USING THE LEARNING KNOWLEDGE BASE: THE CONNECTION BETWEEN PROBLEM SOLVING AND COOPERATIVE GROUP TECHNIQUES

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There is no known "best" way to teach. The most effective teaching method depends on the specific goals of a course, the strengths of the instructor, the needs of the students, and the constraints imposed by the situation. Determining a few achievable course goals is the first, and most important step in teaching. Because most of our introductory students are not our majors, we asked the faculty from departments who required their students to take our courses to choose from a set of possible goals. Based on the results of that questionnaire, problem solving became an explicit goal of our introductory physics courses. This goal seems consistent with the way physics courses are traditionally taught, solving problems to reinforce conceptual knowledge.

We found, however, that what our students were doing was not problem solving. Indeed most of our questions, even though they involved calculation, were not problems. Moreover, physics education research has shown that students often do not understand the concepts underlying that question even when they can calculate the correct answer to a typical physics question. In order to teach introductory physics using problem solving, we were forced to adopt the techniques of cooperative grouping, develop a problem structure called Context Rich Problems, and teach an expert-like problem solving framework. The resulting curricular tool, called Cooperative Problem Solving, is based on a research foundation from cognitive psychology, education, and discipline specific educational research in chemistry, mathematics, and physics. In what follows, we will briefly describe this foundation upon which you can build your own curricular tools. The details of Cooperative Problem Solving and the questionnaire we used can be found on our web site, http://groups.physics.umn.edu/physed/.

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A large amount of research has shown that students come to us with a well-developed knowledge base, including personal ideas about any subject matter. These personal ideas often do not match established concepts of the discipline. For example, about 80% of students entering our calculus-based introductory physics course think that, during a collision between a large truck and a small car, the force of the truck on the car is larger than the force of the car on the truck. Often these personal ideas are very resistant to change. We can appreciate why if we think of a student's knowledge base as a network of ideas and connections. Some knowledge is completely isolated -- easily changed, easily forgotten, and difficult to use. Most knowledge is interwoven with other experiences so it can be retained and used. Changing parts of this knowledge network is a complex process requiring the establishment, refinement, and deletion of connections that differ in detail for every individual. Because all perceptions are interpreted using this knowledge network, we can understand why neither clear explanations, dramatic demonstrations, nor hands-on activities are sufficient for a majority of students to learn.

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Using a learning theory can help point a way out of this dilemma. As in science, it is not necessary that a theory be TRUE in some absolute sense for it to be useful. A useful learning theory makes connections between as many different aspects of teaching and learning as possible. Of course, it agrees with the currently available data and has some predictive power. Luckily there are really only three fundamentally different learning theories from which to choose. Of those, the newest, called Cognitive Apprenticeship directly addresses the difficulties of teaching our classes. This theory is based on two observations.

1. Learning is a complex process that depends on student's existing knowledge and how they use that knowledge. Learning depends on the unique background of each learner.

2. Apprenticeship is the most effective type of instruction that humans have devised for learning complex skills. It is, in fact, the basis of graduate education in the sciences.

A key element of apprenticeship is that learning be directly connected to a situation that is meaningful to the student. It is essential that the student observe the action of an expert in its entire context from beginning to end. This is called modeling. The beginning of an action must have a motivation meaningful to students. The end of an action must be a conclusion that students perceive as useful. Observing, however, is not enough for learning to occur. Students must practice what they have observed under the guidance of a coach who allows students to adapt the expert's actions in their own way while giving feedback to make those actions more expert-like. In addition to modeling and coaching, the student must perform the task without guidance. This phased withdrawal of support is called fading. Clearly, modeling, coaching, and fading do not constitute a linear process.

Apprenticeship is probably they way most people would teach if their own teaching knowledge structure had not been influenced by their experiences in a classroom. To illustrate this, suppose that you were interested in teaching a group of people a complex but non-academic skill that requires mental agility and technical skill so that they can make decisions that lead to a definite result. For example, you might want to teach people ignorant of basketball how to play basketball. You would not start by having them learn the history of the game, or the names and performance records of the teams, or the rulebook, or about the motion of the ball starting from kinematics and the definition of velocity and acceleration. You would not even have them begin by learning the necessary skills of shooting, passing, rebounding, and dribbling. You would certainly not give them a logic course showing how to go from premise to conclusion. You would first have them watch a basketball game. Of course, these novices would not notice most of the things that happen on the court, and would misinterpret some events even with your clear explanations. Initially watching a game could be a confusing and boring experience. You might need to supply motivation with your own enthusiasm. Next you would play a game with your students where you concentrate on showing how to perform all the basic skills, such as dribbling and shooting, at a rudimentary level sufficient to start playing. While the students do these tasks, you provide only the most basic feedback and encouragement until they have some success.

Now the students can play a game. While playing the game, the novices coach each other, mostly by demonstrating how they do something. When appropriate, you coach individual students on something they are trying to do. Soon you will take your students to see another game which they will find less confusing than the first one they observed. They will notice a larger fraction of the action and begin to predict what will happen. They might even begin to find some of your narration useful, and even ask some questions. The students will also begin practicing some skills on their own. But you will be careful to initially keep these individual practice sessions short so they do not reinforce bad habits. The interleaved process of watching basketball games (modeling), playing with your coaching (expert coaching), playing without your coaching (peer coaching and fading), and individual practice (fading) continues until each student reaches their desired level of performance. As

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your students learn the basic skills you also explicitly emphasize the important concepts of teamwork, strategy, discipline, and assertiveness.

In cognitive apprenticeship a rich realistic context (the basketball game) and the modeling, coaching, and fading functions must be achieved in a class setting. Problem solving can provide a rich context that requires making decisions by connecting different types of knowledge, such as concepts, facts, and procedures, to arrive at a result. While observing an instructor model problem solving, each student can match their own knowledge network against that of the instructor to become aware of mismatches or missing parts. During coaching, the student practices using their knowledge network to attempt to solve the problem. The coach helps the students identify specific misconnections or missing parts of their particular network. While solving problems on their own, students reinforce new connections with practice, erase ineffective connections by lack of use, and become aware of defects in their knowledge network, so that coaching and modeling become more effective.

This process is usually difficult, time consuming, and frustrating. Most people work very hard to not to engage in real problem solving. There is nothing wrong with avoiding the problem solving. Experts frequently invent techniques to do just that. However, using problem-solving avoidance techniques is certainly counterproductive if you are trying to learn how to solve problems or are using problem solving as the context to investigate and renovate your knowledge network. Left to their own devices, most students avoid problem solving by using techniques such as pattern-matching or formula manipulation. Even textbooks sometimes give procedures that help a student get an answer while avoiding problem solving.

Whether or not a question is a problem depends on the viewpoint of the person seeking a solution. Even though it would be easy and perhaps enjoyable, a college varsity basketball team would not improve by playing an elementary school team. Likewise, students must solve real problems to benefit. Those problems must require that students make decisions that probe their knowledge network. Real problem solving has been described as the decision making process of arriving at a solution when you don't know the path. As soon as a person knows how to construct a specific solution, even if they don't know the answer, then the question is not a problem for them. This does not mean that such questions are without value. Questions that require students to repeat a certain technique are as necessary as practicing a jump shot. Just as one would never confuse jump shot practice with playing a basketball game, this type of question, called exercises, should not be confused with problems. Unfortunately, in physics textbooks this is often the case.

It takes a great deal of confidence for a student to embark on a problem solution based only on fundamental concepts, logic, and mathematics. Most people require the additional guidance of a framework. The purpose of a framework is to guide a person toward making connections both among concepts and between those concepts and the rest of their knowledge. The framework is a logical and organized guide to the decisions necessary to arrive at a problem solution. It gets students started, guides them to what to consider next, organizes their mathematics, and helps them determine if their answer is correct. Research shows that most experts use a similar framework, which has been articulated in many different forms. Perhaps the most well known was given by the mathematician George Polya a half century ago.

1. Understand the Problem (i.e., define the problem)

2. Devise a Plan

3. Carry Out the Plan

4. Look Back (i.e., check your results)

Whatever form of this framework you use, it must be adapted to address the needs of your particular students. There are many examples available, including our own. For most students to engage in solving problems, they must learn and practice using a framework.

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It is clear that appropriate problems can provide the rich context that is necessary for instruction based on cognitive apprenticeship. Solving those problems is a difficult task requiring a student to use a new procedure (a problem solving framework) that requires making decisions about new concepts (e.g., vector kinematics) based on a flawed knowledge network (e.g., heavier objects fall faster), perhaps using new techniques (e.g., integral calculus). It's as complicated as learning how to play basketball. Cognitive apprenticeship provides an instructional framework. First your students need modeling. You need to show students how to solve problems using your version of a problem solving framework by solving appropriate problems in detail. This detail must include identifying and making explicit all of the decisions that an average student would encounter. Unfortunately solution examples in textbooks never have the details necessary to be problem solving models. This modeling can be provided by lectures and written examples posted on the web. Initially, most students will not be able to follow these solutions because they will seem too complicated, even when accompanied by your clear and detailed narration. This is no different than seeing your first basketball game. Just seeing the game does not make you a basketball player.

Now the students need coaching. Students must work on appropriate problems that they cannot solve using problem-solving avoidance strategies. Initially they cannot make headway by themselves and constant coaching is necessary. An efficient way of providing this type of coaching is the technique of cooperative grouping. Cooperative group techniques are necessary because most students are not familiar with working efficiently in a group. Indeed research has shown that there is little or no benefit in having students work together in groups without the structure that ensures peer coaching will take place.

As in basketball, peer coaching is not enough. Expert coaching is provided by an instructor who makes short, targeted interventions with a group needing assistance. Coaching aids, called scaffolding, can be employed, such as worksheets that specify a place for each step of the problem-solving framework. This scaffolding must be removed well before the end of the course if students are to integrate their version of the framework into their knowledge network. Although some instructors can arrange cooperative group coaching in a large lecture setting, the most natural place for it to occur is in discussion and laboratory sections. Smaller classes can easily integrate modeling, coaching, and fading during a single class session. Fading occurs when students work as individuals on homework or tests. The interleaved process of watching problems being solved (modeling), solving problems in cooperative groups (peer and expert coaching), and individual practice (fading) continues until each student reaches their desired level of performance.

In science classes, introducing students to problem solving is both an end in itself and a technique for providing a situation of expert practice that is a necessary condition for teaching within a cognitive apprenticeship framework. In turn cognitive apprenticeship provides the motivation for coaching that can be achieved using cooperative group techniques. Combining problem solving and cooperative group techniques, as organized by cognitive apprenticeship, gives a powerful tool for teaching complex subjects and provides an example of using learning research to design teaching strategies.