempted by the author of this study with disastrous results. That attempt to first introduce the strategy was also rejected, because the strategy was too lengthy. The students felt they were being required to spend so much time to learn a cumbersome strategy that they had no time to learn the physics.

Out loud thinking is another feature which has great promise, but it is hard to implement. As indicated by the statistics earlier in this study, many students said they thought that out loud thinking was good for them, and they liked doing it. Yet, whenever the instructor did not insist that it be used, many student groups would slip into old habits of individual work, with perhaps some comparison of answers. Even when the use of out loud thinking was

required, it was difficult for the instructor to monitor each group often enough to insure that they were thinking out loud.

In order to insure that all students give the strategy a chance to work, it must be required. The instructor will receive some criticism for requiring that everyone use it, but in the long run, even those who have fairly well developed problem solving strategies will benefit by compliance. It makes even the brighter students slow down and think about what is happening, and increases their accuracy. Most of the students commented that if the strategy had not been required, that they would not have used it. However, not much incentive is needed to get them to accept the challenge of trying the strategy.

Formula fact sheets also play an important role in the program, but if they are simply handed out to the students, they may be treated as just another handout. It is best to develop them in class.

Implications

Both the mode of this research and its results indicate directions for future research. The author found that individual student interviews and questionnaires influenced him and the direction of the study much more than the statistics. Students were very honest in their evaluation

of the program. The statistics did not reveal much that was not already known; they simply added confirmation to that which was discovered through observation and discussion with the students. This "ethnographic" style of research, which emphasizes the overall impact of the program on individual students, should become more prevalent.

ESPI was adapted from basic educational and psychological principles as applied to the reality of the classroom. Much was discovered that looked good on paper but simply did not work in the classroom. Educational research should be conducted by those who are both experienced in teaching and well versed in their subject matter. They must also be willing to investigate the theoretical foundation upon which they want to build. Knowledge of sophisticated research techniques is not as important as careful observation, attention to detail, a knowledge of the structure of the material, and a sensitivity to student needs. There are so many factors involved that trying to eliminate all but one, which seems to be the prevalent practice in educational research, is hardly ever worth attempting.

This study indicates that the use of a strategy with auxiliary aids can prove extremely helpful to students. In this study the strategy was taught briefly and drilled extensively. Perhaps future research could focus on better

ways of teaching the strategy and helping students to learn to use it effectively. One of the main unanswered questions of this study is whether those students who used the strategy and did well, did not already have the problem solving skills which would allow them to attack a problem systematically.

Students with very poor math skills seem to be unable to do well even if they use the strategy. Exactly what incoming level of math skill is required for reasonable success needs to be investigated further.

Another problem that became apparent during the study was that of student misconception and difficulties with abstract thought. Although the system was set up to address these issues concretely, it was discovered that many concepts such as torque or pressure were by their very nature difficult to teach. These topics were more formal than ideas such as heat or distance. Other topics such as the difference between mass and weight are difficult to teach, because students come into the course with definite preset ideas about them. Research into problems of misconception and abstract concepts needs to be done to complement work done with the strategy.

The WISE strategy is easily adaptable to structured areas of physics such as mechanics. Work needs to be done to see how to use the strategy most effectively with other less structured areas.

Out loud thinking is another area of concern. The effectiveness of this concept is fairly well established, but teaching it and encouraging its use in the classroom is quite a task. Much more classroom experience is needed to document exactly how and with whom this concept can best be applied

Conclusion

This study indicates that a well integrated program built around the use of a problem solving strategy is perceived by students and instructors as improving communication, increasing accuracy, and promoting organization. The almost total absence of negative feedback from the students on the final versions of the ESPI program along with positive experiences of the instructor indicates that such a program has great promise. Students feel that they understand the physics better and are not simply plugging numbers into equations. The goal of most physics teachers is not to make miniature physicists of their non-physics majors, but to give such students a feeling for how

the physical world operates and to teach problem solving skills. The principle strength of ESPI is that its approach tackles both of these problems in a very direct way.

The ESPI program offers benefits to most of those involved with it. It helps instructors monitor student progress with problem solving and improves their ability to communicate with students. The less prepared students find that they are able to begin to organize or structure their problem solving abilities. The students who already have developed some problem solving skills are able to fine tune those skills. Everyone involved with ESPI has found the process to be a positive way to emphasize the physics and put less emphasis on number crunching. It was found that if a student had sufficient math skills and was willing to do his homework, his chances for success were definitely enhanced if he used the WISE strategy for problem solving.

References

- 1 Benjamin S. Bloom and Lois J. Broder, Problem Solving Processes of College Students (University of Chicago Press, Chicago, Illinois, 1950), p. 3.
- 2 Herbert Linn, *The Physics Teacher* 20(3), 151(1982).
- X 3 Jack Lochhead and John Clement, in Cognitive Process Instruction, edited by Jack Lochhead and John Clement (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p. iii.
- 4 Robert G. Fuller, Robert Karplus and Anton E. Lawson, *Physics Today* 30(2), 23(1977).
- 5 Eugene L. Chiapetta, *Science Education* 60(2), 253(1976).
- 6 Robert G. Fuller, *Physics Today*, 30(2), 43(1982).
- 7 David Hestenes, *The Physics Teacher* 17(4), 235(1979).
- 8 Francis P. Collea, Robert G. Fuller, Robert Karplus, Lester G. Paldy and John Renner, Workshop on Physics Teaching and the Development of Reasoning (American Association of Physics Teachers, Stoney Brook, N.Y., 1975), p. 8-4.
- 9 Anton E. Lawson and John W. Renner, *Today's Education* 1976, 38.
- 10 See reference 8, p. 6-8.
- 11 See reference 7.
- 12 Richard E. Mayer, Thinking and Problem Solving (Scott Foresman and Company, Glenview, Illinois, 1977), pp. 140-141.
- 13 See reference 7.
- 14 Jill Larkin, John McDermott, Dorothea P. Simon, Herbert A. Simon, *Science* 208, 1335(1980).
- 15 See reference 14.
- 16 Frederick Reif, *The Physics Teacher* 19(5), 310(1981).
- 17 Herbert Simon and Allen Newell, *American Scientist* 52, 281(1964).
- 18 Michelene T. H. Chi and others, ERIC Document ED 215 899,

p. 23.

19 Jill Larkin, *American Journal of Physics* 49(6), 534(1981); ERIC Document ED 178 264, p. 16.

20 Jill Larkin, in Cognitive Process Instruction, edited by Jack Lochhead and John Clement (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p. 236.

21 V. A. Krutetskii, The Psychology of Mathematical Abilities in Schoolchildren (University of Chicago Press, Chicago, Illinois, 1976), p. 95.

22 Mary Grace Kantgowski, *Journal for Research in Mathematics Education* 1977, 163.

23 Arthur Whimbey, *Phi Delta Kappan* 59(4), 255(1977).

24 Arthur Whimbey and Jack Lochhead, Problem Solving and Comprehension, 2nd Ed. (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p. 25.

25 See reference 24, pp. 28-29.

26 See reference 1, p. 27.

27 Jerry Stonewater, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (American Society for Engineering Education, Washington D.C., 1980), pp. 161-162.

28 Jack Lochhead, *Cognitive Development Project Report*, University of Massachusetts, Amherst, 1980.

29 See reference 16.

30 Bat-Sheva Eylon, Ph.d. Dissertation, University of California at Berkeley, 1979.

31 See reference 18, pp. 110-113.

32 Frederick Byron and John Clement, ERIC Document ED 214 755, pp. 1-21.

33 David E. Towbridge and Lillian C. McDermott, *American Journal of Physics* 48(12), 1020(1980).

34 Norman H. Fredette and John J. Clement, *Journal of College Science Teaching* 1981, 284.

- 35 F. Reif, Jill H. Larkin and George C. Brackett, *American Journal of Physics* 44(3), 212(1976).
- 36 Alvin Hudson and Rex Nelson, University Physics (Harcourt, Brace and Jovanovich, New York, N.Y., 1982), p. 94.
- 37 Herbert A. Simon, in Problem Solving and Education: Issues in Teaching and Research, edited by D. T. Tuma and F. Reif (Lawrence Erlbaum Associates, Hillsdale, N.J., 1980), p. 92.
- 38 Arnold Arons, *The Physics Teacher* 19(3), 166(1981).
- 39 Donald R. Woods, Cameron M. Crowe, Terrence Hoffman and Joseph D. Wright, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (ASEE, Washington D.C., 1980), pp. 42-43.
- 40 Alan H. Schoenfeld, in Cognitive Process Instruction, edited by Jack Lochhead and John Clement (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p. 315.
- 41 See reference 39, p. 40.
- 42 Alan Schoenfeld, *Journal for Research in Mathematics Education* 1979, 173; Cognitive Process Instruction, pp. 315-316.
- 43 See reference 35.
- 44 D. R. Woods, *Problem Solving News* 14, pp. 12-13.
- 45 See reference 35.
- 46 J. L. Aubel, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (ASEE, Washington D.C., 1980), pp.76-77.
- 47 C. T. C. W. Mettes, A. Pilot, H. J. Roossink, H. Kramers-Pals, *Journal of Chemical Education* 58(1), 882(1981).
- 48 See reference 2.
- 49 D. R. Woods, *PS News* 14, p. 14.
- 50 D. L. Marples, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (ASEE, Washington D.C. 1980), pp. 111-112.

- 51 See reference 18, p. 21.
- 52 H. Kramers-Pals, J. Lambrechts and P. J. Wolff, *Journal of Chemical Education* 59(6), 509(1982).
- 53 Alan Schoenfeld, *Journal for Research in Mathematics Education* 1979, 173.
- 54 John F. Lucas, *Journal for Research in Mathematics Education* 1974, 36.
- 55 D. R. Woods, *PS News* 16, pp. 9-10.
- 56 See reference 35.
- 57 Dale Ewen and LeRoy Heaton, Physics for Technical Education (Prentice Hall Inc., Englewood Cliffs, N.J., 1981)
- 58 Jesse David Wall, Introductory Physics: A Problem Solving Approach (D. C. Heath and Company, Lexington, Mass., 1978), p. xi.
- 59 John Ward, Solving Physics Problems (Benjamin Cummings, Menlo Park, Calif., 1983).
- 60 See reference 7.
- 61 Jeremy Kilpatrick, ERIC Document ED 156 446, pp. 14-15.
- 62 Jack Lochhead, in Cognitive Process Instruction, edited by Jack Lochhead and John Clement (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p.4.
- 63 Elliot W. Eisner, *Education Forum* XLIV(3), 373(1980).
- 64 Malcolm Parlett and David Hamilton, in Introduction to Illuminative Evaluation: Studies in Higher Education, edited by Malcolm Parlett and Gary Dearden (Pacific Soundings Press, Cardiff-by-the-Sea, Calif., 1977), p. 11.
- 65 *Websters New Collegiate Dictionary* (G and C Merriam Company, Springfield, Mass., 1977), p. 404.
- 66 See reference 9.
- 67 See reference 50, pp. 111-112.
- 68 Jill Larkin, *American Journal of Physics* 49(6), 534(1981).

69 See reference 39, pp. 43.

70 See reference 24, pp. 33-308.

71 See reference 64, pp. 9-29.

72 See reference 61, pp. 14-15.

73 See reference 24.

74 SPSS X Users Guide (McGraw Hill, New York, N.Y., 1983).

75 $t = (M_1 - M_2) / SED$ M_1 and M_2 are means of two groups of measurements. The standard error of the difference (SED) is the square root of the sum of squares of standard errors of the mean. The standard error of the mean is the standard deviation divided by the square root of the sample size.

76 Armand J. Galfo, *Interpreting Educational Research* (Wm. C. Brown Company, Dubuque, Iowa, 1975), p. 377.

77 $r = (\sum xy) / NS_x S_y$ where xy is the product of deviations of x and y measurements from their respective means, N is the number of pairs of measurements, and S_x and S_y are the standard deviations of the x and y group scores.

78 See reference 76, p. 374.

79 F-ratios have the same purpose as t-ratios, except they may be used in the comparison of two or more groups.

80 George A. Ferguson, *Statistical Analysis in Psychology and Education*, 4th ed. (McGraw-Hill Book Company, New York, N. Y., 1976), pp. 347-355.

81 Chi-square = $(O_f - E_f)^2 / E_f$ where O_f is the observed frequency and E_f is the expected frequency.

82 See reference 76, p. 373.

Appendices

Appendix A

Appendix A

PROBLEM SOLVING STRATEGIES
FROM THE LITERATURECoherence Guidelines^a

1. A picture of the physical situation (before and after if appropriate).
2. Identification in words or by reference to the picture of all symbols used.
3. A one line description of what is happening in the problem.
4. Identification of all basic equations used (i.e. any equation that does not result from a mathematical manipulation), and a line of justification for each. These basic equations are drawn from a list of broadly applicable equations in order to discourage argument from special cases.
5. A solution worked through with symbols, resulting in a simplified, symbolic answer with numbers substituted only at the end.
6. A check of the answer for correct units.
7. A check to see that, for those values of the symbol for which the answer is obvious or known, the solution gives the expected results.

^a Herbert Linn, *The Physics Teacher* 20(3), 151(1982).

How to Solve It^a

FIRST UNDERSTANDING THE PROBLEM

What is the unknown? What are the data?
What is the condition?

Is it possible to satisfy the condition?

Draw a figure. Introduce suitable notation.

Separate the various parts of the condition.

SECOND DEVISING A PLAN

Have you seen it before?

Do you know a related problem?

Look at the unknown, and try to think of a familiar problem having the same or similar unknown.

Here is a problem related to yours and solved before. Could you use it?

Could you restate the problem?

If you cannot solve the proposed problem, try to solve first some related problem.

Did you use all the data?

THIRD CARRYING OUT THE PLAN

Carrying out your plan of the solution, check each step. Can you see clearly that the step is correct.

FOURTH LOOKING BACK

Can you check the result? Can you check the argument?

Can you derive the result differently?

Can you use the result, or the method for some other problem.

^a G. Polya, How to Solve It, (Princeton University Press, Princeton, N.J., 1948).

Systematic approach to Problem Solving^a

1. READ THE PROBLEM CAREFULLY
2. MAKE A SCHEME
 - a. Draw the system. Draw characteristics of system boundaries.
 - b. Write down characteristics of system boundaries.
 - c. Write down characteristics of the states.
 - d. Write down characteristics of the processes.
 - e. Write down characteristics of other data.
 - f. Write down characteristics of contents of system.
 - g. If necessary plot a graph.
- d h. Write down characteristics of the unknown (math formulation).
 - i. Estimate answer (sign, magnitude, dimension)
3. IS IT A STANDARD PROBLEM? If yes go to 8. If no go to 4.
4. WRITE DOWN POSSIBLY USEFUL KEY RELATIONS PLUS CONDITIONS FOR VALIDITY, BY LOOKING FROM THE UNKNOWN AND/OR DATA AT,
 - a. Charts with key relations
 - b. Charts with non-thermo relations^b
 - c. Relations which follow directly from data
5. CHECK RELATIONS FOR THEIR VALIDITY IN THIS PROBLEM SITUATION
6. CONVERSION TO STANDARD PROBLEM
 - a. Write down the unknown using the appropriate symbols
 - b. Write down a valid key relation in which the unknown occurs (from list at 4)

^a C.T.C.W. Mettes, A. Pilot, H.J. Roossink, H. Kramers-Pals, Journal of Chemical Education 58(1), 882(1981).

^b This chart referred specifically to thermodynamics problems

SYSTEMATIC APPROACH TO PROBLEM SOLVING (continued)

- c. Replace general quantities by specific quantities in this relation.
 - d. Check which specific quantities are still unknown.
 - e. Write them down as new unknowns.
 - f. When all specific quantities are known, substitute them by numerical values and dimensions.
7. IF NOT SOLUBLE:
- a. Check whether there are still key relations lacking
 - b. Introduce alternate processes, or
 - c. Separate variables, or
 - d. Make assumptions in connection with validity.
8. EXECUTE ROUTINE OPERATIONS, HAVE COMPUTATION AND ANSWER WELL-ORDERED
9. CHECK ANSWER AGAINST ESTIMATION OF THE UNKNOWN
- a. Sign
 - b. Magnitude
 - c. Dimension
10. CHECK WHETHER YOU MADE MISTAKES ON THE
- a. estimation
 - b. setting up the scheme
 - c. writing down key relations
 - d. conversion to standard problem
 - e. executing routine operations
- Correct, then procede to 9
11. All PROBLEMS SOLVED? If yes, then finished. If no, then
- a. fill in answer in the scheme
 - b. see whether same procedure is again applicable

Problem Solving Strategy^a

DEFINE	Identify the actual problem
THINK ABOUT IT	What are the attributes Identify area of knowledge Collect information Flowchart solution
PLAN	Think up alternative plans Translate
CARRY OUT PLAN	Solve
LOOK BACK	Check reasonableness and math Check criteria and constraints Study related problems Identify applications in engineering, everyday behavior ... Identify and memorize order-of-magnitude numbers Develop successive approximation strategies Study problem-solving skills learned Communicate results

^a Lois Greenfield, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (ASEE, Washington, D.C., 1980), p. 89, citing Donald Woods.

Problem Solving Method^a1. Read the Problem Carefully.

- a. The first time read it through from beginning to end to get a general overview.
- b. Next, read through a second time slowly and completely, thinking ahead to the following steps.

2. Make a Sketch.

Make a sketch whenever possible. Often seeing a sketch will show if you have forgotten important parts of the problem.

3. Write down all the Given Information.

This is necessary to get all essential facts in mind before looking for the solution.

4. Write down the Unknown or Quantity asked for in the Problem.

Many students have difficulty solving problems because they do not know what they are looking for and solve for the wrong quantity.

^a Dale Ewen and LeRoy Heaton, Physics for Technical Education (Prentice Hall Inc., Englewood Cliffs, N.J., 1981) pp. 44-45.

Problem Solving Method (continued)

5. Write down the Basic Equation or Formula that relates the Known and Unknown Quantities.

We find the basic formula or equation to use by studying what we are given and what we are asked to find. then look for a formula or equation that relates these quantities.

6. Find a Working Equation by Solving the Basic Equation or Formula for the Unknown Quantity.

7. Substitute the Data in the Working Equation, including the Appropriate Units.

It is important that you carry the units all the way through the problem as a check that you have solved the problem correctly.

8. Perform the Indicated Operations and Work out the Solution

Although this will be your final written step in the solution, in every case you should ask yourself, "Is my answer reasonable?" Here and on the job you will be dealing with practical problems. A quick estimate will many times reveal an error in your calculations.

Problem Solving Strategy^a

- I SETUP --- Translation task from English to symbols and pictures
 - A List given quantities with appropriate, meaningful symbols.
 - B Assign reasonable symbols to the requested unknowns.
 - C Sketch a picture for each unique time implied in the problem and label it with the symbols from A and B.

- II ANALYSIS-PHYSICS ---The objective here is to find sufficient independent equations to solve for the desired unknowns.
 - A Consider constraints-Use them to write equations
 - B Consider definitions of knowns and unknowns
 - C Consider conservation laws
 1. Choose a clearly defined system.
 2. Choose an appropriate time interval over which the conservation law is valid.
 3. Choose a convenient coordinate system for each moving object.
 4. Write the conservation law.
 - D Consider Kinematics equations

^a J. L. Aubel, in Teaching of Elementary Problem Solving in Engineering and Related Fields, edited by James L. Lubkin (ASEE, Washington D.C., 1980), pp. 76-77.

Problem Solving Strategy (continued)

E Consider Newton's second law

1. Isolate an object so that its mass and its vector acceleration are clearly definable.
2. Draw a free-body diagram for that object
3. Choose a coordinate system with the positive x axis along the direction of the acceleration of the object.
4. Write Newton's second law in scalar form for each significant axis.
5. If there are other moving masses in the problem which affect the answers, repeat E for those masses

F Consider other physics relations

III Analysis-Math

A Obtain an algebraic solution

B Test the algebraic solution for reasonableness

1. Check for correct physical dimensions
2. Check for the expected behavior in intuitively obvious situations. Do the relations seem plausible.

C Plug in numbers

D Check your answer for physical reasonableness and appropriate units

Steps in the Derivation of Equations in Physics Problems^a

1. Identify the known and unknown quantities from what's given.
2. Translate what's given and wanted into symbols, a sketch.
3. Recognize the underlying laws that apply (major premises).
4. Identify the relevant definitions (minor premises).
5. Substitute the defining equations into the law or laws.
6. Solve the equation using symbols not numbers.

Example

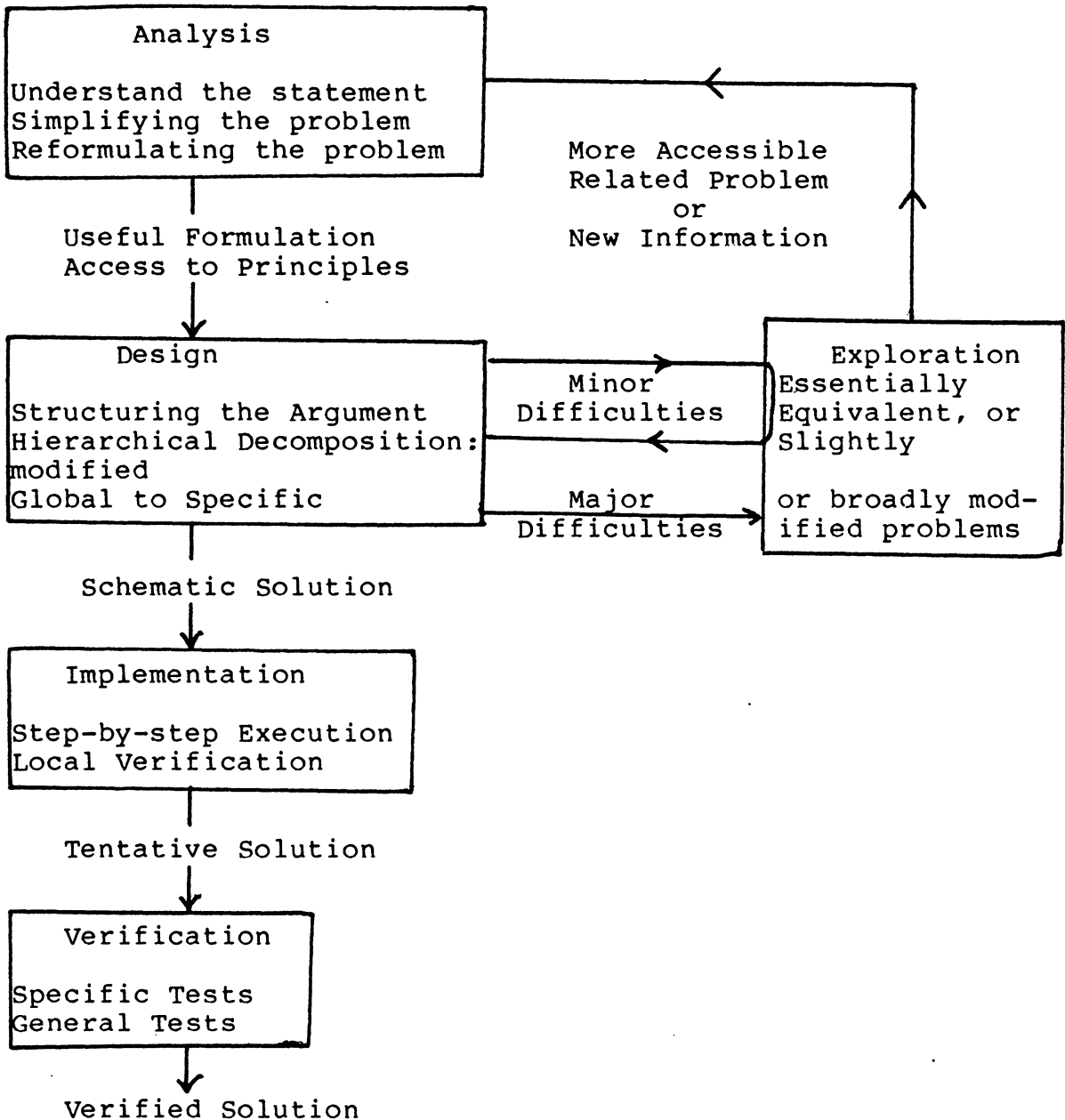
A spherically symmetric body has a mass m , a radius r , and a moment of inertia about the center of $I = kmr^2$. It starts from rest at a height h above the bottom of a round bowl of radius R , where $R > r$, and rolls without slipping. From energy considerations, find the velocity, v_b , of this body at the bottom of the bowl, point b . Obtain v_b in terms of h, k , and whatever else.

1. State "find the velocity v_b "
2. State $v_b = ?$
3. State $E_1 = E_2$ or $PE_1 + KE_1 = PE_2 + KE_2$
4. State $PE_1 = mgh$, $PE_2 = 0$, $KE_1 = 0$, $KE_2 = 1/2 mv_b^2 + 1/2 I\omega^2$
 $v_b = r\omega$, $1/2 I\omega^2 = 1/2 kmv_b^2$
5. State $mgh + 0 = 0 + 1/2 mv_b^2 + 1/2 kmv_b^2$
6. State $v_b^2 = 2gh/(1+k)$

^a Richard Hohly, ERIC Document ED 180 776.

Problem Solving Strategy^a

Given Problem



^a Alan Schoenfeld, in *Cognitive Process Instruction*, edited by Jack Lochhead and John Clement (Franklin Institute Press, Philadelphia, Pennsylvania, 1980), p. 322.

Appendix B

Appendix B

DOCUMENTS: DEVELOPMENT OF ESPI

General Heuristic

I UNDERSTANDING THE PROBLEM

A Read the entire problem and restate in an understandable form. (Restate)

B Physical Sketch

C Diagram involving the physics of the problem (i.e. vector diagram, velocities and displacements on a labeled coordinate system, etc.)

D Identify known, unknowns, constraints, and conditions
Define symbols and check units

E Estimate the answer (units, magnitude, sign)

II PLAN OF ATTACK

A Qualitative Planning

1. Identify the general physical principle

2. Split into subproblems and outline procedure
(Schematic)

3. Identify which Key Relations may be useful

B Solve the problem symbolically by working backwards
(Chain of questions)

C If problems arise, try restating the problem or referring to a related problem.

General Heuristic (continued)

III EXECUTE THE PLAN (PLUG AND CHUG)

Routine operations with actual numbers and units

IV LOOKING BACK (CHECK)

A Is the answer reasonable and complete?

B Do the dimensions, algebra, numerical work, and logic check?

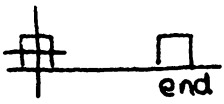
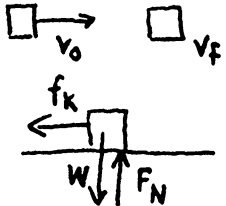
C Does this give any insight into how to solve other problems?

D Is there a way to solve this problem more effectively?

Heuristic Guidesheet

I UNDERSTAND

A Restate Friction brings the block to a stop. Find how many meters it will slide in the process of slowing down.

B Sketch	C Diagram	D Identify	E Estimate
		$v_0 = 10 \text{ m/s}$ $g = 9.8 \text{ m/s}^2$ $v = 0$ $\mu = .2$ $m = 2 \text{ kg}$ $S = ?$	$S < 50 \text{ m}$

II PLAN A Key Relations Physical Principle/Outline

$$v^2 - v_0^2 = 2as$$

$$s = \frac{1}{2}at^2 + v_0t$$

$$s = \frac{1}{2}(v + v_0)t$$

$$F = ma \quad f_k = \mu F_N$$

To find distance we must know acceleration, but acceleration depends on force. Only force acting is friction. Find friction, then acceleration, then distance.

B Solve Symbolically

$$v^2 - v_0^2 = 2as \longrightarrow S = \frac{v^2 - v_0^2}{2a} \quad \text{'a' unknown}$$

$$F_k = ma \longrightarrow a = \frac{F_k}{m} \quad \text{'F_k' unknown}$$

$$F_k = \mu F_N \longrightarrow \text{'N' unknown}$$

$$F_N = mg \longrightarrow \text{everything known}$$

$$F = \mu mg$$

$$a = \frac{-\mu mg}{m}$$

$$S = \frac{v^2 - v_0^2}{2(\mu g)}$$

III Execute

$$S = \frac{0^2 - (10 \text{ m/s})^2}{2(.2)(9.8 \text{ m/s}^2)} = 25.5 \text{ m}$$

IV Check

Reasonable ✓
 Dimensions ✓
 Algebra ✓

Mass makes no difference.

Working Backwards^a

- I For any particular problem or subproblem, determine which is the desired unknown (e.g. T)^b
- II Write an equation in which the unknown occurs (e.g. $PV=nRT$)
- a The equation must conform to the conditions and constraints of the problem
- b If there are several valid equations, pick the one which contains the smallest number of other unknown quantities.
- III Solve the equation for the unknown (e.g. $T=PV/nR$)
- IV If no other unknown quantities are present in the equation, then the problem is solved
If one or more other unknowns are present, then these should be solved for as explained in steps II and III.
(e.g. $P=F/A$)
- V The process explained in steps II, III, and IV should be repeated until all quantities are known
(e.g. $A=\pi r^2$)
- VI All of the equations should now be combined symbolically

$$(A = \pi r^2 \longrightarrow P = F / \pi r^2 \longrightarrow T = \frac{(F / \pi r^2) V}{nR}$$

^a C.T.C.W Mettes, A. Pilot, J.J. Roossink, H. Kramers-Pals, Journal of Chemical Education 58(1), 882(1981).

^b Examples added by author of this study

Basic Game Plan

Identify Physical Principles

1. Define Symbols

- a Use a sketch/diagram/coordinate system if needed
- b Use proper units (i.e. MKS)

2. Solve for the Unknown

- a Outline procedure first (sequence of equations) if helpful
- b If solution becomes cumbersome, numerical values may be used
- c Make comments as needed to insure coherence

3. Plug in numbers

Include both magnitude and units

4. Check

- a Check magnitude, units and sign
- b State what is not reasonable and search for error

General Strategy for Problem Solving

UNDERSTANDING THE PROBLEM

KNOWNNS AND UNKNOWNNS

Identify and label what is given and what is required

DIAGRAM

Draw a sketch or digram

PHYSICAL PRINCIPLE

Identify the basic physical principles involved in the problem

SOLVE SYMBOLICALLY

SELECT EQUATION

Identify an equation that will enable you to solve for the unknown

SOLVE FOR THE UNKNOWN

COHERENT?

Make enough comments to insure coherence

SEARCH SYSTEMATICALLY

If it is not possible to find a single equation to do the job, then utilize the basic physical principles in the problem to identify other equations that may be solved simultaneously to find the unknown.

PLUG AND CHUG

Substitute the known quantities including the units into the solved equation to obtain the numerical solution

CHECK

Check to see that the magnitude units and sign are reasonable. If a vector, check to see that both magnitude and direction are reported correctly

A WISE Strategy for Problem Solving

WHAT'S HAPPENING

Physical Principle

Identify the basic physical principles involved in the problem.

Diagram

Draw a sketch or diagram.

Knowns and Unknowns

Identify and label what is given and what is required, using appropriate units.

ISOLATE THE UNKNOWN

Select an Equation

Identify an equation that will enable you to solve for the unknown.

Solve Symbolically

Using only the symbols, solve for the unknown.

Search Systematically

If one equation is not enough, then use the basic physical principle to identify other equations to solve simultaneously.

SUBSTITUTE

Plug in both the numbers and the units.

EVALUATE

Are the sign, magnitude, and units correct? Compare with your diagram, intuition, and knowledge. If you like your answer, place a check mark beside it.

Outloud Thinking Test^a

1. Cathy knows French and German, Sandra knows Swedish and Russian, Cindy knows Spanish and French, and Paula knows German and Swedish. If French is easier than German, Russian is harder than Swedish, German is easier than Swedish, and Spanish is easier than French, which girl knows the most difficult language?
2. Boris, Irwin and Steven are engaged in the occupations of librarian, teacher and electrician, although not necessarily in that order. The librarian is Steven's cousin. Irwin lives next door to the electrician. Boris, who knows more facts than the teacher, must drive 45 minutes to visit Irwin's house. What is each man's occupation?
3. In a different language luk eir lail means "heavy little package," bo lail means "heavy man" and luk jo means "pretty package." How would you say "little man" in this language. (Words in this tongue are not always spoken in the same order as in English)
4. Sally loaned \$7 to Betty. But Sally borrowed \$15 from Estella and \$32 from Joan. Moreover, Joan owes \$3 to Estella and \$7 to Betty. One day the girls got together at Betty's house to straighten out their accounts. Which girl left with \$18 more than she came with?
5. Belvedere Street is parallel to St. Anthony Street. Davidson Street is perpendicular to River Street. River Street is parallel to St. Anthony Street. Is Davidson Street parallel or perpendicular to Belvedere?
6. How many inches short would a piece of cloth be if you measure off 24 ft of cloth with a yardstick that is warped and is 2 inches short?

^a Questions from Problem Solving and Comprehension, Second Edition, by Arthur Whimbey and Jack Lochhead. Published by Franklin Institute Press.

Outloud Thinking Test (continued)

7. If Bob's weekly income doubled he would be making \$50.00 a week more than Tom. Bob's weekly income is \$70 more than one half of Phil's. Phil makes \$180 a week. How much does Tom make?
8. Ornamental chain sells for \$1.23 a foot. How much will farmer Jones have to spend for chain in order to enclose a 70 ft by 30 ft patch of ground leaving a 4 ft entrance in the middle of each of the 30 ft sides.
9. A certain ball when dropped from any height, bounces one third of the original height. If the ball is dropped from 54 ft, bounces back up and continues to bounce up and down, what is the total distance that the ball has traveled when it hits the ground for the fourth time? Remember to count both the ascending and descending portions of the ball's path in computing the total distance.
10. A car starts on a trip from city A to city B which is 60 miles away. It runs out of gas after it has gone one third of the second half of the trip. How many miles still remain of the trip to city B.

Appendix C

Appendix C

HOW TO IMPLEMENT A PROGRAM OF
EXPLICITLY STRUCTURED PHYSICS INSTRUCTION

Explicitly Structured Physics Instruction (ESPI) is a procedure to help students organize their work, increase their accuracy, eliminate initial panic or lack of direction in approaching a problem, increase confidence in problem solving, promote understanding as opposed to rote memory, and improve their ability to communicate with the instructor and other students.

It is designed to be flexible enough to fit the style of the instructor using it and does not require extensive training or expense. It can be used with virtually any physics text and can be taught in the traditional lecture period. It may also be expanded to include recitation sections or even the computer.

When implemented, it should not only benefit the student, but also the instructor. It makes it easier for the instructor to diagnose student problems and direct his teaching to the needs of the students. It also promotes and enhances his communication with the students.

There are four major components to ESPI: A format for solving problems called the WISE strategy, a structure for examining equations known as the formula fact sheet, the use of lecture time, and a problem solving session for providing practice and feedback. All necessary problem solving skills are explicitly taught.

A WISE Strategy for Problem Solving

The WISE strategy is taught early in the quarter (See Figure A). The teacher must use the strategy in all problems that he works. The use of the strategy must be required on all homework and tests and it is utilized in tutoring and problem sessions. If it is not required, many will not even try it. It takes a while to convert someone to the system. Many will not like it at first, because it slows them down.

There are many advantages to using the strategy. Since instructor and student are using the same strategy to solve problems, they can communicate easier. It is much easier to look at a student's paper and tell exactly where his problems are, because the paper is organized. Also, when tutoring, a framework of questions is already developed (i.e. What are the unknowns? What is the physical

WHAT'S HAPPENING

Physical Principle	Identify the basic physical principles involved in the problem.
Diagram	Draw a sketch or diagram.
Knowns and Unknowns	Identify and label what is given and what is required, using appropriate units.

ISOLATE THE UNKNOWN

Select an Equation	Identify an equation that will enable you to solve for the unknown.
Solve Symbolically	Using only the symbols, solve for the unknown.
Search Systematically	If one equation is not enough, then use the basic physical principle to identify other equations to solve simultaneously.

SUBSTITUTE

Plug in both the numbers and the units.

EVALUATE

Are the sign, magnitude, and units correct? Compare with your diagram, intuition, and knowledge. If you like your answer, place a check mark beside it.

Figure A

A WISE Strategy for Problem Solving

principle?). Students can follow the instructor's work, because he always attacks problems in the same way and explains his reasoning. Group problem solving is also enhanced, because each of the students in the group is speaking the same language and is attacking the problem in approximately the same order.

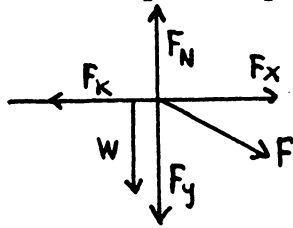
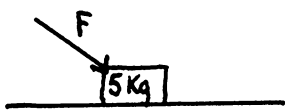
Students develop a general scheme for attacking problems. This builds confidence, gives them a starting point, and helps them understand the physics of the problem. This avoids fishing for an equation and plugging in numbers. Accuracy is improved as students use symbolic solutions and check their answers. Students will eventually realize that the process of solving problems is more important than just the answer. (See Figure B for a problem solved using the WISE strategy.)

How to Sell the System

Because students are used to a system of simply plugging in the numbers and grinding out the answers in many of their other classes, they may object to a system which is designed to slow them down and make them think. Hence it is the responsibility of the instructor to sell the program to the students. In order to sell the system, several steps are recommended:

1. Point out its advantages.

Problem: A box is pushed across the ground with a steady force of 100 N that is inclined at an angle of 20 degrees below the horizontal. If the box has a mass of 5 kg, and the coefficient of friction is .2, what will the speed of the box be after 5 meters of pushing.



$$\begin{aligned} m &= 5 \text{ kg} & v &= ? \\ F &= 100 \text{ N} & a &= ? \\ \mu &= .2 \\ x &= 5 \text{ m} \\ x_0 &= 0 \text{ m} \\ v_0 &= 0 \end{aligned}$$

$$\Sigma F_y = F_N - W - F_y = 0$$

$$F_N = W + F_y = (5 \text{ kg})(9.8 \text{ m/s}^2) + (100 \text{ N} \sin 20^\circ) = 83.2 \text{ N}$$

$$F_k = \mu F_N = .2(83.2 \text{ N}) = 16.6 \text{ N}$$

$$\Sigma F_x = ma_x = F_x - F_k$$

$$a_x = \frac{F_x - F_k}{m}$$

$$a_x = \frac{100 \text{ N} \cos 20^\circ - 16.6 \text{ N}}{5 \text{ kg}} = 15.5 \frac{\text{kg} \cancel{\text{m}}/\text{s}^2}{\cancel{\text{kg}}}$$

$$\begin{aligned} v^2 - v_0^2 &= 2a(x - x_0) \\ v^2 &= 2ax \end{aligned}$$

$$v = \sqrt{2ax} = \sqrt{2(15.5 \text{ m/s}^2)(5 \text{ m})} = 12.5 \text{ m/s} \checkmark$$

Figure B

Problem Worked with WISE Strategy

- a. Symbolic solutions solve a whole class of problems.
 - b. Symbolic solutions avoid dumb errors and make it easier to catch mistakes when checking.
 - c. Symbolic solutions keep the student closer to the physics of the problem.
 - d. Use of a diagram in conjunction with knowns and unknowns keeps better track of signs. Initial and final states of the problem are also better defined.
 - e. Checking work will uncover mistakes in algebra and reasoning.
 - f. Identifying the physical principles of the problem helps students identify basic procedures for handling classes of problems.
 - g. Having a set procedure helps to avoid the initial panic of not knowing where to start.
2. On tests the instructor should have a few problems that are very similar to each other, so that students that have solved symbolically have a great advantage.
 3. The instructor must use the strategy exclusively and constantly explain the reasons for each step that he takes.
 4. The instructor must give feedback to the students on their use of the system. This may be easily done by grading one homework problem on each assignment on the basis of the strategy. (This could be simply a check, check minus or check plus.)
 5. The instructor must give personal feedback to the students whenever possible during problem sessions or when handing back papers. (i.e. " If you had checked your answer you would have found this algebra mistake, because your answer has the wrong units." " If you had solved symbolically you would have saved a lot of work on this second problem.")

6. The instructor should not require the strategy on extremely simple problems. It is good to insist that the students use the system on other than hard problems, because it is good practice for them. If, however, the strategy is required on trivial problems (e.g. If the period is 2 seconds, what is the frequency?), the students will resent it. Other problems will not lend themselves to the use of diagrams or other parts of the strategy.
7. When preparing tests, keep in mind that it takes longer to do the problems in the detail required by the WISE strategy.
8. Pieces of the strategy should be taught individually. The students should be taught how to draw useful diagrams, how to solve symbolically, etc.
9. Do not take the process too seriously. Some problems do not lend themselves to complete symbolic solutions. For example, if a variable is zero, it is much more convenient to cross it out early, in the problem instead of keeping it in the equation. When solving simultaneous equations where one equation only has one of the unknowns, it is easier to obtain a numerical solution for that first equation instead of plugging a lot of symbols into the second equation. Be aware, however, that students will feel that any equation any more complicated than $F=ma$ should not be solved symbolically. They will take some time to be converted to the system.
10. Adapt the system to your personal experience, but don't complicate the system. If you add too many extra steps, the students will get lost. They will become so involved with making sure that all the steps are completed, that they will forget what the problem is.

11. The system is flexible enough to allow all or only parts of the problems to be done in class. Thus, the students may be asked to practice symbolic solutions or setting up the problem.
12. Always remind the students that the process is just as important as the product.

General Instructions for Using the WISE Strategy

WHATS HAPPENING-Knowns and Unknowns

$$m=2 \text{ kg} \quad d=2\text{cm} \times 1\text{m}/100\text{cm} = .02 \text{ m} \quad t= ?$$

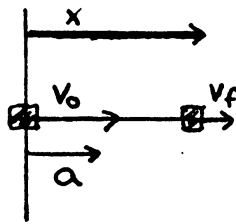
Units should be changed at this point of the problem to a consistent set of units such as MKS.

WHATS HAPPENING-Diagram

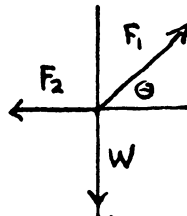
Diagrams may be drawn with the use of a coordinate system (e.g. Force Diagram) or may be a sketch depending on the circumstances.



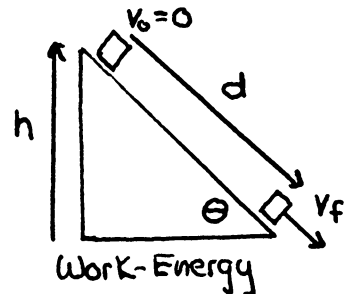
Resonance



Kinematics



Statics



Work-Energy

WHATS HAPPENING-Physical Principle

This does not necessarily need to be written down, but it should be considered. Long explanations are not necessary, but it is necessary to try and classify the type of problem being attacked. This will help the student identify a general plan of attack (e.g. if it is a statics problem the student knows that he must sum the forces to zero in order to solve the problem). Key words and cues need to be taught to help the student be able to identify the problem type.

ISOLATE THE UNKNOWN-Select an Equation

Since the basic physical principle has already been selected and the list of knowns and unknowns made the choice will be very narrow.

ISOLATE THE UNKNOWN-Solve Symbolically

Many students dread this step. They like it once they become accustomed to it. To help them get used to the techniques, the instructor may introduce the following strategy:

1. Clear square roots by squaring both sides of the equation.
2. Clear denominator by multiplying both sides by the lowest common denominator.
3. Clear parenthesis by the distributive property.
4. Place terms with knowns on one side of the equation and the terms without the unknown on the other side by the use of addition and subtraction.
5. Combine like terms and factor out the unknown if it appears in more than one term.
6. Divide by the coefficient of the unknown to isolate the unknown.
7. Clear the square by taking the square root of both sides.

It is a good idea to practice this strategy separately just to get a feel for how it works. Students rarely have a problem with $f=ma$, but $1/p + 1/q=1/f$ causes trouble.

ISOLATE THE UNKNOWN-Search Systematically

If it is impossible to find an equation that has the required unknown as the only unknown, then the student must select another equation that he can solve simultaneously with the first. Instead of simply beginning a fishing trip to find the equation, the student should refer back to the physical principles of the problem. Equations that seem to be used in conjunction with each other

are indicated as companion equations on the formula fact sheet (e.g. It is fairly common to have Newton's Second Law used in conjunction with the kinematics equations).

SUBSTITUTE

It is vital to have the student plug in both the units and magnitude of the variables. He should write down his substitutions on paper and not simply enter them in the calculator. Also, if using derived units (Newtons, Pascals, etc.) it is valuable to change to the basic units before the final analysis.

$$a=F/m= 6\text{N}/2\text{kg}= 6 \text{ kgm/s}^2/2\text{kg}= 3 \text{ m/s}^2$$

Too often the students are content to say that the answer is in meters per second squared simply because they know that these are the units of acceleration. This defeats the purpose of including the units. If an algebra mistake is made earlier in the problem, or if the student does not convert all of his units to an appropriate system, these errors will show up as improper units in the answer, and the student will know to check his work. Also if the students do the calculations only in the calculator, the instructor will be unable to find out where the mistakes are.

EVALUATE

Students usually complete a problem and look for the answer in the back of the book if it is available. If the answer is unavailable they simply go on to the next problem. It would be good to have the students double check their method, reflect on how they solved the problem and ask how changes in some of the variables would affect the outcome. However, it is probably more realistic to simply have them look at the answer to see if it makes sense. They should check the sign to see if it agrees with the diagram. The units must also be appropriate. Many times it will also be possible to see if the magnitude is in the right range. This will not always be possible, but the students will know that it does

not take 400 seconds for a dropped ball to hit the floor, or that the final velocity of a dragster is not 0.005 m/s.

If the students still like their answer after reflecting on these three things, they place a check mark after the answer. If they do not like the answer, they check their work to find the mistake. If they can not find the mistake, a question mark should follow the answer.

Formula Fact Sheet

The formula fact sheet is a tool to structure the examination of formulas (See Figure C). Rather than just memorizing a formulas, the sheet allows students to understand when and under what conditions the equation is to be used, what its limitations are, what units and signs to use, whether it is a scalar or a vector equation and what equations are used in conjunction with it. This enables the students to have at their fingertips a summary of the equation, instead of just a formula. In order to successfully use the WISE strategy the students must understand all of the information on the formula fact sheet.

The instructor should make up a reference sheet in advance to use as a guide (See Figure D), but the students should be given only a blank guide sheet. The students will fill in their sheets in the process of a group discussion. The instructors reference sheet will insure that all

.....

 $F=ma$

When/what:

Force is directly proportional to acceleration

Scalar _____

Vector X

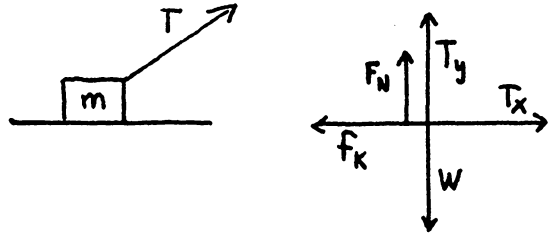
Component X

Magnitude only _____

Direction _____

Requires A and A_0 _____

Diagram



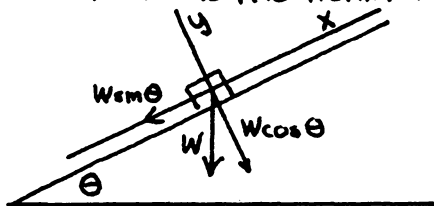
Symbol	Name	Units (Derived)	Basic & Notes
F	force	N (kg m/s ²)	use "resultant" force
m	mass	kg	
a	accel.	m/s ²	in direction of force
F_N	normal force	N	component of contact force

Notes: Hints/Constraints

$$\Sigma F_x = ma_x \quad \Sigma F_y = ma_y$$

If $a_y = 0$ then $F_y = 0$

This fact is used to find normal force



Put x axis in direction of motion

$$x - x_0 = \frac{1}{2}at^2 + v_0t$$

$$v = v_0 + at$$

$$v^2 - v_0^2 = 2a(x - x_0)$$

$$f_k = \mu F_N$$

$$W = mg$$

μ coefficient of friction

Figure D

pertinent points are covered, although it is not crucial that students use exactly the same wording or even all of the items as the instructor.

The formula fact sheet should not be prepared at the beginning of the chapter, but after some classroom discussion of the fundamentals and hopefully after they have read the textbook. The instructor might want the students to begin filling it out on their own so that the students could contribute to the classroom discussion. The instructor should also remind the students to add to their sheets as they receive insight into the formula in the process of completing the topic.

The instructor should encourage the students to refer to their formula fact sheets. If a question is asked in class that they can not answer, ask them to refer to their sheets. Ask them specific questions from the sheets several days after they have first produced them. (e.g. Is this a vector or scalar equation? When is it not possible to use this equation?) Asking them questions from their sheets will encourage them to use and understand them. If they refer back to their sheets and still can not find the answer, this is an opportunity to add information to the sheet.

Allow the students to use the sheets when doing homework or studying for tests, but not when taking the test. Some instructors might consider giving the students the raw formulas on the tests. By now the students should realize that there is much more to a formula than just variables and plus and minus signs.

How to Use the Formula Fact Sheet

When/What

This should be a statement of the purpose of the equation with clues of when to use it. It may also be a statement of the proportionality of the equation (e.g. Force is directly proportional to acceleration). Students will probably give the following statement for $F=ma$: Force is equal to mass time acceleration. This obviously will not add any insight to their present understanding of the problem. A lot of coaching will be required to help them produce useful descriptions of the equations.

It is essential to include key words or ideas on the sheet that will enable the student to know when to use the equation (i.e. This equation enables you to find the gravitational force between two objects if you know the masses of the two objects and their separation. Hookes law is used to find the force that a spring exerts when it is displaced from its equilibrium position).

If the statement in the When/What section is insufficient, then the problem should be addressed in the Notes section (e.g. Key word: Collision implies that conservartion of momentum should be used. Projectile problems usually will require the use of this equation).

Diagram

The diagram should include a typical example of the type of diagram that will be useful in solving the equation. (e.g. A force diagram for statics problems or just a sketch of the situation for work energy problems.) Sometimes there will not be an appropriate diagram (e.g. Ice dropped into a bucket of water). At other times a graph or sketch will prove helpful in this slot (e.g. A resonance pattern in the section on waves).

Vectors/Scalars

It is possible to classify most equations into one of three categories.

Component Vector Equations	Magnitude only Vector Equations	Scalars Equations
$x = 1/2 at^2 + v_0t$	$F = Gm_1m_2/r^2$	$PV = nRT$
$F_x = ma_x$	$v = rw$	$V = IR$

Students have an especially hard time with vectors. It is important for them to know whether to divide up into components or not and whether the answer will have a direction. Therefore, part of the formula fact sheet asks them to decide what kind of equation they are working with. (The magnitude only vectors are essentially vectors in polar form where the direction is designated by something other than the formula such as the right hand rule, or a line between centers)

Requires A and A₀

This question asks whether the problem requires a beginning and an end. This is to alert the student to the necessity of searching for and defining a beginning and an end before starting the problem (e.g. The beginning: Car passes light pole. The end: Car comes to a complete stop).

The kinematics equations and all equations involving a change in a variable (e.g. $\Delta Q = mc\Delta T$) are good examples of this.

Defining of Variables

This middle section will analyze the variable in somewhat the same manner that the rest of the sheet examines the equation. The notes will remind the student of any limitations (e.g. t must be positive) or simply reminders (e.g. Must use the resultant force for F). The students may identify the fact that v is really v_x and not the resultant or that Kelvin is Celsius plus 273.. In the units column the student needs to list both the derived units (e.g. Joules, Newtons) as well as the basic units (e.g. kgm/s^2) and possibly some intermediate units such as Newton-meter for Joule.

Notes: Hints/Constraints

This section should be used to help identify when and why to use the equation. It is also important to know when not to use the equation (e.g. Can not use this equation if you do not have constant acceleration). This section would contain information about how to handle multistep problems. Everything that seems important to understand the equation, but doesn't seem to fit anywhere else, is placed in this section.

Companion Equations

This section is to make students aware of which equations can be used in conjunction with the major equation of the sheet. Newton's laws, for example, are very often used in conjunction with the kinematics equations. When discussing the inclusion of the companion equations, the instructor should also mention what would motivate the use of each equation. Once again it is important to remember that students need to know what the cues are to using certain equations (e.g. If there is friction in the problem, the student should be made aware that he will probably need to use the definition of weight in order to find the normal force and the definition of friction in terms of the normal force).

Lecture

The instructor should not attempt to alter his form of delivery in lecture to such a great extent that he is uncomfortable. One of the most important aspects of this approach to teaching physics, is that the students must perceive that the instructor has confidence in the system and feels comfortable with it. Hence, for example, if the instructor has never in his life performed a demonstration, this may not be the time to start, along with everything else.

At the beginning of the year, it is a good idea to begin slowly with the content. The essence of the program is to teach problem solving skills as well as physics content. Certain skills need to be taught explicitly at the beginning of the course such as the WISE strategy and solving symbolically. Other skills can be practiced as they arise, such as drawing free body diagrams. Group problem solving skills should also be taught. It would also be wise to review such topics as dimensional analysis and metrics, quadratic equations and simultaneous equations if time permits.

A good basic outline to follow is to teach physical principles with the aid of demonstrations and practical examples, then examine the formulas carefully with the use of the formula fact sheet. The instructor then works

problems on the board either by himself or as part of a group effort and finally the students work problems in their seats either alone or in a small group.

It is important to give good feedback to the students. If the class is small enough, have the students work problems at their seats as the instructor walks around and observes the work. Because the students are using the WISE strategy, their work is always organized in approximately the same way and this makes it very easy to tell what they have done wrong or where they are stuck. In a large class, the students could work the problem on their own for several minutes, and then either the instructor or one of the students could put the problem on the board, allowing students to ask questions. As a variation to this, the instructor could ask the students only to complete part of the problem.

The most important aspect of the lecture time is to get the students actively involved. Otherwise the lecture simply becomes an oral textbook. Also, some way of keeping the students up to date with their studying is required. One way of doing this is to have at least a few homework problems due at every lecture section. These can be graded as to process as well as product and thus give the students feedback as to how they are using the WISE strategy. Quizzes

could also be given based on the homework. If there is no "carrot" to be regularly prepared, the lectures will not be nearly as effective.

Problem Solving Session

An effective although not totally essential aspect of Explicitly Structured Physics Instruction is the problem solving session. This is held as part of the laboratory period, during the recitation period, or as part of an optional session. One of the most effective ways of running this session is pair problem solving. Students work in pairs with one student acting as the problem solver and the other as the listener. The problem solver is required to think out loud as he solves the problem. He follows the WISE strategy and does not leave out any steps. The listener has the assignment to continually check the accuracy of the problem solver. To do this he must actively work along with the problem solver and follow every step that he takes. He does not let the problem solver get ahead of him and should ask if he doesn't understand why the problem solver did something or if he feels that he has done something wrong. He is not to work the problem separately nor is he to tell the problem solver what to do other than

to give hints. If the hints do not seem to help, he can give more direct help. The listener should also insure that the problem solver continues to talk out loud.

This process does not come naturally to all students. It is important to find a good match with the pairings. It is also a good idea to give them some practice in the technique with non-physics problems (See Figure E for an example of such problems). This acquaints them with talking out loud and working with a partner.

As the students are working as pairs the instructor wanders around and helps steer those who are way off base without helping those who would be able to eventually solve the problem. He asks leading questions, especially those from the WISE strategy. Because all of the students know the WISE strategy they are able to communicate with each other better, and also with the instructor.

The instructor may want to tie loose ends together at the end of the period by having either himself or one of the students put the problems on the board and then discuss them.

After the students have practiced pair problem solving for a period of weeks, the instructor may want to loosen up the guidelines by allowing the students to swap roles of

1. Cathy knows French and German, Sandra knows Swedish and Russian, Cindy knows Spanish and French, and Paula knows German and Swedish. If French is easier than German, Russian is harder than Swedish, German is easier than Swedish, and Spanish is easier than French, which girl knows the most difficult language?
2. Boris, Irwin and Steven are engaged in the occupations of librarian, teacher and electrician, although not necessarily in that order. The librarian is Steven's cousin. Irwin lives next door to the electrician. Boris, who knows more facts than the teacher, must drive 45 minutes to visit Irwin's house. What is each man's occupation?
3. In a different language luk eir lail means "heavy little package," bo lail means "heavy man" and luk jo means "pretty package." How would you say "little man" in this language. (Words in this tongue are not always spoken in the same order as in English)
4. Sally loaned \$7 to Betty. But Sally borrowed \$15 from Estella and \$32 from Joan. Moreover, Joan owes \$3 to Estella and \$7 to Betty. One day the girls got together at Betty's house to straighten out their accounts. Which girl left with \$18 more than she came with?
5. Belvedere Street is parallel to St. Anthony Street. Davidson Street is perpendicular to River Street. River Street is parallel to St. Anthony Street. Is Davidson Street parallel or perpendicular to Belvedere?
6. How many inches short would a piece of cloth be if you measure off 24 ft of cloth with a yardstick that is warped and is 2 inches short?

Figure E

Outloud Thinking Test^a

^a Questions from Problem Solving and Comprehension, Second Edition, by Arthur Whimbey and Jack Lochhead. Published by Franklin Institute Press.

7. If Bob's weekly income doubled he would be making \$50.00 a week more than Tom. Bob's weekly income is \$70 more than one half of Phil's. Phil makes \$180 a week. How much does Tom make?
8. Ornamental chain sells for \$1.23 a foot. How much will farmer Jones have to spend for chain in order to enclose a 70 ft by 30 ft patch of ground leaving a 4 ft entrance in the middle of each of the 30 ft sides.
9. A certain ball when dropped from any height, bounces one third of the original height. If the ball is dropped from 54 ft, bounces back up and continues to bounce up and down, what is the total distance that the ball has traveled when it hits the ground for the fourth time? Remember to count both the ascending and descending portions of the ball's path in computing the total distance.
10. A car starts on a trip from city A to city B which is 60 miles away. It runs out of gas after it has gone one third of the second half of the trip. How many miles still remain of the trip to city B.

Figure E (continued)

problem solver and listener during a problem, or in other words, to simply work together by sharing ideas. The instructor may also want to try groups of larger than two.

The instructor needs to be aware that if the problems are too complicated at first, or if the students are required to work problems that have not been covered in class in any detail, they will become soured on the process. There will also be students that feel that they know it all already, and don't need any more practice. These students need to be convinced that by helping others they will be able to solidify their knowledge. Perhaps two such students could be paired together and given harder problems than the rest of the class. Students generally appreciate such a problem session, but if asked to stay after a lab on a volunteer basis and work problems, they will want to disappear. Presumably they feel that even though they do not understand it, there is still time to make it up.

Tutoring can also be done using the method of pair problem solving. If a student comes to the office with a specific question about a problem, that problem can be answered and then the student can be asked to work a similar problem on the board. He should think out loud as he works the problem and the instructor will play the role of the listener. This also works effectively in small groups, where one student works a problem on the board and the other

students along with the instructor act as the listener. A variation to the problem can have the student asking questions of the rest of the students when he is stuck, with the instructor helping out only when absolutely required.

If the students become adept enough at working together and helping each other with problems, then the need for the instructor will fade and the students will be able to hold their own study sessions.

Another possibility for tutoring can be the use of the computer. The student could work the problem based on the WISE strategy with the computer giving feedback when he strays off course, or the computer could ask the student to perform specific parts of the strategy.

The glue that holds this whole thing together is the WISE strategy. Because all students and the instructor use the same strategy, communication is enhanced tremendously.

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