Strategies for the Development of Student Problem Solving Skills in the High School Physics Classroom

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Introduction

This document is a review of the literature related to the teaching and learning of problem solving in the context of a high school physics course. The literature review turned up 14 relevant articles (see bibliography). From these articles six basic instructional strategies were identified that have shown promise in promoting high school physics students' problem-solving ability. This document describes the general features of each of these six strategies as well as how they manifest themselves in the various instructional systems. The purpose of this document is to provide basic information about these strategies for high school teachers who are interested in furthering the problem-solving abilities of their students and need an introduction to the relevant literature.

Alternative Problems

What is it?

Alternative problems are problems not traditionally found at the end of the chapter. They involve using concepts rather than solving equations and the problem solution is more important than a numeric answer. Sometimes there is no numeric answer. Alternative problems can provide more information than is needed or be poorly defined like problems found in the real world.

How is it used?

In the classroom alternative problems are used in place of the traditional end of textbook problems. It is not necessary to replace all the textbook problems but there needs to be a sufficient amount of alternative problems. The time require to complete alternative problems will vary depending on the type of problems chosen. However, students usually show some resistance to the “new” type of problems at first. These problems also typically take longer for students to solve than more traditional problems. Teachers should give students plenty of examples and feedback on the type of solution each problem requires.

Why use it?

Solving alternative style of problems has shown to help students improve their problem solving skills and understanding of physics concepts.

- *Students learn concepts by applying them in problems.* By completing more conceptual problems students can no longer follow routines to get a numeric answer. These routines required little understanding of physics to complete. Instead, alternative problems require students to focus on how the concept works in order to determine the solution.
- *Students are prepared to handle problems outside of school.* Textbook problems tend to be nicely defined for the student. All the information given in the problem is used in the solving the problem and what is being asked for is clearly stated. However, real-world problems often contain extra details or poorly defined problem statements. Students need to practice these types of problems in the classroom so they will be able to solve these problems when they are outside the classroom.

Examples:

1. Minds on Physics

This curriculum developed by Leonard et. al. (1999) attempts to improve students’ conceptual knowledge of physics. In addition to improving students’ conceptual knowledge several suggestions are given for improving students’ ability to solve problems that involve the use of alternative problems.

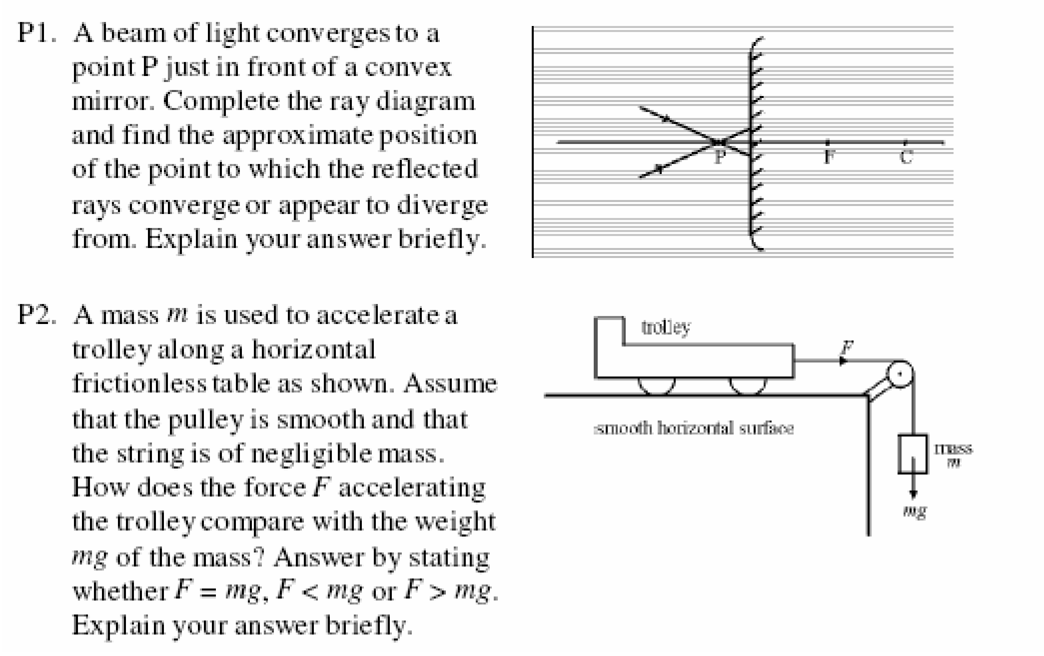
- *Students should explain how they would solve a problem.* By explaining the problem instead of solving it students focus on the important concepts needed to solve the problem. Since it takes more time to solve a problem than it does to plan a solution, students can gain experience with many more problems by just planning solutions instead of solving. For example, in one type of activity, students are asked to write a solution for a particular problem. They are then given another problem that has some

similarities and some differences with the first problem and are asked to describe how the solution for the second problem would be different.
(see Leonard 2, 1999, p.438)

- *Match the solution to the problem.* Students are asked to match problem statements with general solution strategies. This matching type exercise allows students to quickly see a number of types of problems and focus students on the linking the type of problem to the style of solution. (see Leonard 2, 1999, p.434-5)

2. Qualitative Problems

Tao's (2001) work suggests that students working qualitative problems can help increase students' conceptual understanding. Qualitative problems force students to work with the concepts rather than the formulas. A student comment from Tao's study supports this finding, "I've learned how to think in physics, not just memorize" (p.138). The following problems are examples of a qualitative problems used in Tao's study. Another problem from Tao's study can be found in the Multiple Representation section.



P1. A beam of light converges to a point P just in front of a convex mirror. Complete the ray diagram and find the approximate position of the point to which the reflected rays converge or appear to diverge from. Explain your answer briefly.

P2. A mass m is used to accelerate a trolley along a horizontal frictionless table as shown. Assume that the pulley is smooth and that the string is of negligible mass. How does the force F accelerating the trolley compare with the weight mg of the mass? Answer by stating whether $F = mg$, $F < mg$ or $F > mg$. Explain your answer briefly.

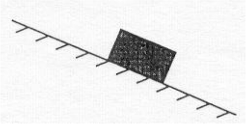
(Examples from Tao, 2001a, p.1204)

3. Qualitative before Quantitative

Ploetzner et.al. (1999) studied the order in which students should be presented different problem types. They found qualitative problems should be taught before quantitative problems because quantitative information is more easily integrated into a qualitative mindset than the other way around. In addition if quantitative problems are taught first students may fail to realize the importance of the qualitative features of a problem and only look at a problem quantitatively. Students should solve problems that demonstrate how a qualitative representation of the problem can make the quantitative problem easy to solve. An example illustrating the differences between qualitative, quantitative and a combination of both qualitative and quantitative is given below.

Qualitative problem:

A block is projected up an inclined, frictionless plane. For each force on the block, draw an arrow which indicates the force on the block!



Quantitative Problem:

A block rests on a plane. There is a gravitational force F_g = 240 N on the block. The plane is inclined at an angle $\alpha = 35°$. What is the magnitude of the normal force F_n on the block?

Problem requiring both qualitative and quantitative aspects for its solution:

A vehicle of mass m = 25 kg is projected up an inclined plane with the velocity v = 12 m/s. The plane is inclined at an angle of $\alpha = 30°$. The coefficient of friction f between the tires of the vehicle and the plane equals 0.4. What is the vehicle's velocity v after the time t = 1 s?

(problems from Ploetzner et.al., 1999, p. 195)

4. Experiment Problems

Van Heuvelen has developed many laboratory problems that follow problems students could encounter in real life. He has published a series of the mechanics problems (1995) and electricity and magnetism problems (1999). Additional experiment problems can be found on-line at http://www.physics.ohio-state.edu/~physedu/index2.html. The problems require students to focus a poorly defined problem, plan a solution, solve individual parts of the problem, make necessary measurements, identify any approximations used in the solution, evaluate the results of their problem and finally perform the experiment. If the student's experiment did not work as expected the student must determine what went wrong. One experiment problem can take up to two hours to complete. Some examples of problems used are given below.

- **A Frictionless Bobsled—Maybe:** A company is developing a bobsled that supposedly has less friction than other sleds. To evaluate the friction, they suggest that you measure the time interval needed for the sled to travel between two sections of a uniformly inclined bobsled track and to compare that time interval to the time interval that is expected if there is no friction between the sled and the track. To test your theory, you perform a similar experiment and analysis with an air cart that slides down an inclined air track or with a dynamics cart that slides down its track. At about 20 cm and 140 cm from the starting position, you place photogates that will measure the time interval needed for the cart to traverse the distance between the gates. However, before measuring that time interval, develop a theory and make the necessary measurements to predict the time interval needed to travel between the photogates, assuming no friction. Then try the experiment and measure the actual time interval needed for the trip between the gates. Based on this measurement, indicate the upper limit of the magnitude of the friction force that the track exerts on the cart. (1995, p.178)

- **Spring Launch:** You are hired by a carnival to develop a new human canon launching device. Instead of propelling the human with explosive gunpowder, you are to launch the person with a stretched spring. Upon release, the person is launched from the canon, flies through the air, and lands in the net a certain distance from the canon. To test the idea, you build a laboratory scale model. The model uses a spring that is slid down around a dowel until the last turn of the spring, which has been bent across the center opening, prevents the spring from sliding farther. You launch the spring by stretching it so that when released it flies from the dowel, through the air, and lands in a box across the room. Develop the theory needed to make this launching system work so that the spring lands in the box of the first shot. Then you can work on the human launching system. (1995, p.176)

5. Overview, Case Study Physics

Van Heuvelen (1991) also uses case study problems as culminating activities for each topic area studied in the Overview, Case Study program. Each case study contains problems that require the use of many concepts and often need to be broken into parts to be solved. Like the experimental problems case studies can poorly defined to force students to determine the important information needed in the problem. The following is a thermodynamics case study taken from the author's article.

> It has been proposed that 60 million years ago, a meteorite about 10 km in diameter (roughly the size of Mt. Everest) collided with the earth. The energy transformation in the collision caused the meteorite to vaporize producing a cloud of debris that enshrouded the earth blocking sunlight for longer than a month. Over that time interval, the debris drifted downward on the rotating earth depositing a 1 cm thick layer of clay over the earth's surface.
>
> Your task is to analyze this process to see if it is reasonable. Start with a meteorite of the dimension described above when very from the earth's surface. Try to determine if the energy in the initial situation is enough to produce a vaporized meteorite at an elevation somewhat about the earth's surface. Indicate clearly any assumptions used in your analysis.
>
> (Case study from Van Heuvelen, 1991, p.906)

6. Context-Rich Problems

Neto and Valente (1997) and Huffman (1997) suggest using these problem statements to give a better contextual description of the problem. Because of the complete description of the problem students are better able to visualize and internalize the problem. Context-rich problems often provide more information than is needed to solve the problem or rely on the student to make estimates or bring in additional relevant information. An example of such a problem is given below.

> Two friends (both with mass 75 kg) were spending their summer holidays at Albufeira Beach in Algrave. One of them owns a quite sophisticated Japanese speedboat made of fiberglass, and with mass about 300 kg. They used to spend all the time on the sea, in an attempt to keep beating their nautical previous speed record. For that, they used to measure the interval of time needed to reach a certain buoy, floating 0.8 km away from the coast. The best they had ever been able to do was 40 s. One morning, when their holidays were about to finish, they had a feeling that they would beat their nautical record. It was a nice day with a flat sea and a pleasant breeze. Just on the first run, they verify from the boat speedometer that in the first ten seconds the speed had uniformly been increasing from zero to 36 km/h. Then, they decided to keep moving at the same rate of speed along the remaining part of the run. When they got to the buoy how do you think the two friends felt? Real delight? Obvious disappointment?
>
> (problem statement from Neto, 1997, p.28)

Group Problem Solving

What is it?

Group problem solving strategies allow students to develop their problem solving skills and conceptual understanding through explanations to their fellow students. Group problem solving also focuses on opening peer to peer and peer to instructor communication.

How is it used?

Class time is dedicated for allowing students to work on problems in groups. During their work students are expected to spend time explaining their thinking to their classmates. Groups work on challenging qualitative and quantitative problems. Two main strategies are often employed for group problem solving. In one, students work individually on solving a problem and then take time to explain their solutions to another classmate. In the other, students work together to form a group solution either on paper or small whiteboard.

Why use it?

Group work can help students improve their problem solving skills.

- *Students get practice developing and using the language of physics.* Students get to practice talking about physics topics using physics language.
- *Students must deal with and resolve their individual misconceptions.* When students disagree they must discuss and resolve their differences. These discussions often get at the important aspects of the topic that the students working individually would not notice.
- *Each student in a group brings a unique set of skills and experiences.* Students can learn from one-another and the group can accomplish tasks that the strongest student could not accomplish alone.
- *Students are more comfortable exposing their misunderstandings to a small group than to the whole class.* Admitting to a lack of understanding in front of the whole class is difficult for most students. In a small group, though, it is easier for students to ask for help and easier for peers to provide the help.

Examples:

1. Peer Instruction

Crouch and Mazur (2001) have developed and implemented an active learning strategy in large lecture classes. Instead of just asking informal question in class, the class is broken up into a series of short presentations each followed by a set of questions covering the concepts just presented that students answer on their own. After a couple minutes students discuss their answers in small groups. Students attempt to convince the other in the group about the correctness of their answers. After a few minutes the instructor polls the class on their answers, explains the correct answer and moves on to the next topic. While students are not graded on their answer, they are encouraged to participate because the questions are similar to questions that will be asked on future tests.

The questions asked of students need to be of appropriate difficulty. If the questions are too easy, student discussion leads to little insight. Similarly if the questions are too difficult the students will not be able to have an effective discussion. The right balance generates discussions by having students with different positions trying to support their answers with the underlying physics concepts.

1. A rubber bullet and an aluminum bullet, equal in size and mass, are fired at a block of wood at the same speed. The rubber bullet bounces back, while the aluminum one penetrates. Which is more likely to knock the block over?

Answer: The rubber bullet is more likely to knock over the block of wood.

2. The Levi Straus trademark shows two horses trying to pull apart a pair of pants. Suppose Levi had only one horse and attached the other side of the pants to a fencepost. Using only one horse would: (a) cut the tension on the pants by one-half, (b) not change the tension on the pants at all, (c) double the tension on the pants?

Answer: (b) not change the tension on the pants at all

(from Koman, 1995)

2. Cooperative Group Problem Solving

In the intervention described by Huffman (1997) students practiced solving problems using a problem solving framework while working in cooperative learning groups.

Knowledge Organization

What is it?

Experts typically have their physics knowledge hierarchically organized around physics concepts. This organization facilitates identification of the principle(s) relevant to a particular problem situation. Knowledge Organization instructional strategies explicitly focus students on organizing their physics knowledge in a meaningful way.

How is it used?

Knowledge organization emphasizes the interrelationship of concepts and principles. A common feature of the various approaches is explicitly making the connections between related concepts and principles. Teachers focus on organizing information. As new content is covered students and/or teachers generate links to previous concepts. Teachers provide connections to future information. Diagrams are often used to help students visualize the organizational structure of information.

Why use it?

A focus on Knowledge Organization has been shown to improve students understanding and retention of physics content and as well as improve several aspects of problem solving.

- *Apply appropriate concepts and procedures.* In order to solve a problem correctly students need to have a strong understanding of the relevant concepts and procedures. Having an organized knowledge base helps students learn when and when not to apply a given concept. Once a problem is categorized students associated the problem to the proper concepts and procedures.
- *Easy access to concepts and procedures.* Without easy access to information students often struggle to find a correct solution to a problem. Too much of their cognitive ability is being used to understand the concepts being used in the problem. With a structured knowledge base students can more efficiently conceptualize the problem and spend more time focusing on developing the solution to the problem.
- *Expert problem solvers have hierarchal knowledge structure*. Focusing students on a knowledge structure helps students develop more expert-like knowledge structure and problem solving behaviors.
- *Interconnected knowledge.* Students with links relating different concepts can develop more complete solutions. This interconnected information helps students to relate concepts, graphs, diagrams, and equations.

Examples:

1. Formula Fact Sheet

Wright and Williams (1986) developed a one page Formula Fact Sheet that students fill out as they learn the purpose of each formula used in class. On the top of the page students list the formula along with a short description of when it is used and what it means conceptually. Diagrams are often added to the sheet to highlight important parts of the formula. Also included are sections for definitions of the equations variables, companion equations related to the main equation, as well as, a section for problem-solving hints and constraints for typical problems that use this equation. The completion of the Formula Fact Sheet helps students focus on how the formula fits into the framework of physics.

2. Overview, Case Study Physics

Van Heuvelen's (1991) Overview, Case Study Physics focuses developing a knowledge hierarchy where students' general ideas are at the top and specific points at the bottom. Students first focus the majority of their time on a conceptually analysis of all the parts in a topic area. When the students begin to cover the mathematical representations for the concepts they are given a hierarchial chart organizing all the parts of a topic area. The content is arranged in a tree-chart format from general to specific. The organization is designed to help students see the similarities and differences within a topic area.

3. Minds on Physics

Leonard et. al. (1999) developed a curriculum that focuses on developing students' conceptual knowledge of physics. The authors believe that problem solving is directly related to conceptual knowledge and how that knowledge is organized. Knowledge is divided into three areas operational and procedural knowledge, conceptual knowledge, and problem-state knowledge. Expert problem solvers have "rich, hierarchical (prioritized) clustering of conceptual knowledge" (p. 8) while novices have weak links if any.

The authors give many instructional suggestions to help improve student conceptual knowledge:

- *Use many representations for the same concept.* Different representations help students develop links between concepts. Students often rely on only the algebraic representation to describe a concept. Additionally links between concepts, procedures and problems can be developed through different representations. Use graphs as representations that allow for qualitative analysis while still being related to the formula. Students should translate formulas into sentences explaining the concept behind the formula.
- *The first few examples need to be similar only in the feature being studied*. If more than one key similarity is present in the first few examples students are likely to form improper links between concepts. For example, when developing knowledge about the normal force the first example can show the normal force straight up from a flat surface but a second example should be on an angled surface so that students do not over simplify and believe that normal force always points upward.
- *Focus on the edges of students' knowledge*. Students learn as they push on the boundaries of their knowledge. Students need to compare similar situations to find the qualities that are important to group situations together. Students should also study a situation and then evaluate what happens when something in the original situation is changed. Concepts need to be connected to the students' world by having students give examples from their life where a concept is seen or not seen.
- *Give students opportunities for reflection*. Students need time to solve a problem and then reflect on the solution. While experts engage in this reflection automatically, students typically need the time and focus questions to help them reflect. Students also need time to discuss and prioritize ideas to form a hierarchical organization of knowledge. A section of reflection questions follow each activity in the Minds on Physics program. The reflection questions ask general, qualitative questions that require the student to use the concepts from the activity. For example, after a section on computing

potential energy students are asked to reflect upon if and when the potential energy could be negative. (Leonard 2, p.402)

4. Concept Maps

Ploetzner et. al. (1999) showed that concept maps are a successful way to teach both qualitative and quantitative physics. The concept maps used in this study were very structured and organized. Instructors presented each qualitative aspect of the content in a hierarchal construction with large concepts connected down to finer points. Linking verbs were used to connect each part of the concept map. Each aspect was followed with examples and several exercises. Students often developed maps of their own to describe the relationship between topics or to find solutions to problems. The maps formed external representations of knowledge structures.

Metacognitive Strategies

What is it?

Metacognitive strategies are activities that focus a student to reflect upon their problem solving approach. Metacognitive strategies attempt to identify strengths and weaknesses of the problem solver.

How is it used?

Class time is used to explicitly teach students reflection skills. Students also need time to practice these reflection skills during and after they work problems. A specific routine needs to be implemented by the teacher that requires the students to reflect upon their problem solving as well as provide a framework that helps guide the students in their reflection.

Why use it?

Learning metacognitive strategies has shown to help students improve their problem solving skills.

- *Teach students to the skills necessary for reflection.* Self-reflection is a skill expert problem solvers often use to help them work through a problem. However it is not a skill many students practice. By teaching students explicit metacognitive skills students will help them become more like expert problem solvers.
- *Allows teachers/students to identify the area of problem solving process where difficulty occurs.* By analyzing the problem solving process students and teachers spend time reflecting on their strengths and weaknesses. Once identified weaknesses can be specifically worked on to improve overall problem solving ability.

Examples:

1. Metacognitive problem questions

Neto and Valente (1997) developed a common list of questions that they answer when solving each problem. Special problems are used that provide detailed descriptions of the context of the problem (see Alternate Problems). Some of the questions help the students better define the problem and work toward an answer. However, many of questions that focus on reflecting upon the students' perception of problem and their ability to solve it. The following questions are paraphrased from p. 28-30 of their article. Emphasis is given the those questions that help students think metacognitively about their problem solving. The other questions are used to specifically provide a framework for the students to solve the problem and are emphasized in the Problem Solving Framework section.

1. What is the problem in question?
2. What are the physics concepts or laws that the problem is related to?
3. What are the key words you think are absolutely necessary to solve the problem?

4a) Your comprehension level of the problem proposed;
very high ____:_____:_____:_____:_____:_____:_____ very low
4b) level of difficulty the problem seems to offer you;
very high ____:_____:_____:_____:_____:_____:_____ very low
4c) level of confidence in your ability to solve the problem;
very high ____:_____:_____:_____:_____:_____:_____ very low

4d) your level of competence on the subjects of the problem;
very high ____:_____:_____:_____:_____:_____:_____ very low

5. Estimate an answer for the problem. Describe your reasoning.
6. Develop a plan to solve the problem. Your plan should be organized and specific.
7. Solve the problem quantitatively. Organize your solution and provide a diagram of the problem situation.

8. Make a list of the most relevant information you had to retrieve from memory (physics facts, concepts, laws, equations…)

9a) Did you really read the problem statement carefully? What is your attention level on this task?
very high ____:_____:_____:_____:_____:_____:_____ very low
9b) Did you really understand the problem situation suggested? What is your level of comprehension?
very high ____:_____:_____:_____:_____:_____:_____ very low
9c) Have you been really concerned with monitoring and evaluating your thinking processes and products? What level did you attain on this task?
very high ____:_____:_____:_____:_____:_____:_____ very low
10a) "In my opinion, this problem proved to be…"
very easy ____:_____:_____:_____:_____:_____:_____ very difficult
10b) "My commitment to the task was…"
very high ____:_____:_____:_____:_____:_____:_____ very low
10c) "My confidence level in the answer done is…"
very high ____:_____:_____:_____:_____:_____:_____ very low
10d) "My approach to the solution was…"
very efficient ____:_____:_____:_____:_____:_____:_____ quite inefficient

2. Problem Solving Pentagon

Bagayoko and Keiley (2000) studied a procedure called the Problem Solving Pentagon, PSP, that divides the problem-solving process into the following five categories: 1. Knowledge base, 2. Skill base, 3. Resource base, 4. Strategy-Experience base, and 5. Behavioral base. Successful implementation of the PSP program is dependent on engaging dialogues between students, extensive comments and categorization of each step in the problem, and the slow pace (caused by the dialogues and categorization) helps students to retain concepts as well as problem-solving strategies. In using the PSP framework, the class categorizes each step in the problem-solving process within one of the five categories. Each of the five categories is discussed in more detail below.

1. Knowledge base
   - Cognitively condensed and meaningfully organized knowledge.
   - e.g. Students should be easily able to recall $PV = nRT$ which leads to recall of the terms of pressure, volume, number of moles, ideal gas constant and temperature as well as being able to recall any of the three basic gas laws
2. Skill base
   - Cognitively condensed procedural knowledge
   - e.g. Being able to perform algebraic manipulations to solve equations
3. Resource base
   - Human and material resources are need to be accessible when solving problems
   - e.g. calculators, protractors, computers, software packages, books, and journals
4. Strategy-Experience base
   - Gain experience in solving different types of problems

- Practice enhances proficiency with certain types of problems
- Different from category 2 in that it refers to the overall problem solving process not just the individual skills

5. Behavioral base
   - Self-discipline that is needed to continue working on difficult problems
   - Some of these emotional and behavioral traits can be developed through practice

3. Minds on Physics

This curriculum developed by Leonard et.al. (1999a) has some metacognitive aspects. The course consists of numerous activities that involve students in answering questions and solving problems. At the end of each activity a series of reflection questions helps students reflect on and organize the key concepts studied in the activity. Some of the questions are designed to help students think about their ability to solve problems and reflect on where their difficulties occur. Students are also encouraged to reflect upon their problem solving approach. The following questions are asked after an activity where the students solved problems using the work-kinetic energy theorem.

> R1. Which problems did you have difficulty solving? Do you know why these problems were difficult? Summarize and explain the difficulties you had.
>
> R2. While solving these problems, did you ask yourself any of the following questions?
>
> - What forces are exerted in this situation?
> - What is the change in kinetic energy?
> - Which forces do work?
> - What is the total work done in this situation?
> - Is each work done positive or negative?
>
> If you did not, then you probably had difficulty solving these problems. Pick a problem you could not do before and try it again, keeping in mind these questions.
>
> (Example from Leonard, 1999b, p.388)

Multiple Perspectives

What is it?

Physicists are able to look at problems from many different perspectives, with each perspective providing different types of information about the problem situation. For example, a particular problem situation can be thought of in terms of words, diagrams, graphs, and equations. Being able to use different perspectives to reason qualitatively about a problem is one of the key differences between expert and novice problem solvers. Class activities that emphasize multiple perspectives have been shown to improve students' problem solving skills and their ability to reason qualitatively about the relevant physics concepts.

How is it used?

Teaching students to use multiple perspectives requires teachers to spend more time on a given concept. Students need time to practice the different ways to represent a concept such as with diagrams, graphs and equations. Additional time is also needed for students to reflect upon alternate solutions brought about from the different perspective. As the students grow more accustomed with using the different representations less time is needed for focusing on individual perspectives as they appear in other topic areas. Qualitative problems are emphasized because the different perspectives often lead to alternative solutions and discourage the rote use of equations. Students must rely upon their representation of the problem to help develop a solution.

Why use it?

The use of multiple perspectives when solving problems has several benefits.

- *Multiple perspectives help students of all learning styles.* Describing the problem in several different ways helps students understand the problem thoroughly and allows students with different learning styles to focus in on the perspective that makes the most sense to them.
- *Students can handle problems presented in different formats.* Because they understand how to interpret many different perspectives students are better prepared for new problems that may not be worded the same way as in the book.
- *Students focus on concepts to connect the word problem to the equation.* Instead of immediately jumping from the written problem to an equation, students are asked to represent the problem with physics concepts. The concepts are used as a way to describe the problem and to provide rational for using a particular equation. This not only helps students solve problems but also reinforces the concepts of physics.
- *Students see there can be multiple solutions to the same problem*. By focusing on the many ways to represent a problem students develop different methods for solving the same problem. By sharing these different methods students will gain a more complete picture of concepts being studied. Students are able to learn new approaches to problem solving and better understand how the concepts relate to each other. Many students report that these experiences help them think about the concepts instead of just the formula.

Examples:

1. Overview, Case Study Physics

Van Heuvelen (1991) believes that in order to understand physics and be able to solve physics problems students must learn how to represent physics problems in many ways. Students should start with qualitative representations and reason from the qualitative to a quantitative solution. His Overview, Case Study Physics (OCS) focuses students on learning to represent physics with multiple representations. In OCS students receive explicit instruction and practice in making and using different forms of representing problems. The problems used in class are designed to have solutions requiring multiple representations.

Each topic is taught from several different representations that are combined at the end to solve difficult case study problems. The general pattern of a topic is shown below.

Overview

- Basic knowledge is presented, students actively inquire, preconceptions confronted
- Students learn and practice graphical techniques for representing physical processes
- Students are tested on the qualitative concepts taught in the overview

Exposition

- Students learn the same concepts taught in overview in mathematical form
- Students use multiple representations in problem-solving (see figure below)
- Students use format sheets, that have space for each representation, to solve quantitative problems

Case studies

- Problems that involve more than one concept and often need to be broken into parts to be solved
- Some case studies are poorly defined to force students to determine the relevant information needed to solve the problem.

Review

- Short period at the end of the year when hierarchical chart for each knowledge chunk are developed.
- Students are asked to identify the concept needed to solve but not solve 30-40 problems.

Students use a standard format with solving problems in OCS that helps students focus on the different representations. Specific spaces on the paper are used for pictorial, physical, and mathematical representations.

2. Multiple solutions

Tao's (2001) instructional strategy uses multiple solutions for qualitative problems. During a class period students solve several qualitative problems. The next day the graded problem solutions are returned along with several correct solutions for each problem. The students reflect upon the differences between their solution and the given solutions. Tao has shown that reflecting upon mistakes and being confronted with multiple solutions to the same problem has three positive effects:

1. It enhances students' conceptual understanding and improves problem-solving skills.
2. It can cause students to reflect upon content material, problem-solving strategies, and approach to learning.
3. It enhances students' ability to see things from different perspectives. (p.139)

Problem Solving Framework

What is it?

A problem solving framework is designed to provide guidance to students as they work through problems during the course. The purpose of a framework is to break down the problem and make explicit the things that an expert does or thinks about when solving problems. Frameworks are usually general enough to be applied to many different types of problems.

How is it used?

A classroom using a problem solving framework is very similar to a traditional classroom -- the solving of quantitative problems is a prominent feature of both. The key difference is that students using a problem solving framework are required to engage in the framework activities as they solve the problems. When a student gets stuck, the teacher will explicitly refer to the framework to help the student determine where the difficulty is and how to proceed. Some time is needed at the beginning of the course to define and teach the problem solving framework. The framework can often be taught in the context of solving physics problems and refined as the course develops. Teachers typically adjust their grading practices to reinforce the use of the framework.

Why use it?

Consistent use of a problem solving framework has been shown to help students improve their problem solving skills and understanding of physics concepts.

- *Students learn physics concepts through problem solving*. A problem solving framework eliminates the random guessing often done by students where problem solving is reduced to finding an equation and placing the numbers from the problem into it. This style of problem solving does little to help the students understand or apply the appropriate physics concepts. A framework focuses students on the important physics concepts.
- *Students gain problem solving skills*. A problem solving framework gives students a structure in which real problem solving can be practiced. As they solve the problem students become familiar with and eventually internalize the general problem solving steps. This allows them to be better able to solve future problems.
- *Students gain confidence in solving problems*. Using a problem solving framework, students are able to solve complex problems that may appear very difficult at first. They spend less trapped in misguided attempts to solve the problem and instead follow a logical path to a solution. Students are also less likely quit the problem before they find the solution because of frustration or a perceived “waist of time”.
- *Communication is improved*. Teachers or students can point directly to specific parts of the framework when discussing problem solving. Students-student and student-teacher communication improves because everyone is using the same language.

Examples:

1. A WISE Strategy

Wright and Williams (1986) us a simple acronym to help students remember their framework. Students apply the WISE Strategy while solving traditional end of textbook problems. Each letter of WISE stands for a part of the problem-solving approach to be used in each problem.

What's Happening – Identify the physical principle, Make a sketch or Diagram
Isolate the unknown – Select an equation, solve symbolically, if one equation is not enough look for others to solve simultaneously.
Substitute – Solve equations with both numbers and units.
Evaluate – Check for correctness in sign, magnitude and units. Does the answer make sense? (p. 212)

2. Emphasis on self-reflection

Neto and Valente (1997) use a problem solving framework that gives students a common list of questions that they answer when solving each problem. Special types of problems are used that require the student visualize and internalize the problem situation (see Alternate Problems). For each problem students are required to represent the problem, analyze the problem qualitatively, plan and implement a strategy to solve the problem quantitatively, and evaluate their thinking throughout the solution process. The following questions are paraphrased from p. 28-30 of their article. Emphasis is given the those questions that are specifically providing a framework for the students to solve the problem. The other questions are used to help students think metacognitively about their problem solving and are emphasized in the metacognitive section.

1. What is the problem in question?
2. What are the physics concepts or laws that the problem is related to?
3. What are the key words you think are absolutely necessary to solve the problem?

4a) Your comprehension level of the problem proposed;
very high ____:_____:_____:_____:_____:_____:_____ very low
4b) level of difficulty the problem seems to offer you;
very high ____:_____:_____:_____:_____:_____:_____ very low
4c) level of confidence in your ability to solve the problem;
very high ____:_____:_____:_____:_____:_____:_____ very low
4d) your level of competence on the subjects of the problem;
very high ____:_____:_____:_____:_____:_____:_____ very low

5. Estimate an answer for the problem. Describe your reasoning.
6. Develop a plan to solve the problem. Your plan should be organized and specific.
7. Solve the problem quantitatively. Organize your solution and provide a diagram of the problem situation.
8. Make a list of the most relevant information you had to retrieve from memory (physics facts, concepts, laws, equations…)

9a) Did you really read the problem statement carefully? What is your attention level on this task?
very high ____:_____:_____:_____:_____:_____:_____ very low
9b) Did you really understand the problem situation suggested? What is your level of comprehension?
very high ____:_____:_____:_____:_____:_____:_____ very low
9c) Have you been really concerned with monitoring and evaluating your thinking processes and products? What level did you attain on this task?
very high ____:_____:_____:_____:_____:_____:_____ very low
10a) "In my opinion, this problem proved to be…" very easy ____:_____:_____:_____:_____:_____:_____ very difficult
10b) "My commitment to the task was…" very high ____:_____:_____:_____:_____:_____:_____ very low
10c) "My confidence level in the answer done is…" very high ____:_____:_____:_____:_____:_____:_____ very low
10d) "My approach to the solution was…" very efficient ____:_____:_____:_____:_____:_____:_____ quite inefficient

3. A Problem Solving Flowchart

Wood (1985) provides a flowchart to help students solve problems. The flowchart (see below) is designed like a computer program complete with “goto” statements that often loop the student back to a previous step if more information is needed. The flow chart is designed to be presented to students after they have solved some problems and are able to identify most of the steps used. Some practice is needed for students to become comfortable in using the flow chart. The author suggests using the flow chart during whole-class discussions leading to a problem solution in order to help students understand the meanings of the various steps and to give struggling students a chance to observe the thought processes involved in solving the problems. Wood also suggests that the difficulty of the problem can be determined by counting how many loops of the procedure are need to solve the problem.

4. A More Detailed 5-Step Framework

Huffman (1997) used a framework in his study that was based on a 5-step framework designed by Heller and Hollabaugh (1992, *American Journal of Physics* article). An example of a problem solved with the framework is shown below along with a brief summary of the steps involved.

1. Focus the problem:
    - Sketch the problem
    - Restate the question being asked by the problem
    - Write a descriptive approach for solving the problem
2. Describe the physics:
    - Define the variables given and unknown
    - Sketch a graph that helps understand the problem or represent the problem in a different way
    - State quantitative relationships
3. Plan the Solution:
    - Write a procedure for solving the problem
    - Outline the steps needed
    - Check for sufficiency (2 equations for 2 unknowns)
4. Execute the Plan:
    - Solve the problem algebraically for the unknown
    - Insert numbers to solve the final numerical answer
5. Evaluate the Solution:
    - Check units of answer
    - Evaluate the reasonability of the answer
    - State a complete answer to the question being asked by the problem.

Annotated Bibliography

Huffman, Douglas. (1997). Effect of Explicit Problem Solving Instruction on High School Students' Problem-Solving Performance and Conceptual Understanding of Physics. *Journal of Research in Science Teaching*, v34 n6, 551-70.

> *Accession Number: EJ549742*
> This semester study looked at 145 students of a suburban high school in the Midwest. Both the experimental group and the control group received instruction in a problem-solving strategy. The experimental group was taught an explicit problem-solving strategy while the control group was taught to use a textbook problem-solving strategy. Then the groups were instructed with identical units on Newton's laws but practiced using their specific problem-solving strategy. Both groups were randomly assigned and measured using a pretest/posttest experimental design. This study found that the explicit problem-solving strategy helped improve some of the aspects of the students' performance in problem-solving. In particular, students with the explicit approach had better qualitative descriptions of the problem. There was no difference found between the two groups in terms of the students' planning, organization and mathematical execution. The study also showed that there was no difference in the conceptual gain experienced by both groups.

Koman , K. (1995). Newton, one-on-one. retrieved Sep 15, 2004, from Eric Mazur's physics class at Harvard Web site: http://www.columbia.edu/cu/gsapp/BT/RESEARCH/mazur.html.

> Website with an article from the *Harvard Journal* discussing Eric Mazur's physics class and gives some examples of questions that students are asked to solve.

Leonard, William J., Gerace, William J.; Dufresne, Robert J., (1999a). Concept-Based Problem Solving: Making Concepts the Language of Physics. Technical Report. 1-20.

> *Accession Number: ED468197*
> This article highlights the key content area used to design the Minds on Physics curriculum. The authors focus on five areas that help students understand conceptual physics: exploring current student concept, clustering concepts, develop analytical and reasoning skills, develop problem solving skills, and structuring knowledge in memory. For each area is presented with research supporting concept, teaching instruction and examples of classroom instruction and practices. The focus of the curriculum is to develop deep understanding of content instead of memorizing superficial ideas.

Leonard, William J., Dufresne, Robert, J., Gerace, William J., and Mestre, Jose P. (1999b). *Minds On Physics Activities and Reader: Conservation Laws & Concept-Based Problem Solving.* Kendall/Hunt Publishing Co., Dubuque, Iowa.

> Student text book for the Minds on Physics program. This particular text is the third in the series focusing on collisions, work and energy. Thirty activities of questions are given for the students along with two chapters of text.

Neto, Antonio, Valente, Maria Odete. (1997). Problem Solving in Physics: Towards a Metacognitively Developed Approach. *Paper presented at the Annual Meeting of the National Association for Research in Science Teaching*, 1-30.

Accession Number: ED405217
The use of a metacognitive problem-solving strategy improved student performance in problem-solving skills and in qualitative and quantitative physics problems. Approximately 80 Portuguese high school students participated in this study of using metacognitive strategies in solving physics problems. Three sections of students participated in a five-month introductory mechanics class that used the metacognitive strategies. A fourth section, control group, learned for the five months under a traditional mechanics class that closely followed the text. Students were tested for both quantitative and qualitative problem solving ability as well as metacognitive problem solving strategies. Students were also measured for their attitude toward physics, physics problem solving and metacognitive problem solving. Students who followed the metacognitive strategies experienced a larger change from pre-test to post-test for their ability to solve qualitative problems, quantitative problems, and their understanding of metacognitive strategies. Students in the traditional group experienced a decrease in their attitude for physics while their counterparts in the experimental groups had no change in their attitudes.

Ploetzner, Rolf; Fehse, Eric; Kneser, Cornelia; Spada, Hans. (1999). Learning to Relate Qualitative and Quantitative Problem Representations in a Model-Based Setting for Collaborative Problem Solving. *Journal of the Learning Sciences*, v8 n2, 177-214.

Accession Number: EJ586625
This study looked at twenty-four female tenth grade German students' ability to solve mechanics problems based upon whether they studied qualitative or quantitative problems first. All students had attended classes on the basics of mechanics prior to participating in the study. The students were divided into three groups. All students took a pretest, intermediate test, and posttest to measure their progress through the weeklong study. The qualitative and quantitative groups both received instruction in using and developing concept maps (the method of instruction in this study) as well as instruction in the aspects of qualitative or quantitative mechanics prior to the intermediate test. After the intermediate test, pairs of students were formed with one member being from the qualitative group and the other from the quantitative group. The pairs then worked on problems that are more difficult collaboratively. The problems were designed to use both qualitative and quantitative aspects so that each member of a pair would learn from the other. After several problems were solved collaboratively, the posttest was given. The control group was not given any instruction between tests nor received any feedback on their tests. Both experimental groups test scores showed improvement throughout the study while the control group remained constant. Both experimental groups showed about the same increase from pretest to intermediate test indicating that the instruction with concept maps was effective. The test results also indicated that the qualitative students learned more from their quantitative partners than the other way around.

Tao, Ping-Kee. (2001a). Developing Understanding through Confronting Varying Views: The Case of Solving Qualitative Physics Problems. *International Journal of Science Education*, v23 n12, 1201-18.
Tao, Ping-Kee. (2001b). Confronting Students with Multiple Solutions to Qualitative Physics Problems. *Physics Education*, v36 n2, 135-139.

Accession Number: EJ638167 & EJ635903

A class of secondary students in Hong Kong took a test of qualitative problems covering topics they studied in the previous class. Students worked in pairs to solve the problems. The next day each pair used their graded test and a set of solutions to the problems to compare their solution to those presented. Multiple solutions were presented for each problem. The student groups performed very poorly on the test even though the material was a review of the previous year. When asked to reflect upon their solutions compared to the multiple solutions given for the problem, the students gave deep responses highlighting where they made their mistakes and sometimes on their approach to the problem. Student performance increased significantly on a second test given months later indicating that the approach helped students to improve their conceptual knowledge on physics. Many of the students commented that the experience helped them to think more about the concepts of physics instead of relying on just the formula.

Van Heuvelen, Alan. (1991a). Overview, case study physics. *American Journal of Physics*, v59 n10, 898-907.

Accession Number: 4013883
The study consisted of various trials of Overview case study physics (OCS) between 1987 and 1990. The trials looked at both pre-calculus and calculus based beginning physics classes at major universities. Each trial compared a section using OCS with a section following traditional instruction. Both sections were given a qualitative pretest and posttest and a quantitative final exam. In the various trials, it was shown that students in the OCS sections had a larger gain in scores on the qualitative tests and scored significantly higher on the quantitative final for the class. It was also shown that after eight months students in the OCS students scored higher than students that were just one month removed from a traditional class. The author concludes that students learning under OCS experience a significant gain in qualitative understanding that is not seen by students in traditional course and students who use qualitative representations in their quantitative problem-solving score better on quantitative tests.

Van Heuvelen, Alan. (1991b). Learning to think like a physicist: a review of research-based instructional strategies. *American Journal of Physics*, v59 n10, 891-7.

Accession Number: 4013882
This article presents the general principles for using Overview, Case Study Physics (Studied in Van Heuvelen 1991 *Overview, case study physics*). Example problems are given as well as the underlying rationale for using the OCS program. Several instructional strategies are discussed.

Van Heuvelen, A. (n.d.). retrieved Aug 20, 2004, from Ohio State Physics Education Research Group Web site: http://www.physics.ohio-state.edu/~physedu/index2.html.

Experiment problem example for the efficiency of an electric toy truck. The webpage provides links to other Experiment Problems.

Van Heuvelen, Alan; Allen, Leith; Mihas, Pavlos. (1999). Experiment Problems for Electricity and Magnetism. *Physics Teacher*, v37 n8, 482-85.

Accession Number: EJ593899
Article that provides examples of electricity and magnetism problems that are designed to be used as laboratory exercises. Each problem provides information for instructors on how to implement the problem.

Van Heuvelen, Alan. (1995). Experiment Problems for Mechanics. *Physics Teacher*, v33 n3, 176-80.

Accession Number: EJ500188
In this article Van Heuvelen provides a framework for using experiment problems in class. Also included are several examples of problems from the mechanics section. Some of the problems involve more advanced topics such as spring constants and circular motion.

Wood, Charles, (1985). Solving Physics Problems. *Physics Teacher*, v23 n1, 32-33.

Accession Number: EJ312595
A high school teacher in Pennsylvania presents the idea of giving students a problem-solving strategy in the form of a flow chart. His premise is that students following a consistent strategy will improve their problem solving ability and be able to solve problems of moderate difficulty.
There was no experiment used to test the helpfulness of the method. Although no study is conducted for this strategy, the author points out that instruction on the skills of problem solving have been shown to increase students' performance in physics and other classes.

Wright, David S., Williams, Clayton D. (1986). A WISE Strategy for Introductory Physics. *The Physics Teacher*, v24, 211-216.

Accession Number: BEDI86010947
Using a structured problem-solving strategy for every problem can improve student communication and performance. When problem-solving skills are improved, students have a better attitude about physics. No formal study of this problem-solving approach was conducted. It was developed as an instructional tool based upon "recent research in cognitive process instruction" (p. 215). Students and the instructor were surveyed and interviewed several times to support the validity of the approach. After using the problem-solving approach designed by the authors, students had a better attitude about physics and developed confidence in solving physics problems. The authors also found that students were better able to communicate to the instructor and each other because the problem-solving approach gave them a common framework in which to discuss the problems and concepts of physics.