

# Brief Introduction to Roles of Computers in Problem Solving

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# **Brief Introduction to Roles of Computers in Problem Solving**

## **Preface**

This document provides a relatively short overview of a large and complex field—problem solving and roles of Information and Communication Technology (ICT) in problem solving. The document has two main audiences and purposes:

1. It is intended for use in non-ICT courses for preservice and inservice teachers. There, it provides background needed as the courses focus on their main content areas. Within these non-ICT content areas, a course will emphasize both lower-order and higher-order skills. Instruction in both components of a discipline is intended to increase expertise in posing, representing, and solving the problems of the discipline. Thus, problem solving is part of every discipline.
2. It is intended for use in workshops for inservice teachers, school administrators, and teachers' aides. Here the intent is to improve education by helping educators understanding the steadily increasing power of ICT to empower students in posing, representing, and solving complex problems.

The field of problem solving is being aided by the current rapid progress in Brain Science. An introduction to Brain Science for educators is available on the Oregon Technology in Education (OTEC) Website.

This document is divided into a number of short parts, or units. Each contains some suggestions for immediate actions (implementations) for teachers. Each part ends with a set of activities that are suitable for self-study, use in a workshop, or use in a course.

## **Part 1: Introduction and Overview**

We all solve problems, all of the time. The mind/body processes of living involve continually dealing with a host of problems. But, essentially all of this takes place at a subconscious level, and you are born with the ability to solve such problems at a subconscious level.

When you carry on a conversation or read a book, you are solving complex communications problems. While much of what you are doing is taking place at a subconscious level, it took thousands of hours to train your brain to perform the needed tasks quickly and with little conscious effort. Simultaneous with the automated subconscious efforts, your brain is actively and consciously involved in making meaning and conveying meaning in these endeavors.

Your brain has a considerable ability to learn. Learning and practicing what you have learned are natural and ongoing activities within your brain. That is, we are all life-long learners.

Our PreK-12 and higher formal education systems were designed to develop the capacity of your brain to deal with the problems that our society feels you might encounter as you grew into adulthood. As you progressed along this formal education trail, you gradually took more responsibility for yourself in deciding what courses to take and what general academic areas to pursue. You developed your knowledge and skills in knowing how to learn. You gradually gained increased expertise in being an independent, self-sufficient learner in the types of areas covered by formal education and other areas that interested you. You got better at solving the types of problems and accomplishing the types of tasks that you encountered at work, school, play, and in other components of your everyday life.

It may feel strange to you to think about life from the point of view of getting better at solving problems and accomplishing tasks. But, that is one way to think about our informal and formal education systems. So, if you are going to spend your life increasing your capacity as a problem solver, likely you will find it worthwhile to gain efficiency in this endeavor. If you are a preservice or inservice teacher, then certainly you want to get better at solving the problem (accomplishing the task) of helping your students get better at problem solving. That is the purpose of this document.

This document gives a brief overview of the "subject" of problem solving and of roles of Information and Communication Technology (ICT) in problem solving. It is targeted specifically toward preservice and inservice teachers. The ideas from this document can be woven into instruction in almost any curriculum area.

Problem solving and critical thinking are closely connected fields of study. Diane Halpern's area of specialization is critical thinking as a component of cognitive psychology. In her 2002 article *Why Wisdom? Educational Psychologist*, 36(4), 253-256, she says:

The term critical thinking is the use of those cognitive skills or strategies that increases the probability of a desirable outcome. It is purposeful, reasoned, and goal directed. It is the kind of thinking involved in solving problems, formulating inferences, calculating likelihood, and making decisions. Critical thinkers use these skills appropriately, without prompting, and usually with conscious intent, in a variety of settings. That is, they are predisposed to think critically. When we think critically, we are evaluating the outcomes of our thought processes—how good a

decision is or how well a problem is solved. Critical thinking also involves evaluating the thinking processes—the reasoning that went into the conclusion we have arrived at or the kinds of factors considered in making a decision.

For more about cognitive psychology and critical thinking see the Diane Halpern article given in the references of this document.

Indiana University Purdue University Indianapolis provides a somewhat more functional definition of critical thinking (IUPUI).

[Critical thinking is] [the ability of students to analyze information and ideas carefully and logically from multiple perspectives. This skill is demonstrated by the ability of students to:

- analyze complex issues and make informed decisions;
- synthesize information in order to arrive at reasoned conclusions;
- evaluate the logic, validity, and relevance of data;
- solve challenging problems, and;
- use knowledge and understanding in order to generate and explore new questions.

The term “higher-order” thinking is often used in discussing problem solving. The work of Lauren Resnick is often quoted in discussing this issue (Resnick, 1987). She states that higher order thinking:

- Is nonalgorithmic—the path of action is not fully specified in advance;
- Is complex—with the total path not visible from any single vantage point;
- Often yields multiple solutions, each with costs and benefits;
- Involves nuanced judgment and interpretation;
- Involves the application of multiple criteria, which sometimes conflict with one another;
- Often involves uncertainty, because not everything that bears on the task is known;
- Involves self-regulation of the thinking process, rather than coaching at every step;
- Involves imposing meaning, finding structure in apparent disorder;
- Is effortful, with considerable mental work involved.

In this document we use the term **problem solving** to include all of the following activities:

- posing, clarifying, and answering questions
- posing, clarifying, and solving problems
- posing, clarifying, and accomplishing tasks
- posing, clarifying, and making decisions
- using higher-order, critical, and wise thinking to do all of the above

Problem solving and critical thinking are very broad ideas and activities. They are an important aspect of every academic area.

Our educational system attempts to differentiate between lower-order cognitive (thinking) skills and higher-order cognitive (thinking) skills. While there is no clear line of demarcation, in recent years our educational system has placed increased emphasis on the higher-order skills end of such a scale. In very brief summary, we want students to learn some facts (a lower-order skill), but we also want them to learn to think and solve problems using the facts (a higher-order skill).

Often the thinking and problem solving that we want students to do is to recognize, pose, clarify, and solve complex, challenging problems that they have not previously encountered.

For example, consider the teaching of writing. You may consider good penmanship and correct spelling to be important, but most people would consider these to be lower-order goals. Learning to write in a manner that communicates effectively is a higher-order goal. In some sense, each writing task is a new problem to be solved.

Moreover, writing is a powerful aid to the brain. Miller (1956) discusses the magic number  $7 \pm 2$ . He and many others have observed that a typical person's short term memory is limited to about  $7 \pm 2$  pieces or chunks of information. Thus, probably you can look up a phone number (seven digits) and remember it long enough to key in into a telephone pad. Your short-term memory is easily overwhelmed by a problem that contains a large number of components that need to be considered all at one time. Skill in reading and writing extends the capabilities of your brain to deal with complex, multi-component problems. That is, reading and writing are brain tools that significantly increase your problem-solving abilities.

A few schools actually offer specific courses on problem solving. For the most part, however, students learn about problem solving through instruction in courses that have a strong focus on a specific content area such as art, history, reading, science, mathematics, music, and writing. Every teacher teaches problem solving within the specific subject matter areas of their curriculum.

Many people have observed that the "every teacher teaches problem solving" is a haphazard approach, and that the result is that students do not get a coherent introduction to problem solving. When a student reaches a specified grade level, can the teacher assume that a student knows the meaning of the terms problem, problem posing, and problem solving? Can the teacher be assured that the student has learned certain fundamental ideas about posing, representing, and solving problems? Can the teacher be assured that the students know a variety of general-purpose strategies for attacking problems? In our school system at the current time, the answer to these questions is "no."

Thus, each teacher is left with the task of helping his/her students master both the basics (fundamentals) of problems solving and then the new problem-solving topics that the teacher wants to cover.

This document covers the basics (fundamentals) of problem solving. It is designed as a general aid to teachers who need to cover the basics with their students. Of course, the basics need to be interpreted and presented at a grade-appropriate level. This document does not try to do that. It is left to individual teachers to understand the basic ideas and then present them in a manner that is appropriate to their students.

This document places particular emphasis on several important problem-solving ideas:

1. Posing, representing, and solving problems are intrinsic to every academic discipline or domain. Indeed, each discipline is defined by the specific nature of the types of problems that it addresses and the methodologies that it uses in trying to solve the discipline's problems.
2. There are some tools (for example, reading and writing) that are useful in addressing the problems in all disciplines. Information and Communication Technology provides us with some new and powerful tools that are useful aids to problem solving in every discipline.
3. Much of the knowledge, techniques, and strategies for posing, representing, and solving problems in a specific domain requires a lot of knowledge of that domain and may be quite specific to that domain. However, there are also a number of aspects of posing, representing, and solving problems that cut across many or all domains, and so there can be considerable transfer of learning among domains. Our educational system should help all students gain a significant level of expertise in using these broadly applicable approaches to problem solving. Learning to effectively do transfer of learning is one of the more important goals in education.

### **Immediate Actions for Part 1**

Part 1 suggests that every teacher teaches problem solving, lower-order skills, higher-order skills, and transfer of learning. Talk to your fellow teachers about this set of ideas. Look for the nature and extent of agreement and disagreement among teachers of a variety of disciplines and grade levels. Engage your students in the same conversation. By carrying on such conversations with your fellow teachers and students you will increase your understanding of problem solving, lower-order skills, higher-order skills, and transfer of learning.

### **Activities for Part 1**

1. Select a discipline that is a standard part of the PreK-12 curriculum. Name several important lower-order skills within the discipline. Name several important higher-order skills. Compare and contrast lower-order and higher-order skills within the discipline. Keep in mind that there is no fine dividing line between lower-order and higher-order skills. However, try to select examples in which you feel there is a clear distinction.
2. Repeat Activity 1, but with a different discipline. Then: A) Compare and contrast the lower-order skills within the two disciplines; and B) Compare and contrast the higher-order skills within the two disciplines. Keep in mind that every discipline has lower-order and higher-order skills. This idea parallels the idea that every discipline can be defined by the types of problems that it addresses and the types of methodologies that it uses to represent and solve problems.
3. Select two different broad discipline areas such as social studies and science. Compare and contrast your problem-solving skills in these two areas. To do this, you might want to name some typical problems that each area addresses. Then analyze your current level of skill in addressing these problems. Pay particular attention to the differences that you find between

your level and type of expertise in the two areas. This type of self-analysis is an important aspect of getting better at problem solving.

4. Name several relatively challenging problems that you have solved during the past few days. Your problems should come from a variety of settings, such as home, work, play, school, and so on. Think about what you learned by solving these problems. That is, do metacognition, and be reflective. Metacognition and reflectiveness are key aspects of getting better at problem solving.
5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 1 of this document from the point of view of applicability to students at that grade level and/or in that content area.
6. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 1. Identify your current strengths and weaknesses in ICT from this point of view. One of the topics you might want to address is the issue of memorization versus learning to “look it up.” ICT has made it much easier to search for and retrieve needed information.



## Part 2: What is a Formal Problem?

Problem solving consists of moving from a given initial situation to a desired goal situation. That is, problem solving is the process of designing and carrying out a set of steps to reach a goal. Figure 2.1 graphically represents the concept of problem solving. Usually the term *problem* is used to refer to a situation where it is not immediately obvious how to reach the goal. The exact same situation can be a problem for one person and not a problem (perhaps just a simple activity or routine exercise) for another person.

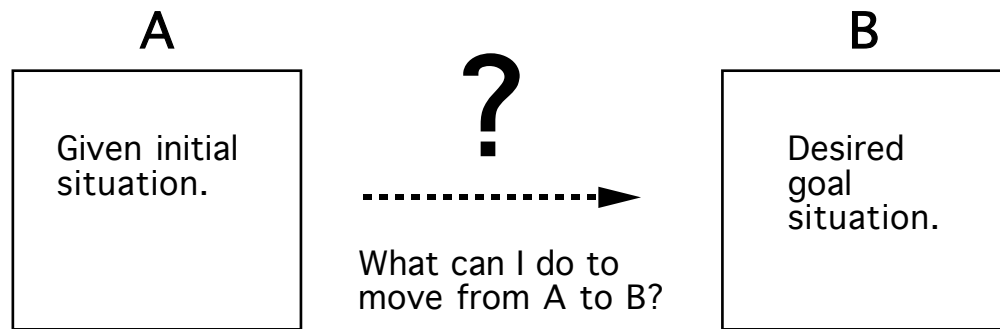


Figure 2.1. Problem-solving—how to achieve the final goal?

There is a substantial amount of research literature as well as many practitioner books on problem solving (Polya, 1957; de Bono, 1985; Frensch and Funke, 1995; Moursund, 2001). Here is a formal definition of the term problem. You (personally) have a problem if the following four conditions are satisfied:

1. You have a clearly defined given initial situation.
2. You have a clearly defined goal (a desired end situation). Some writers talk about having multiple goals in a problem. However, such a multiple goal situation can be broken down into a number of single goal problems.
3. You have a clearly defined set of resources that may be applicable in helping you move from the given initial situation to the desired goal situation. There may be specified limitations on resources, such as rules, regulations, and guidelines for what you are allowed to do in attempting to solve a particular problem.
4. You have some ownership—you are committed to using some of your own resources, such as your knowledge, skills, and energies, to achieve the desired final goal.

These four components of a well-defined (clearly-defined) problem are summarized by the four words: givens, goal, resources, and ownership. If one or more of these components are missing, you have an ill-defined problem situation rather than a well-defined problem. An important aspect of problem solving is realizing when you are dealing with an ill-defined problem situation and working to transform it into a well-defined problem.

There is nothing in the definition that suggests how difficult or challenging a particular problem might be for you. Perhaps you and a friend are faced by the same problem. The problem might be very easy for you to solve and very difficult for your friend to solve, or vice versa. Through education and experience, a problem that was difficult for you to solve may become quite easy for you to solve. Indeed, it may become so easy and routine that you no longer consider it to be a problem.

People often get confused by the resources (component 3) of the definition. Resources merely tell you what you are allowed to do and/or use in solving the problem. Indeed, often the specification of resources is implied rather than made explicit. Typically you can draw on your full range of knowledge and skills while working to solve a problem. But, typically you are not allowed to cheat (for example, steal, copy other's work, plagiarize). Some tests are open book, and others are closed book. Thus an open book is a resource in solving some test problems, but is cheating (not allowed, a limitation on resources) in others.

Resources do not tell you how to solve a problem. For example, you want to create a nationwide ad campaign to increase the sales by at least 20% of a set of products that your company produces. The campaign is to be completed in three months, and it is not to exceed \$40,000 in cost. Three months is a time resource and \$40,000 is a money resource. You can use the resources in solving the problem, but the resources do not tell you how to solve the problem. Indeed, the problem might not be solvable. (Imagine an automobile manufacturer trying to produce a 20% increase in sales in three months, for \$40,000!)

For many types of problems, ICT is a powerful resource. Thus, people who have a broad range of ICT knowledge and skill, and access to ICT facilities, have a very useful and general-purpose resource. This creates the same type of situations as exists for open book versus closed book tests. Authentic assessment strives to have the assessment environment close to the performance environment that students will encounter in the "real world." Open book and open computers are standard resources when solving real-world problems. But, often they are not allowed in tests in school setting.

Problems do not exist in the abstract. They exist only when there is ownership. The owner might be a person, a group of people such as the students in a class, or it might be an organization or a country. A person may have ownership "assigned" by his/her supervisor in a company. That is, the company or the supervisor has ownership, and assigns it to an employee or group of employees.

The idea of ownership can be confusing. In this document we are focusing on you, personally, having a problem—you, personally, have ownership. That is quite a bit different than saying that our educational system has a problem, our country has a problem, or each academic discipline addresses a certain category of problems that helps to define the discipline.

The idea of ownership is particularly important in teaching. If a student creates or helps create the problems to be solved, there is increased chance that the student will have ownership. Such ownership contributes to intrinsic motivation—a willingness to commit one's time and energies to solving the problem. All teachers know that intrinsic motivation is a powerful aid to student learning and success.

The type of ownership that comes from a student developing a problem that he/she really wants to solve is quite a bit different from the type of ownership that often occurs in school settings. When faced by a problem presented/assigned by the teacher or the textbook, a student may well translate this into, "My problem is to do the assignment and get a good grade. I have little interest in the problem presented by the teacher or the textbook." A skilled teacher will help students to develop projects that contain challenging problems that the students really care about.

Many teachers make use of Project-Based Learning (PBL) within their repertoire of instructional techniques (Moursund, 2002a). Within PBL, students often have a choice on the project to be done (the problems to be addressed, the tasks to be accomplished), subject to general guidelines established by the teacher. Thus, students have the opportunity to have a significant level of ownership of the project they are working on. Research on PBL indicates that this ownership environment can increase the intrinsic motivation of students.

### **Immediate Actions for Part 2**

Talk to your students about what they feel are really important aspects of education. Delve deeply, looking for possible problem-solving areas where your students have ownership. Then explicitly bring up the idea of ownership of "schooling." Engage your students in talking about their ideas of what schools might do to increase student ownership of schooling. Such conversations will increase your insights into why schools seem quite relevant to some students and not particularly relevant to others.

### **Activities for Part 2**

1. Specify two well-defined and significantly different problems that you have encountered and solved recently. For each, give a clear statement of the givens, goal, resources, and ownership. Discuss similarities and differences between the two problems, including relative degree of difficulty of the problems from your point of view. Reflect on how easy or difficult this activity is for you. Over time, you can get better at recognizing and stating the four components of problems that you deal with.
2. Give an example of a type problem that you have encountered frequently in the past, and that you now find much easier to solve than in the past. What did you do to make this type of problem easier to solve? What are some educational implications of this type of learning?
3. Give some examples of clearly defined problems that:
  - A. Have more than one solution.
  - B. Have no solution.
4. Think back to when you were a high school student. What did the teachers do to encourage intrinsic motivation and to give you increased ownership of the various types of homework problems (tasks, assignments) given to you? Cite some good and not so good examples. Include some of your thoughts on what teachers can do to increase intrinsic motivation of their students.

5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 2 of this document from the point of view of applicability to students at that grade level and/or in that content area.
6. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 2. Identify your current strengths and weaknesses in ICT from this point of view.

### **Part 3: Problem Posing and Clarification**

Many of the things that people call problems are actually ill-defined (poorly-defined) problem situations. In such cases, one or more of the four components of a clearly defined problem are missing. For example, you turn on a television set and you view a brief news item about the homeless people in a large city and the starving children in a foreign nation. The announcer continues with a news item about students in our schools scoring poorly on an international test, relative to those from some other countries. The announcer presents each news item as a major problem. But, are these really clearly defined problems from your point of view?

You can ask yourself four questions:

1. Is there a clearly defined given initial situation? (Do I really know the facts? Can I check out the facts through alternative sources that I feel are reliable?)
2. Is there a clearly defined goal? (Is it really clear to me how I would like things to be? Are there a number of possible goals? Which goal or goals seem most feasible and viable? Will I be able to tell if the goal I select has been achieved?)
3. Do I know what resources are available to me that I could use to help achieve the goal? In addition, are there rules, regulations, and guidelines that I need to know about as I work to solve this problem?
4. Do I have ownership—do I care enough to devote some of my own resources? (Am I willing to spend some of my own time, money, and mental and physical energy on achieving the goal?)

If you can answer "yes" to each of these questions, then you (personally) have a formal, clearly defined problem.

Often, your answer to one or more of the questions will be "no." Then, the last question is crucial. If you have ownership—if you really care about the situation—you may begin to think about it. You may decide on what you feel are appropriate statements of the givens and the goal. You may seek resources from others and make a commitment of your own resources. You may then proceed to attempt to solve the problem.

Remember, just because you have a clearly defined problem does not mean that you (or indeed, anyone else) can solve it. A clear definition of a problem is a starting point for attempting to solve a problem. Often the process of attempting to solve a problem leads to posing a new, related problem that better fits your knowledge and skills, resources, and level of commitment.

The process of creating a clearly defined problem is a combination of problem posing and problem clarification. It usually proceeds in two phases. First, your mind/body senses or is made aware of a problem situation. You decide that the problem situation interests you—you have some ownership. Second, you begin to work on clarifying the givens, goal, and resources. Perhaps you consider alternative goals and sense which would contribute most to your ownership of the problem situation.

Identifying and posing problem situations, and then transforming them into well-defined problems, are higher-order thinking tasks. These tasks are not adequately addressed in our educational system. To a very large extent, students are asked to work on problems that are posed by the teacher and/or the curriculum materials. The problems tend to be quite limited in scope and typically lack a "real world" quality. Typically, students are not asked to explore problem situations such as hunger, homelessness, prejudice, terrorism, and so on. They tend to (incorrectly) "learn" that all problems have solutions, and that they are "dumb" or not working hard enough if they do not find "the solution" to a problem that has been assigned.

The result of the problem-posing process is a problem that you understand well enough so that you can begin to work on solving it. As you work on the problem, you will likely develop a still better understanding of it. You may redefine the goal and/or come to understand the goal better. You may come to understand the given initial situation better; indeed, you may decide to do some research to gain more information about it. Problem posing and clarification are an ongoing process as you work to understand and solve a problem.

Problem posing is a higher-order thinking skill that is an integral component of every domain. Moreover, it is an aspect of problem solving that cuts across all discipline areas.

### **Immediate Actions for Part 3**

Talk to your students and colleagues to see what they know about the general ideas of problem and problem solving. Focus the discussion on the nature of the types of problems that one encounters in the "real world" versus the nature of the types of problems that one studies in school. For example, are the real-world problems that they deal with less clearly defined and/or much more complex than the types of problems that schools focus on?

### **Activities for Part 3**

1. In your own words, explain the importance of distinguishing between an ill-defined problem and a well-defined problem. Give one or more personal examples to support your analysis.
2. Consider some issues such as the environment, global warming, homeless, hunger, poverty, prisons, terrorism, war, etc. Select a specific topic and develop two different well-defined problems for that topic. For example, you may feel that global warming is a very important issue that people face. You feel that all people on earth should have individual and group ownership of the problem of global warming. But the reality is that many people are not aware of this problem situation, many claim that global warming is not occurring, and others claim that it is not a serious threat. From this type of confused situation you are to develop two well-defined problems. Remember, these must satisfy the 4-component definition of a well-defined problem.
3. Problem posing is a relatively new idea in school curriculum. Think back over your formal education. Give examples in which problem posing was discussed and you were encouraged to pose problems. If you cannot think of any examples, this suggests that problem posing was not covered in your education. In that case, discuss why you think problem posing was omitted.

4. Select a grade level and a subject area. Give some examples of problem posing that you feel are appropriate to this grade level and subject area. How would you assess student knowledge and skill in problem posing at this grade level and in this subject area?
5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 3 of this document from the point of view of applicability to students at that grade level and/or in that content area.
6. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 3. Identify your current strengths and weaknesses in ICT from this point of view. Be sure to include a discussion of your knowledge and skills in using ICT as a resource in problem solving across the disciplines that you teach or are preparing to teach.

## Part 4: Problem and Task Team

Information and Communication Technology (ICT) includes a wide variety of tools (resources) that can aid a person in solving a problem. In addition, ICT is often a useful aid as one works to pose a problem and/or to transform an ill-defined problem situation into a well-defined problem.

Donald Norman is a cognitive scientist who has written extensively in the area of human-machine interfaces. Norman (1993) begins with a discussion of how tools (physical and mental artifacts) make us smart. That is, tools make it possible for us to solve a wide range of intellectual and physical problems that we cannot solve without the tools.

David Perkins (1992) uses the term "Person Plus" to refer to a person making use of physical and mental tools. He notes that in many situations, a person with appropriate training, experience, and tools can far outperform a person who lacks these aids.

Donald Norman, David Perkins, and many others have put forth the idea of a person or team of people working together with mental and physical tools to solve complex problems and accomplish complex tasks. In this document we use the term Problem or Task Team (P/T Team) to refer to a person or a group of people and their physical and mental tools. Figure 3.1 illustrates the P/T Team. The concepts that make up the diagram are explained in subsequent paragraphs.

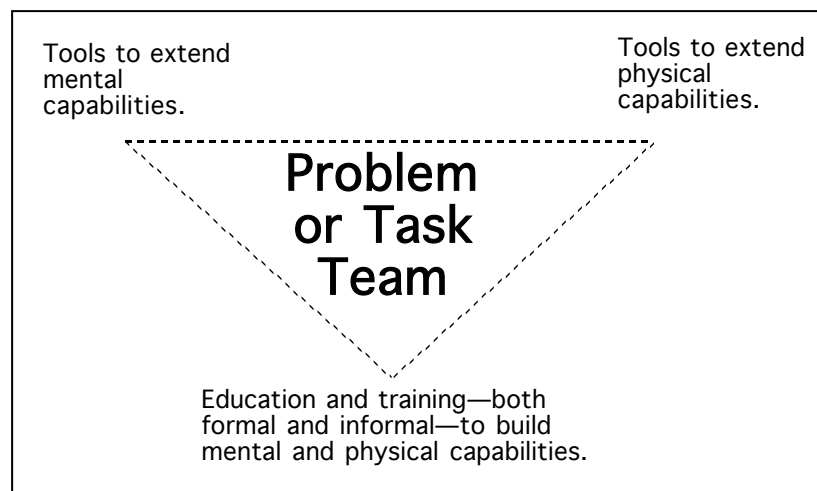


Figure 3.1. The P/T Team—People aided by physical and mental tools.

Figure 3.1 shows a person or a group of people at the center of a triangle of three major categories of aids to posing and solving problems:

1. Mental aids. Even before the invention of reading, writing, and arithmetic (about 5,000 years ago) people made use of notches on bones, drawings on cave walls, and other aids to counting and to keeping track of important events. Reading, writing, and arithmetic are mental aids.



These have led to the development of books, math tables, libraries, calculators, computers, and many other mental aids. Mental aids supplement and extend capabilities of a person's mind.

2. Physical aids. The steam engine provided the power that led to the beginning of the industrial revolution. Well before that time, however, humans had developed the flint knife, stone ax, spear, bow and arrow, plow, hoe, telescope, and many other aids to extend the physical capabilities of the human body. Now we have cars, airplanes, and scanning electron microscopes. We have a telecommunications system that includes fiber optics, communications satellites, and cellular telephones.
3. Educational aids. Education is the glue that holds it all together. Our formal and informal educational systems help people learn to use the mental and physical tools as well as their own minds and bodies.

The P/T Team diagram points to ways in which we can improve the performance of a P/T Team. We can develop better physical and mental aids, and make them available to the P/T Team. We can improve our educational system, so that the individual team members have more knowledge and skills—both in general, and in making use of the physical and mental tools. And, we can help team members learn to work effectively together.

At one time, computers were a costly and not readily available resource. This situation has changed dramatically over the years. In the United States and a number of other countries it is relatively common for a person to have easy access to a desktop computer at home, at work, and at school. Today's \$1,000 desktop computer is more powerful than the \$1,000,000 mainframe computer of 20 years ago.

ICT is a combination of both mental and physical aids. One way to think about this is the use of computers to automate factory machinery. Such machinery stores (contains, embodies) a certain type of knowledge, and the machinery can use that knowledge to carry out certain manufacturing tasks. An artificially intelligent, computerized robot provides another example of a combination of mental and physical tools.

The mental and physical aids components of a P/T Team are dynamic, with significant changes occurring over relatively short periods of time. The pace of change of ICT seems breathtaking to most people (Moursund, 1998).

On the other hand, our formal educational system has a relatively slow pace of change. This has led to the interesting situation of many preschool children growing up with routine access to mental and physical aids, learning their use through our informal educational system, and then encountering formal education that is woefully inadequate in dealing with such aids. For example, many elementary school students have more ICT knowledge and skill than do their teachers.

In our current society, people who are skilled at functioning well in a P/T Team environment have a number of distinct advantages over those who lack the knowledge, skills, and access to the facilities. Such analysis leads to the recommendation that the P/T Team and problem solving should be central themes in education.

Project-Based Learning (PBL) and ICT-Assisted PBL can be used to create environments in which teams of students work together to address complex problems. Indeed, the ideas of the P/T Team constitute strong arguments for routine use of ICT-Assisted PBL in our schools (Moursund, 2002a).

#### **Immediate Actions for Part 4**

Talk to your fellow teachers and to your students about the idea that in the “real world” many problems are worked on by teams of people. Move the conversations in the direction of teams of students learning to work together to solve complex problems. What do your students think about this idea? Similarly, what do your fellow teachers think about this idea both for students and for teachers? Ask your students and colleagues about their thoughts on possible roles of “loners” in a world where so many people are expected to work on teams as they solve problems.

#### **Activities for Part 4**

1. Make a list of some of the physical tools (aids to your physical body) that you routinely use. You will want to include clothing and shelter on your list. Do you have the knowledge and skills to survive without these physical tools?
2. Make a list of some of the mental tools (aids to you mind) that you routinely use. Do you have the knowledge and skills to survive without these mental tools?
3. Select several physical tools and several mental tools that you use frequently. Compare and contrast (physical tools versus mental tools) the time and effort that it has taken you to learn to make effective use of these two different categories of tools.
4. Discuss your current level of skills in working as a member of a team of people that is addressing a complex problem or working to accomplish a complex task. What have you done in the past to get better at being a team member and a team leader?
5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 4 of this document from the point of view of applicability to students at that grade level and/or in that content area.
6. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 4. Identify your current strengths and weaknesses in ICT from this point of view.

## Part 5: Transfer of Learning

Transfer of learning deals with transferring one's knowledge and skills from one problem-solving situation to another. You need to know about transfer of learning in order to help increase the transfer of learning that you and your students achieve.

Transfer of learning is commonplace and often done without conscious thought. For example, suppose that when you were a child and learning to tie your shoes, all of your shoes had brown, cotton shoelaces. You mastered tying brown, cotton shoelaces. Then you got new shoes. The new shoes were a little bigger, and they had white, nylon shoe laces. The chances are that you had no trouble in transferring your shoe-tying skills to the new larger shoes with the different shoelaces.

This example gives us some insight into one type of transfer of learning. Transfer occurs at a subconscious level if one has achieved automaticity of that which is to be transferred, and if one is transferring this learning to a problem that is sufficiently similar to the original situation so that differences are handled at a subconscious level, perhaps aided by a little conscious thought.

However, there are many transfer of learning situations that are far more difficult than shoe tying. For example, a secondary school math class might teach the metric system of units. From the math class, students go to a science class. Frequently the science teacher reports that the students claim a complete lack of knowledge about the metric system. Essentially no transfer of learning has occurred from the math class to the science class.

On a more general note, employers often complain that their newly hired employees have totally inadequate educations. Part of their complaint is that the employees cannot perform tasks on the job that they “should have” learned to do while in school. Schools respond by saying that the students have been taught to accomplish the tasks. Clearly, this is a transfer of learning problem that is owned jointly by schools, employees, and employers.

The goal of gaining general skills in the transfer of your learning is easier said than done. Researchers have worked to develop a general theory of transfer of learning—a theory that could help students get better at transfer. This has proven to be a difficult research challenge.

At one time, it was common to talk about transfer of learning in terms of near and far transfer. This “near and far” theory of transfer suggested that some problems and tasks are so nearly alike that transfer of learning occurs easily and naturally. A particular problem or task is studied and practiced to a high level of automaticity. When a nearly similar problem or task is encountered, it is automatically solved with little or no conscious thought. This is called near transfer. The shoe-tying example given above illustrates near transfer. A major goal in learning to read is to develop a high level of decoding automaticity. Then your conscious mind can pay attention to the meaning and implications of the material you are reading. A significant fraction of children are able to achieve this by the end of the third grade.

Many potential transfer of learning situations do not lend themselves to the automaticity approach. There are many problems that are somewhat related, but that in some sense are relatively far removed from each other. A person attempting to make the transfer of learning

between two such problems does not automatically “see” the connections between the two problems. Far transfer often requires careful analysis and deep thinking.

The theory of near and far transfer does not help us much in our teaching. We know that near and far transfer occur. We know that some students readily accomplish far transfer tasks, while others do not. We know that far transfer does not readily occur for most students. The difficulty with this theory of near and far transfer is that it does not provide a foundation or a plan for helping a person to get better at far transfer and dealing with novel and complex problems. It does not tell us how to teach to increase far transfer.

In recent years, the low-road/high-road theory on transfer of learning, developed by Salomon & Perkins (1988), has proven to be a more fruitful theory. Low-road transfer refers to developing some knowledge/skill to a high level of automaticity. It usually requires a great deal of practice in varying settings. Shoe tying, keyboarding, steering a car, and one-digit arithmetic facts are examples of areas in which such automaticity can be achieved and is quite useful.

High-road transfer involves: cognitive understanding; purposeful and conscious analysis; mindfulness; and application of strategies that cut across disciplines. In high-road transfer, there is deliberate mindful abstraction of an idea that can transfer, and then conscious and deliberate application of the idea when faced by a problem where the idea may be useful. The next section gives a few examples of such strategies.

### **Use of Strategies in High-Road Transfer**

Learning for high-road transfer can occur in any course. For example, suppose a math class is teaching the strategy of breaking a complex problem into a number of smaller, less complex problems. The goal is to break the complex problem down into a set of less complex problems, all of which you can solve. Give the strategy a name, such as *top-down strategy*. Then have students practice this strategy in many different math problem-solving situations. Then have students practice the strategy in a variety of non-math situations. The top-down strategy is useful in preparing a 4-course dinner, developing a business plan for a business, getting ready to go on a date, designing a building or a garden, writing (for example, creating an outline), and in a huge number of other problem-solving situations.

You want your students to reflect on the strategy and how it fits their ways of dealing with the problems they encounter. When faced by a complex problem, you want your students to consciously consider breaking it into more manageable pieces. That is, you want them to do/use high-road transfer of this strategy.

Similar comments hold for the research strategy of looking up needed information in a library or on the Web. Perhaps you are teaching such research strategies in a social studies course. You want students to transfer these research skills to all other academic domains. Help your students to use the library research strategy in a number of different domains, such as science, sports, and purchasing something they are interested in buying. When faced by a complex problem, you want your students to consciously consider doing research using a library or the Web.

## **Teaching for Low-Road and High-Road Transfer**

This discussion about low-road and high-road transfer of learning points to ways to help your students increase their transfer skills. A well-studied and effective approach is to teach “hugging” and “bridging” (Salomon and Perkins, 1988).

“Hugging,” means teaching so as to broaden the conditions for when low road transfer will occur. The child learning to tie a bowknot in a shoelace can also be learning to tie a bowknot in a string or ribbon holding a package. The child can practice tying bows with a variety of materials in a variety of setting, for a variety of purposes. For example, bow tying can be done with eyes closed or in the dark.

“Bridging,” means explicitly teaching for high-road transfer. Rather than expecting students to achieve high-road transfer spontaneously, the teacher facilitates student practice on some of the high-road transfers that they want students to be able to make. Teachers can point out explicitly the more general principles behind particular skills or knowledge. For example, suppose that you want students to make a high-road transfer between history and current events, and vice versa. Have students explicitly focus on similarities and differences between conditions that led to a civil war or a revolutionary war several hundred years ago, and conditions that might be leading to a civil war or revolutionary war in some country right now. This can be frequently practiced as relevant current events unfold from day to day, and as one looks at historical events throughout the ages.

## **Mindfulness and Reflectiveness**

You can also get better at high-road transfer through mindfulness and reflectiveness (metacognition). When faced by a complex problem, mentally run through your list of general-purpose strategies, checking to see if each strategy might be applicable and useful. View every complex problem-solving situation as an opportunity to learn. After solving a problem, reflect about what you have learned about problem solving by solving the problem. Be mindful of ideas that are of potential use in solving other problems. Similar reflection can profitably be applied to situations in which you try to solve a complex problem, but do not succeed.

## **Immediate Actions for Part 5**

Talk to your students and colleagues about transfer of learning. What does transfer of learning mean to them? In the conversations, ask for specific examples of transfer that they have accomplished inside and outside of the school environment. If the conversations suggest difficulty in transfer of school learning to the real world, use this an opportunity to talk about the relevance of school and how to make it more relevant.

## **Activities for Part 5**

1. Reflect on (do metacognition on) your current level of ability to do transfer of learning.
  - A. Give some examples in which you routinely do low-road transfer of learning. Discuss where, when, and how you achieved the level of automaticity that facilitates this low-road

transfer. An example might be fast keyboarding, a skill you learned in a semester-length course in high school.

- B. Give some examples in which you have recently done high-road transfer of learning. Most likely you will find it more difficult to find such examples than you did in (1A) low-road transfer. If so, reflect on and write about this difficulty.
2. One way to think about lower-order skills and higher-order skills is to think in terms of low-road and high-road transfer. In this type of analysis, lower-order skills are ones in which one can achieve the conditions for low-road transfer. Higher-order skills are ones in which one strives to meet the conditions for high-road transfer. From your point of view, discuss the merits of this approach. Give examples from your own learning and/or teaching.
  3. Bring to mind a moderately complex problem that you have recently solved. Reflect on what you have learned by solving the problem. What did you learn that contributes to increasing your overall expertise as a problem solver?
  4. Generally speaking, it takes a great deal of time and effort to learn something to the level of automaticity that facilitates low-road transfer. Thus, our formal education system needs to think carefully about its choice of areas in which it wants students to achieve low-road transfer. Name two or more current areas in the school curriculum that attempt to teach for low-road transfer, but that you feel could be given significantly decreased attention in the curriculum. Name two or more areas that you feel should be added to the curriculum and taught in a manner to achieve low-road transfer.
  5. Reflect back over your many years of formal education. Give some examples in which your teachers formally talked about transfer of learning and learning to make such transfers. If you have trouble thinking of such example, perhaps it is because little such formal instruction occurred. If that seems to be the case, speculate on why that was the case.
  6. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 5 of this document from the point of view of applicability to students at that grade level and/or in that content area.
  7. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 5. Identify your current strengths and weaknesses in ICT from this point of view.

## Part 6: Expertise and Domain Specificity

One of the goals of instruction in any subject area is to help students increase their expertise at posing, representing, and solving problems in the subject area. People can get better at whatever they do. A person can get better at a sport, at a hobby or craft, or in an academic field. A person's level of expertise can increase through learning and practice. A person who is really good at something relative to his/her peers is considered to be an expert.

It is important to distinguish between having some level of expertise and being an expert. The word expertise does not mean any particular level of ability. For anything that you can do, you can imagine a scale of performance that runs from very low expertise to very high expertise (see figure 6.1). When a person has a high level of expertise in some particular area, we call this person an expert. Bereiter and Scardamalia (1993) contains an excellent summary of research about expertise.

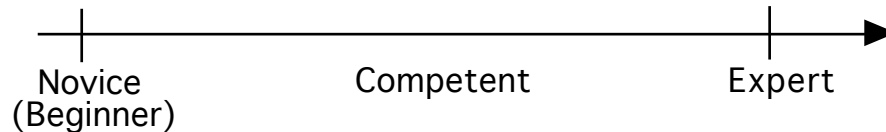


Figure 6.1. An “expertise” scale.

Research on expertise indicates that it takes many years of study, practice, and hard work for a person to achieve their full potential in any particular area of expertise. For example, consider any one of the eight areas of intelligence identified by Howard Gardner (see Pennsylvania State University). Within that intelligence area, select a specific area of expertise. For example, within Bodily / Kinesthetic Intelligence, one might select a specific sport such as gymnastics. If a person is naturally talented in gymnastics, starts when they are quite young, and works really hard for 10 to 15 years within that specific area, they are apt to achieve national or even world-class expertise in that area. And, of course, good teaching (coaching) is a necessity. It is a combination of talent, training, education, and hard work over many years that allows a person to achieve a high level of expertise in an area.

Because it takes so much time and effort to achieve a high level of expertise in just one narrow field, few people achieve a high level of expertise in multiple fields. For example, consider how few professional athletes perform at a world-class level in two different sports. Or, consider the general practitioner versus the specialists in medicine.

Michael Jordan was a world class professional basketball player. At one point in his career he decided to stop playing professional basketball and to become a professional baseball player. He was a superbly trained athlete, and quite a bit of this training transfers. He was dedicated to performing well and being a winner. This tends to transfer. But, it turned out that Michael Jordan

never made it into the Major Leagues in professional baseball. Eventually he moved back into professional basketball and experienced several more years of performance at a world-class level.

The discussion given above focuses on achieving a very high level of expertise within a specific domain. Very roughly speaking, such a high level of expertise can be thought of as having two components. One component is knowledge and skills that are quite specific to the particular domain, while the other component is knowledge and skills that readily transfer (by some combination of low-road and high-road transfer) to other domains.

This type of analysis has been done for many specific domains and for many different people. This has led to an understanding that a high level of expertise within a domain requires a high level of domain-specific knowledge and skill (domain specificity). To achieve one's full potential within a specific domain takes tens of thousands of hours of study and practice. Good teachers (coaches) are very important in this endeavor.

Breadth versus depth is a continuing challenge in designing curriculum and providing learning opportunities for students. Many people believe in a model of all students acquiring a reasonably broad education, and all students then also working to achieve depth in one or more areas in which they have special interests and talents. This approach can be described in terms of the expertise and domain specificity model. Consider two potential goals in education: A) Being a generalist; and B) Being a narrow specialist. If we define "generalist" to be a domain, then this educational model suggests that all students should work toward a reasonably high level of expertise in two domains.

Informal and formal education toward being a generalist begins well before students enter school. It may well continue through a four-year Liberal Arts degree in a college or university, and beyond.

For some people, informal and formal education to be a specialist within a narrow area also begins at an early age. The current success of Tiger Woods (golf) and Serena and Venessa Williams sisters (tennis) illustrate this point. Music, chess playing, and computer programming are also rich sources of examples.

To a large extent, our formal PreK-12 educational system does not follow this two-pronged model. It uses a one-pronged model of helping students to achieve a functional level of expertise in being a generalist across the domains that educators feel are important and appropriate. Broadening of this somewhat narrowly defined "generalist" specialization, and working toward depth within a specific area, is provided by private lessons, participation in club activities, education at home, and so on.

### **Domain-Specific Knowledge in a Productivity Tool**

Computer productivity tools such as word processor, spreadsheet, database, and graphics each "contain" or embody some domain-specific knowledge. Suppose, for example, you are working to gain a reasonable level of expertise in business by taking business courses at the high school or college level. Nowadays, such coursework will include instruction in developing and using spreadsheets. The spreadsheet productivity software is now an integral component of the knowledge and skills of the business discipline.



Similarly, calculators and various types of math productivity are now part of the discipline of mathematics. This is an important aspect of gaining increased expertise in mathematics. The learner can spend a great deal of time gaining speed and accuracy at carrying out pencil and paper algorithms and other procedures in math. However, calculators and computers can carry out such algorithms and procedures. Very slowly, we are seeing a change in math curriculum. Less time is being spent in developing a high level of paper and pencil skill in carrying out algorithms and procedures, and more emphasis is being placed on higher-order cognitive (thinking, problem solving) knowledge and skills.

This type of change is occurring in each discipline where very powerful productivity tools are obviating the need for developing a high level of “by hand” paper and pencil skills. The pace of change has been much faster in some areas than others. For example, the fields of graphic art and engineering drawing have been substantially changed—much more so than math.

### **Immediate Actions for Part 6**

Many teachers enjoy “performing” in front to their students—in essence, demonstrating some of their areas of expertise. Talk to your students and colleagues about some of their areas of (relative) expertise and how they get a chance to demonstrate this expertise to others. As you talk to your students, explore possibilities for your students to demonstrate some of their areas of expertise to their fellow students.

### **Activities for Part 6**

1. Select two different narrowly defined domains in which you have a reasonably high level of expertise. Compare and contrast these domains and your relative levels of expertise. How did you achieve your expertise (formal versus informal education; how long did it take; what was your intrinsic and/or extrinsic motivation; what are your current plans for further increasing your expertise; etc.).
2. Think about your current or future career as a teacher. Think of “teacher” as an area of expertise. How does it fit on a scale of “generalist” to “very narrowly defined domain?” What aspects of this area of expertise are quite domain specific, and what aspects readily transfer to other areas? Give some examples of low-road transfer and high-road transfer that you find applicable toward increasing your expertise as a teacher.
3. Think back over your formal and informal education. Give examples of where the ideas of expertise and domain specificity have been explicitly presented to you. If you cannot give examples, perhaps it is because this was not part of your formal and informal education. In that case, discuss some situations in which it might have been appropriate to include this in your education.
4. Analyze your formal and informal education to date from the point of view of:
  - A. The model of gaining a reasonable level expertise as a generalist and within at least one narrow area of specialization.

- B. The model of gaining expertise as a generalist in the areas covered in school, but broadening this generalization by private lessons, education at home, participation in clubs, and so on.
5. Analyze your current level of expertise as a writer. What is the nature and extent of informal and formal education that has led to this level of expertise? (Include an estimate of the number of hours of your time this has taken.) Then analyze your expertise from a lower-order skills and higher-order skills point of view. For example, did your education include a lot of emphasis on spelling, grammar, and penmanship, and how important has this proven to be in achieving your current level of writing expertise?
  6. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 6 of this document from the point of view of applicability to students at that grade level and/or in that content area.
  7. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 6. Identify your current strengths and weaknesses in ICT from this point of view.

## **Part 7: Some Problem-Solving Strategies**

A strategy can be thought of as a plan, a heuristic, a rule of thumb, a possible way to approach the solving of some type of problem. For example, perhaps one of the problems that you have to deal with is finding a parking place at work or at school. If so, probably you have developed a strategy—for example, a particular time of day when you look for a parking place or a particular search pattern. Your strategy may not always be successful, but you find it useful.

In an earlier section, we discussed domain specificity in problem solving. Every problem-solving domain has a number of domain-specific strategies. Research suggests:

1. There are relatively few strategies that are powerful and applicable across all domains. Because each subject matter (each domain) has its own set of domain-specific problem-solving strategies, one needs to know a great deal about a particular domain and its problem-solving strategies to be good at solving problems within that domain.
2. The typical person has few explicit domain-specific strategies in any particular domain. This suggests that if we help a person gain a few more domain-specific strategies, it might make a significant difference in the person's overall problem-solving performance in that domain. It also suggests the value of helping students to learn strategies that cut across many different domains.

Remember, one of the most important ideas in problem solving is to effectively draw upon and make use of the accumulated knowledge of yourself and others. The Web is a global library that is steadily growing in size and that contains a large amount of accumulated information. A problem-solving strategy that cuts across many, if not all domains, is to become skilled at information retrieval as an aid to solving problems. Research librarians are highly skilled in this type of information retrieval. But, all students can gain considerable facility for retrieving information from the Web and other sources.

The next few sections give examples of rather general-purpose strategies that cut across many domains. While a student may first encounter one of these strategies in a specific domain, each is amenable to teaching for higher-road transfer. A teacher who is teaching one of these strategies within a particular domain has a responsibility of teaching it for transfer and helping students learn to use the strategy in a number of different domains.

### **Top-Down Strategy**

The idea of breaking big problems into smaller problems is called the top-down strategy. The idea is that it may be far easier to deal with a number of small problems than it is to deal with one large problem. For example, the task of writing a long document may be approached by developing an outline, and then writing small pieces that fill in details on the outline.

It is useful to think of the “smaller problems” as building-block problems. You improve your ability to solve problems by a combination of increasing your repertoire of building-block

problems (problems that you know how to solve easily and quickly) and getting better at using the top-down strategy.

Generally speaking, it takes quite a lot of time and effort to learn to solve a building-block problem to a relatively high level of speed and accuracy. Thus, our education system needs to decide how much effort to place on this endeavor when time is also needed to teach higher-order knowledge and skills, general strategies, and other components of high-road transfer.

ICT plays a major role in problem solving because it can automate a huge and growing number of building-block problems. As a simple example, consider “square root.” It doesn’t take very long to learn how to use a calculator to calculate the positive square root of a positive number. This allows our education system to clearly differentiate between the concept of square root and a process or procedure for calculating square root.

Building-block problems exist in every discipline. For example, you can think of the “problem” of spelling a word that you know how to use orally. A dictionary can help, as can a spelling checker on a computer.

Or, consider the problem of cropping a photograph. This can be done with a pair of scissors. But, if the photograph is in a computer, the computer can be used both for cropping and for a range of other manipulation.

### **Don’t Reinvent the Wheel (Ask an Expert) Strategy**

Library research is a type of "ask an expert" strategy. A large library contains the accumulated expertise of thousands of experts. The Web is a rapidly expanding global library. It is not easy to become skilled at searching the Web. For example, are you skilled in using the Web to find information that will help you in dealing with Language Arts problems, Math problems, Science problems, Social Science problems, personal problems, health problems, entertainment problems, and so on? Each domain presents its own information retrieval challenges.

An alternative "ask an expert" approach is to actually ask a human expert. Many people make their livings by being consultants. They consider themselves to be experts within their own specific domains, and they get paid for answering questions and solving problems within their areas of expertise. The "Ask ERIC" system provides a human interface (free consulting) to the ERIC information retrieval system (AskERIC).

### **Scientific Method Strategy**

The various fields of science share a common strategy called Scientific Method. It consists of posing and testing hypotheses. This is a form of problem posing and problem solving. Scientists work to carefully define a problem or problem area that they are exploring. They want to be able to communicate the problem to others, both now and in the future. They want to do work that others can build upon. Well done scientific research (that is, well done problem solving in science) contributes to the accumulated knowledge in the field.

## **Trail and Error, Or Exhaustive Search Strategy**

Trial and error (guess and check) is a widely used strategy. It is particularly useful when one obtains information by doing a trial that helps make a better guess for the next trial. For example, suppose you want to look in a dictionary to find the spelling of a word you believe begins with “tr.” Perhaps you open the dictionary approximately in the middle. You note that the words you are looking at begin with “mo.” A little thinking leads you to opening the right part of the dictionary about in the middle. You then see you have words beginning with “sh.” This process continues until you are within a few pages of the “tr” words, and then you switch strategies to paging through the dictionary, one page at a time.

The “page through the dictionary one page at a time” is an exhaustive search strategy. You could have used it to begin with, starting at the first page of the dictionary. That is a very slow strategy to use for finding a word in a dictionary.

An ICT system might be a billion times as fast as a person at doing guess and check or exhaustive search in certain types of problems. Thus, guess and check, and exhaustive search, are both quite important strategies for the computer-aided solving of certain types of problems.

## **A General-Purpose 6-Step Strategy**

This section contains a general six-step strategy that you can follow in attempting to solve almost any problem. This six-step strategy is a modification of ideas discussed in Polya (1957) and can be called the Polya Strategy or the Six-step strategy. Note that there is no guarantee that use of the Six-step strategy will lead to success in solving a particular problem. You may lack the knowledge, skills, time, and other resources needed to solve a particular problem, or the problem might not be solvable.

1. Understand the problem. Among other things, this includes working toward having a well-defined (clearly defined) problem. You need an initial understanding of the Givens, Resources, and Goal. This requires knowledge of the domain(s) of the problem, which could well be interdisciplinary. You need to make a personal commitment to solving the problem.
2. Determine a plan of action. This is a thinking activity. What strategies will you apply? What resources will you use, how will you use them, in what order will you use them? Are the resources adequate to the task?
3. Think carefully about possible consequences of carrying out your plan of action. Place major emphasis on trying to anticipate undesirable outcomes. What new problems will be created? You may decide to stop working on the problem or return to step 1 as a consequence of this thinking.
4. Carry out your plan of action. Do so in a thoughtful manner. This thinking may lead you to the conclusion that you need to return to one of the earlier steps. Note that this reflective thinking leads to increased expertise.
5. Check to see if the desired goal has been achieved by carrying out your plan of action. Then do one of the following:

- A. If the problem has been solved, go to step 6.
  - B. If the problem has not been solved and you are willing to devote more time and energy to it, make use of the knowledge and experience you have gained as you return to step 1 or step 2.
  - C. Make a decision to stop working on the problem. This might be a temporary or a permanent decision. Keep in mind that the problem you are working on may not be solvable, or it may be beyond your current capabilities and resources.
6. Do a careful analysis of the steps you have carried out and the results you have achieved to see if you have created new, additional problems that need to be addressed. Reflect on what you have learned by solving the problem. Think about how your increased knowledge and skills can be used in other problem-solving situations. (Work to increase your reflective intelligence!)

Many people have found that this six-step strategy for problem solving is worth memorizing. As a teacher, you might decide that one of your goals in teaching problem solving is to have all your students memorize this strategy and practice it so that it becomes second nature. Help your students to make this strategy part of their repertoire of high-road strategies. Students will need to practice it in many different domains in order to help increase transfer of learning. This will help to increase your students' expertise in solving problems.

Many of the steps in this six-step strategy require careful thinking. However, there are a steadily growing number of situations in which much of the work of step 4 can be carried out by a computer. This idea will be discussed later in this document. The person who is skilled at using a computer for this purpose may gain a significant advantage in problem solving, as compared to a person who lacks computer knowledge and skill.

### **Some Other Widely Used High-Road Transferable Strategies**

Here are a few additional strategies that are applicable over a wide range of problem-solving domains. You and your students can benefit through a “bridging” form of instruction on these strategies that is designed to promote high-road transfer.

1. **Brainstorm.** Brainstorming can be done individually or within a group. The idea is to generate lots of ideas that may be relevant to clarifying a problem and developing possible solutions for further detailed analysis.
2. **Draw a Picture or Diagram.** This can range all the way from doodling (which might be considered a type of brainstorming) to a carefully directed effort to represent a problem situation through drawings, diagrams, and other graphical images.
3. **Sleep on It.** This strategy involves getting a problem clearly defined in your mind, and working to solve it. Then, go to sleep. Many people report that some of their best ideas for solving complex problems occur to them while they are asleep. An important variation on this is to get a problem firmly in mind, typically by working on the problem but failing to solve it. Then put the problem aside for a week or more. Researchers in problem solving have

found that this often leads to the generation of new and important ideas on how to solve the problem.

4. Explain It to a Colleague. Many people find that carefully explaining a problem to a colleague often leads to an “Aha, now I see how to solve it.”

### **Strategies Applicable to the Problem of Learning**

This is a “First Draft” note added 5/7/04. It will be expanded later.

Consider the “problem” of learning . Each person is faced by this problem on a daily basis. The normal human brain is designed to be quite good at learning. However, evolution did not design our brains to be good at learning how to read, write, do arithmetic, or learn the various other disciplines that are now taught in schools.

Over the thousands of years in which we have had formal education (schooling), people have learned a great deal about how people learn and how to facilitate learning. Each student gains knowledge and skills in how to learn. That is, as a consequence of formal education, each person gains an increasing level of expertise in attacking various learning problems/tasks.

Since each person is unique, each person is faced by the task of learning to learn in a manner that is appropriate to his or her capabilities, limitations, interests, current knowledge and skills, and so on. In some sense, we are talking about domain specificity, where a person is considered to be a domain.

From a teacher point of view, we thus want to help each student gain both domain specific approaches to attacking the problem of learning (approaches that are specific to a particular student) and domain independent approaches (approaches that cut across many students). We place upon ourselves a requirement to teach in a manner that fits various general learning styles. Thus, we may teach a particular topic in a manner that is consistent with visual, kinesthetic, and aural learning styles. By and large, however, we cannot provide each student with the one-on-one instruction that is specifically geared to the students combination of learning styles that is most appropriate to the specific materials being taught (materials that the student is expected to learn)

Let’s consider a specific example. One strategy for learning is to memorize in a stimulus-response manner, with little or no understanding. Another strategy for learning is to focus strongly on understanding, meaning, how the material ties in with one’s previous knowledge (that is, following the ideas of constructivism), and so on. This leads a teacher to ask questions such as:

1. For a class as a whole and for a specific set of materials being taught, what do I want students to memorize and what do I want them to learning with understanding?
2. For a class as a whole, how do I appropriately assess student progress in these two aspects of learning the specific set of materials I want them to learn?
3. How do I appropriately take into consideration the individual differences among my students?

4. How do I take into consideration ICT both as an aid to each individual student's learning and as an aid to each individual student using his or her learning (to solve problems, accomplish tasks, etc.)?

Rote memorization is an important approach to learning. However, ICT systems are very good at rote memorization. When coupled with a search engine, an ICT system has tremendous capabilities to store and retrieve information. This fact is one of the reasons that our education system is gradually placing increased emphasis on learning for understanding, and learning for problem solving, critical thinking, and other higher-order cognitive activities.

### **Ineffective and Effective Strategies**

You and your students have lots of domain-specific strategies. Think about some of the strategies you have for making friends, for learning, for getting to work or school on time, for finding things that you have misplaced, and so on. Many of your strategies are so ingrained that you use them automatically—without conscious thought. You may even use them when they are ineffective.

The use of ineffective strategies is common. For example, how do you memorize a set of materials? Do you just read the materials over and over again? This is not a very effective strategy. There are many memorization strategies that are better. A useful and simple strategy is pausing to review. Other strategies include finding familiar chunks, identifying patterns, and building associations between what you are memorizing and things that are familiar to you.

What strategies do you use in budgeting your time? Do you frequently find yourself doing a lot of work at the last minute? Perhaps your time-budgeting strategy is not very effective.

Some learners are good at inventing strategies that are effective for themselves. However, most learners can benefit greatly from some help in identifying and learning appropriate strategies. In general, a person who is a good teacher in a particular domain is good at helping students recognize, learn, and fully internalize effective strategies in that domain. Often this requires that a student unlearn previously acquired strategies or habits.

Problem-solving strategies can be a lesson topic within any subject that you teach. Individually and collectively your students can develop and study the strategies that they and others use in learning the subject content area and learning to solve the problems in the subject area. A whole-class ICT-Assisted PBL project in a course might be to develop and desktop publish a book of strategies that will be useful to students who will take the course in the future.

### **Immediate Actions for Part 7**

Engage your students in talking about their strategies for learning and their strategies for getting good grades. One of the things you are looking for is whether they understand that the problems of learning (certain aspects of a topic) and the problems of getting good grades are two different types of problems—sometimes not very closely related. Another thing you are looking for is significant difference in strategies used by different students.



## Activities for Part 7

1. Select two different academic domains (subject areas). For each, make a list of some strategies that are specifically designed to help solve the problems that help to define that domain. A starting point for this activity is to state the big ideas and/or major categories of problems that help to define the domain. You may have trouble with this activity if you do not understand the big ideas that help to define the two domains you have selected, or if you don't know any strategies specific to attempting to solve the problems with the two domains. If you have trouble on this activity, reflect on your past education and your current level of preparation to help others learn these two domains.
2. Pick the same two academic domains used in 1. For each domain, make a list of some of your personal building-block problems. Briefly discuss the time and effort that it took you to achieve your repertoire of building-block problems in these two disciplines.
3. Pick the same two academic domains as you used in 1. Analyze the strengths and weaknesses of the Don't Reinvent the Wheel strategy in these two academic domains.
- 34 Here is a math problem-solving strategy developed by George Polya. "If you cannot solve a problem, then there is an easier problem you cannot solve: find it." The meaning of this is that if you cannot solve a particular problem, pose a related and somewhat similar problem that is less difficult, and work to solve it. This may help you to make progress on the original problem. Discuss the suitability of this strategy for use both in math and non-math domains.
5. Select two different complex problems that you have recently solved. (They need not be school problems.) Compare and contrast your approach and the six-step Polya strategy in solving these two problems.
6. A student or colleague comes to you and says: "I used a strategy, but it did not solve the problem. I thought that a strategy is supposed to solve a problem." Discuss the student's thinking and what you would say to the student to help clarify the situation.
7. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 7 of this document from the point of view of applicability to students at that grade level and/or in that
8. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 7. Identify your current strengths and weaknesses in ICT from this point of view.

## **Part 8: Representations of a Problem**

From a personal or ownership point of view, you first become aware of a problem situation in your mind and body. You sense, feel, or come to understand that something is not the way that you want it to be. This might be at an emotional level. Recent research suggests that emotional intelligence is an important aspect of a person's makeup (Goleman 1995). You form a mental representation—a mental model—of the problem situation. This mental model may include images, sounds, smells, and feelings. You can carry on a conversation with yourself—inside your head, at both a conscious and a subconscious level—about the problem situation. You begin to (mentally) transform the problem situation into a well-defined problem.

Think about how one represents such problem situations as a statue to be sculpted, a painting to be painted, a poem to be written, a musical composition to be composed, a dance to be choreographed and performed, and a play to be written and performed. Clearly there are many steps from an initial conception—perhaps a mental model—of a problem situation and the final product (the solved problem).

### **Non-Mental Models**

Mental representations of problems are essential. You create and use them whenever you consciously work on a problem. But, problems can be represented in other ways. For example, you might represent a problem with spoken words and gestures. This could be useful if you are seeking the help of another person in dealing with a problem. The spoken words and gestures are an oral and body language representation or model of the problem.

You might represent a problem using pencil and paper (a written model). You could do this to communicate with another person or with yourself.

Moreover, writing and drawing are powerful aids to memory. Thus, they are a powerful aid to solving or helping to solve many different types of problems. For example, you probably keep an address book or address list of the names, addresses, and phone numbers of your friends. Perhaps it contains additional information, such as email addresses, birthdays, names of your friends' children, and so on. You have learned that an address book (a type of auxiliary memory) is more reliable than your memory.

Often the process of solving a complex problem involves using a number of different representations. For example, the creation of an animated movie involves a number of steps by a number of people. A script is written, using process writing. Characters are first hand drawn, and repeatedly redrawn in a process drawing approach. Music is composed and repeatedly revised in a process musical composition process. The cast who will provide the voices for the characters is selected and trained. Animation software is developed and debugged. This development process has many of the characteristics of process writing, and may well begin with a block diagram flowchart representation.

For a given problem, different types of representations may have certain advantages and disadvantages. Thus, a particular problem may be quite easy to solve in one representational

system, and quite difficult to solve in another. A good example familiar to most people is provided by Roman Numerals versus Hindu-Arabic Numerals. Learning to write the first few counting numbers I, II, III in Roman Numerals is simpler than 1, 2, 3 in the Hindu-Arabic system. But working with fractions and doing long division is much simpler in the Hindu-Arabic system than it is using Roman Numerals. Similarly, an alphabet-based language is easier to learn to read and write than is a character-based language such as Japanese and the various Chinese written languages. A highly phonetic written language (such as Spanish) is easier to learn to write than is one (such as English) that contains many exceptions to phonetic rules.

### A Math Example

There are still other ways to represent problems. For example, the language and notation of mathematics are useful for representing and solving certain types of problems. Here is a math “word problem.” As shown in the Figure 8.1, two connecting rooms are to be carpeted. One room is 15 feet by 10 feet, and the other room is 12 feet by 8 feet. A particular type of carpet costs \$17.45 per square yard. How much will the carpeting cost for the two connecting rooms?

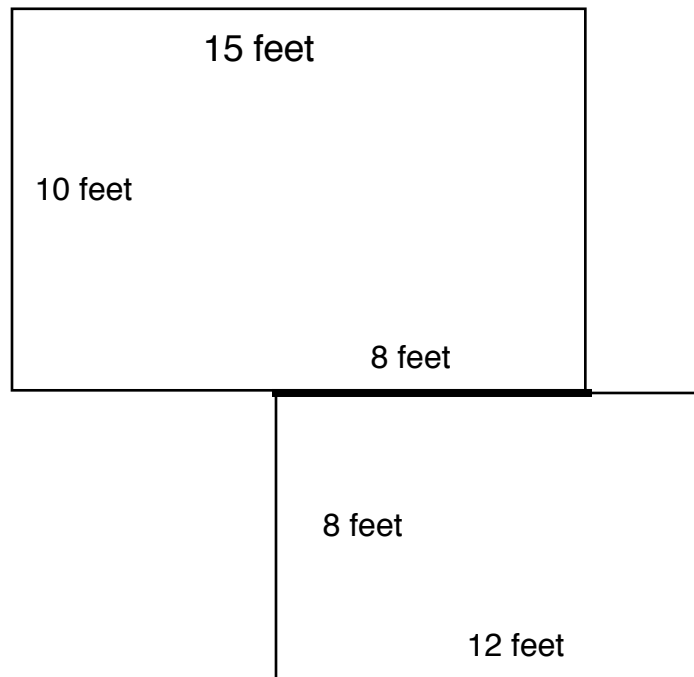


Figure 8.1. Two rooms to be carpeted.

Conceptually, the problem is not too difficult. You can form a mental model or do a drawing of the two rooms. Each room will be covered with carpet costing \$17.45 per square yard. So, you need to figure out how many square yards are needed for each room. Multiplying the number of square yards in a room by \$17.45 gives the cost of the carpet for the room. Add the costs for the two rooms, and you are done. You will likely make use of a formula that area equals length times

width ( $A=LW$ ). You will need to remember (or you will need to retrieve the information in another way) that there are three feet in a yard.

You may note that this is not a good “real world” problem. Carpeting generally comes in long rolls that are 12 feet wide. When people are installing carpeting, they try to have as few seams as possible. At the same time, they do not want to have an unreasonable amount of leftover small pieces of carpeting.

Note also that the dark line between the two rooms is intended to indicate that the wall between the rooms has some thickness. Suppose that this open “doorway” space between the two rooms is six inches by eight feet. Now solve the problem again, and see what you can do to avoid unnecessary seams. You will note that the real world problem is far more challenging than the original “math book” problem. Carpet layers routinely solve such problems, and typically they do not use the math methods taught in school.

A math formula is a commonly used way to represent certain kinds of problems to be solved. There are many thousands of years of accumulated progress in mathematics. This has resulted in the development of many thousands of formulas.

There are two key ideas here. First, some of the problems that people want to solve can be represented mathematically. Second, once a problem is represented as a math problem, much work still remains before the problem is solved. Over the past few thousand years, mathematicians have accumulated a great deal of knowledge about mathematics. They have developed a language of mathematics, consisting of words and symbols, for the precise representation and communication of their accumulated knowledge. Thus, if you can represent a problem as a math problem, you may be able to take advantage of the work that mathematicians have previously done. (Don’t reinvent the wheel.) Mental tools (aids), such as paper-and-pencil arithmetic, calculators, and computers, may be useful. Indeed, ICT-based computational mathematics is now an important approach in representing and attempting to solve a wide range of mathematics problems.

In this short document we will not further pursue the types of differences that tend to exist between “word problems” given in a math class, and “real world” problems of a somewhat similar nature. It suffices to say that many students find considerable difficulty in transferring their school learning to solving the types of problems they encounter outside of school. Appropriately designed Project-Based Learning can help overcome this difficulty.

### **Special Vocabulary and Notation in Other Disciplines**

Each academic discipline has developed its own vocabulary. While many disciplines make use of mathematical notation and mathematics, there are others that have also developed their own special notational systems. Here are a few examples in which you may have seen some of the specialized vocabulary and/or notation that is commonly used to represent and help solve problems within a discipline.

1. Musical notation.
2. Chemistry notation (for molecules and chemical reactions).

3. Medical vocabulary and notation, such as used in medical books and in prescriptions.
4. Various types of diagram notation used to represent plays and movement of players in football and basketball.
5. Architectural drawings, such as blueprints.
6. A spreadsheet with numbers and formulas used in business.
7. Maps.

### **Immediate Actions for Part 8**

Talk to your students and colleagues about what seems to go on in their minds as they sense a problem situation and then begin to think about it. Move the conversation in the direction that some problems seem to come from “feelings” or a “sixth sense.” Some problems seem to come from careful, systematic reflection about a situation and the way you would like the situation to be. Some problems are “assigned” by others (the boss, the teacher).

### **Activities for Part 8**

1. Discuss advantages and disadvantages of Roman Numerals versus Hindu-Arabic Numerals for young children learning to write numbers and do simple arithmetic.
2. Before the development of reading and writing (that occurred a little over 5,000 years ago) “oral tradition” was used to represent and convey a significant amount of accumulated human knowledge. Oral tradition included use of songs, poetry, rhymes, and so on to aid in memorization. Discuss advantages of oral tradition versus reading and writing as ways to represent and convey accumulated human knowledge.
3. Mathematics can be considered to be a language (Moursund, 2002b). It is used in many different disciplines to help represent and solve the problems of the disciplines. Discuss the math education that you received while you were in school. Focus specifically on transfer of learning and on the nature and extent of the teaching of math as a language and as an interdisciplinary aid to representing and solving problems in many different disciplines.
4. Discuss how specialized vocabulary and notation within a discipline affects (helps and hinders) transfer of learning.
5. Perhaps you have heard the assertion “the map is not the territory” that is attributed to Alfred Korzybski. What are similarities and differences between a map and the territory represented by a map? Since a map is not the territory, how can one use a map to represent and solve problems that concern a territory?
6. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 8 of this document from the point of view of applicability to students at that grade level and/or in that content area.

7. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 8. Identify your current strengths and weaknesses in ICT from this point of view.

## **Part 9: Representing Problems Using Computers**

One particularly important feature of a mental model is that it is easily changed. You can "think" a change. This allows you to quickly consider a number of different alternatives, both in how you might solve a problem and in identifying what problem you really want to solve. You can quickly pose and answer "What if?" types of questions about possible alternative decisions you might make.

This aspect of moving toward a well-defined problem and solving a problem is very important. It is a higher-order thinking aspect of problem solving. There are many complex problems that simply overwhelm a brain's ability to hold in active mind the various components and to think through the various possibilities.

Other problem representations, such as through writing and mathematics, are useful because they are a supplement to your brain. Written representations of problems facilitate sharing with yourself and others over time and distance. However, a written model is not as easily changed as a mental model. The written word has a permanency that is desirable in some situations, but is a difficulty in others. You cannot merely "think" a change. Erasing is messy; if you happen to be writing with a ballpoint pen, erasing is nearly impossible.

### **Computer Models**

Many problems can be represented in a form so that a computer can process the representation and perhaps help to solve the problem. For example, a spreadsheet can be used to represent payroll problems and can be used to explore the cost of possible changes in rates of pay. A computer can be used to represent a photograph, and then used to manipulate the photograph to change certain features. A computer can store maps of a territory in a manner that facilitates using a computer to help solve problems concerning the territory.

All of these are examples of computer modeling—the computer representation of problems. For some problems, a computer model has some of the same characteristics as a mental model. Some computer models are easy to change and allow easy exploration of alternatives.

For example, suppose the problem that you face (that is, the task you want to accomplish) is writing a report on some work that you have done. You are probably familiar with the six steps of process writing:

1. brainstorming
2. organizing the brainstormed ideas
3. developing a draft
4. obtaining feedback
5. revising, which may involve going back to earlier steps
6. publishing

When you write using a word processor, you are producing a computer model of a written document. You know, of course, that a key to high quality writing is "revise, revise, revise." This is much more easily done with a computer model of a document than it is with a paper and pencil model of a document. In addition, a computer can assist in spell checking and grammar checking, and it can be used to produce a nicely formatted final product.

In the representation of problems, computers are very useful in some cases and not at all useful in others. For example, a computer can easily present data in a variety of graphical formats, such as line graph, bar graph, or in the form of graphs of two- and three-dimensional mathematical functions. This can be very useful in solving problems that involve a lot of data.

But a computer may not be a good substitute for the doodling and similar types of graphical mind-mapping activities that many people use when attacking problems. Suppose that one's mental representation of a problem is in terms of analogy, metaphor, mental pictures, smells, and feelings. Research that delved into the inner workings of the minds of successful researchers and inventors suggests this is common and perhaps necessary. A computer may be of little use in representing such a mental model.

### **Some Applications of Computer Models**

One of the two winners of the 1998 Nobel Prize in Chemistry was awarded the prize for his work in Computational Chemistry. For more than 15 years, he had been developing computer models of chemistry processes. Similar progress has occurred in all of the sciences. For example, in Physics it used to be that a research physicist was classified as either a theoretical physicist or an experimental physicist. Now there is a third category—a computational physicist. There are computational biologists, computational mathematicians, and so on.

Computer modeling is now an essential component of architecture, business, engineering, industrial manufacturing, and military operations. Indeed, computer modeling is such a powerful aid to representing and solving problems that it has become an integral tool in almost every academic discipline.

It is now common for groups of workers throughout the world to be working together in developing and using a specific computer model. This type of collaboration was not possible before the development of computer models and a worldwide telecommunications system.

In all cases, a computer model allows one to ask and answer "What if" questions. It allows one to do "process" as in process writing. It facilitates communication among teams of people working to solve a problem. Clearly, computer modeling adds a new dimension to problem solving.

### **Artificial Intelligence (Machine Intelligence)**

Many computer scientists work in the field of Artificial Intelligence (AI). This field is also called Machine Intelligence. In essence, AI researchers work to develop computer programs and computer systems that can solve a wide range of problems.



One can think of a handheld calculator as having some Artificial Intelligence. More sophisticated calculators can solve a wide range of math problems. A spelling checker in a word processor has a certain level of intelligence, as does a grammar checker. A robot working on an assembly line (for example, doing welding or spray painting ) has a certain level of intelligence. In 1997, a chess program defeated the reigning human world chess champion in a six-game match. The point is, progress in AI is providing us with powerful aids to problem solving in many different domains.

One of the successes in the field of Artificial Intelligence has been the development of Expert Systems—computer programs that exhibit a considerable level of expertise in solving problems within a specific (typically, very narrow) domain. In a number of narrowly defined domains, Expert Systems or humans working together with an Expert System can perform at a national-class or world-class level. This, of course, has profound implications in education. Suppose a computer program (an Expert System) exists with a specific domain that is being covered in a school curriculum. Now, what do we want students to learn about solving problems in that domain? Do we want students to learn to compete with the Expert System, or learn to work with the Expert System? (See Artificial Intelligence.)

### **IT-Assisted Project-Based Learning**

Many teachers make use of Project-based Learning (PBL). PBL is a multi-goaled activity that goes on over a period of time, resulting in a product, presentation, or performance. Typically, a PBL lesson has milestones and other aspects of formative evaluation as the project proceeds.

Project-based learning is learner centered. Students have a significant voice in selecting the content areas and nature of the projects that they do. There is considerable focus on students understanding what it is they are doing, why it is important, and how they will be assessed. Indeed, students may help to set some of the goals over which they will be assessed and how they will be assessed over these goals. All of these learner-centered characteristics of PBL contribute to learner motivation and active engagement. A high level of intrinsic motivation and active engagement are essential to the success of a PBL lesson.

The process of developing a product, presentation, or performance has much in common with Process Writing. Increasingly, students make use of computers in PBL lessons (Moursund 2002a). In particular, major aspects of a product, presentation, or performance may be represented in a computer as part of the process. For example, it is now common for a presentation to make use of a slide show or other visuals that have been created and/or edited using a computer.

### **Immediate Actions for Part 9**

Talk to your students and your colleagues about artificial intelligence. What are their thoughts and feelings about a machine being “smart” and having “intelligence?” In what ways are human intelligence and computer machine intelligence the same and different? Will computers eventually be smarter or more intelligent than people? What do they feel about such a possibility?

## Activities for Part 9

1. What are some similarities and differences between a physical model (for example, a wooden or metal model of an airplane wing that is designed for testing in a wind tunnel), and a computer model of the same thing?
2. Discuss why architects develop scale physical models of buildings as part of the process of designing buildings. What are some advantages and disadvantages of a scale model, a hard copy blueprint model, and a computer model of a building?
3. A computer or a computerized robot can outperform a human in an increasingly wide variety of problem-solving situations. Present and analyze your thoughts and feelings on how this should affect our educational system.
4. Most likely you use the writing process when you write. A word process allows you to represent your document electronically (that is, as a computer model of the document) and facilitates the “revise, revise, revise” process as well as the final publication process. Give several examples from your own educational experiences in which you learned to use computer models and a “revise, revise, revise” process to solve non-writing problems. If you are unable to think of examples, perhaps this means that this is a missing part of your education. If so, present your thoughts on why this was the case and whether it is appropriate that this topic should continue to be left out of the education of today’s and future children.
5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Part 9 of this document from the point of view of applicability to students at that grade level and/or in that content area.
6. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Part 9. Identify your current strengths and weaknesses in ICT from this point of view.

## **Part 10: Summary of Important Ideas**

Each classroom-teaching situation provides an environment that can be used to help students improve their problem-solving and higher-order thinking skills. Students will make significant progress if:

1. They have ownership of the problems to be solved and the tasks to be accomplished. They are intrinsically motivated.
2. Students build on their previous knowledge. (That is, constructivist learning theory ideas are routinely used.)
3. The problems to be solve and the tasks to be accomplished are challenging—they stretch the capabilities of the students.
4. There is explicit instruction on key topics such as:
  - A. Problem posing.
  - B. Problem representation.
  - C. Building on the previous work of yourself and others.
  - D. Transfer of learning, using the high-road, low-road model.
  - E. Mindfulness, metacognition, and reflection.
  - F. Capabilities and limitations of ICT.
  - G. Roles of ICT in each discipline being taught.

We are all life-long learners. Through conscious effort, we can all get better at posing, representing, and solving the types of problems that we encounter throughout our lives.

### **Immediate Actions for Part 10**

Think about something that you feel is especially important about problem solving and roles of computers in problem solving. Try sharing this idea with your colleagues and students. Reflect about your successes and failures in this endeavor.

### **Activities for Part 10**

1. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of this entire document from the point of view of applicability to students at that grade level and/or in that content area.
2. Analyze a lesson plan that you have developed and/or routinely use from the point of view of ideas presented in this document. Revise the lesson plan so that it better incorporates the ideas from this document.

3. Repeat (2) above on two additional lesson plans.
4. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in this document. Identify your current strengths and weaknesses in ICT from this point of view.

## Appendix A: Brain/Mind Science and Problem Solving

This Appendix added in March 2004 may eventually be integrated into the book as a chapter and/or parts of several chapters. The Appendix provides a brief introduction to some ideas from brain/mind science that fit in well with ICT and our general knowledge about improving expertise in problem solving. You can think of this Appendix as containing background information that is useful in learning about ICT and problem solving. Or, you can think of it an integral component of the topic ICT and problem solving.

### List of Big Ideas in this Appendix

Continuing research on the science of the mind (psychology), recent research on the science of the brain (neuroscience), and rapid continuing progress in ICT are making significant contributions to the field of problem solving in all disciplines. This section lists three of the Big Ideas emerging from this progress.

#### Brain Versus Computer

In the early days of computers, people often referred to such machines as *electronic brains*. Even now, more than 50 years later, many people still use this term. Certainly a human brain and a computer have some characteristics in common. However:

- Computers are very good at carrying out tasks in a mechanical, “non-thinking” manner. They are millions of times as fast as humans in tasks such as doing arithmetic calculations or searching through millions of pages of text to find occurrences of a certain set of words. Moreover, they can do such tasks without making any errors.
- Human brains are very good at doing the thinking and orchestrating the processes required in many different very complex tasks such as carrying on a conversation with a person, reading for understanding, posing problems, and solving complex problems. Humans have minds and consciousness. A human’s brain/mind capability for “meaningful understanding” is far beyond the capabilities of the most advanced computers we currently have.

**Big Idea # 1:** There are many things that computers can do much better than human brains, and there are many things that human brains can do much better than computers. Our educational system can be significantly improved by building on the relative strengths of brains and computers, and decreasing the emphasis on attempting to “train” students to compete with computers. We need to increase the focus on students learning to solve problems using the strengths of their brains and the strengths of ICT.

#### Chunks and Chunking

Here are three different types of human memory:

- Sensory memory stores data from one's senses, and for only a short time. For example, visual sensory memory stores an image for less than a second, and auditory sensory memory stores aural information for less than four seconds.
- Working memory (short-term memory) can store and actively process a small number of chunks. It retains these chunks for less than 20 seconds.
- Long-term memory has large capacity and stores information for a long time.

Research on short-term (“working”) memory indicates that for most people the size of this memory is about  $7 \pm 2$  chunks. This means, for example, that a typical person can read or hear a seven-digit telephone number and remember it long enough to key into a telephone keypad. When I was a child, my home phone number was the first two letters of the word diamond, followed by five digits. Thus, to remember the number (which I still do, to this day) I needed to remember only six chunks. But, I had to be able to decipher the first chunk, the word “diamond.”

Long-term memory has a very large capacity, but this does not work like computer memory. Input to computer memory can be very rapid (for example, the equivalent of an entire book in a second), and can store such data letter perfect for a long period of time. The human brain can memorize large amount of poetry or other text. But, this is a long and slow process for most people. By dint of hard and sustained effort, an ordinary person can memorize nearly letter perfect the equivalent of a few books. However, the typical person is not very good at this. At the current time, the Web contains the equivalent of many millions of books.

On the other hand, the human brain is very good at learning meaningful chunks of information. Think about the chunks such as constructivism, multiplication, democracy, transfer of learning, and Mozart. Undoubtedly these chunks have different meanings to me than they do for you. As an example, for me, the chunk “multiplication” covers multiplication of positive and negative integers, fractions, decimal fractions, irrational numbers, complex numbers, functions (such as trigonometric and polynomial), matrices, and so on. My breadth and depth of meaning and understanding was developed through years of undergraduate and graduate work in mathematics.

It is useful to think of a chunk as a label or representation (perhaps a word, phrase, visual image, sound, smell, taste, or touch) and a pointer or index term that does two things:

1. It can be used by short-term memory in a conscious, thinking, problem-solving process.
2. It can be used to retrieve more detailed information from long-term memory.

**Big Idea # 2:** Our education system can be substantially improved by taking advantage of our steadily increasing understanding of how the mind/brain deals learns and then uses its learning in problem solving. Chunking information to be learned and used is a powerful aid to learning and problem solving.

## Augmentation to Brain/Mind

In essence, reading and writing provide an augmentation to short-term and long-term memory for personal use and that can be shared with others. Data and information can be stored and retrieved with great fidelity.

The strongest memory is not as strong as the weakest ink. (Confucius, 551-479 B.C.)

Writing onto paper provides a passive storage of data and information. The “using” of such data and information is done by a human’s brain/mind.

Computers add a new dimension to the storage and retrieval of data and information. Computers can process (carry out operations on) data and information. Thus, one can think of a computer as a more powerful augmentation to brain/mind than is provided by static storage on paper or other hardcopy medium.

**Big Idea # 3:** ICT provides a type of augmentation to one’s brain/mind. The power, capability, and value of this type of augmentation continue to grow rapidly. Certainly this is one of the most important ideas in education at the current time.

## Brain/Mind Science

Brain science is one of the current buzz words in education. Many people use the term in an all-inclusive manner that covers both the science of the mind (psychology) and the science of the brain (neuroscience).

John T. Bruer is president of the James S. McDonnell Foundation. He has written extensively about brain/mind science and the McDonnell Foundation has provided substantial funding for research in this area. An excellent introduction to the field is available in Bruer (1999). In this article, Bruer talks about a long-standing schism between research in the science of the mind and research in the science of the brain.

It is only in the past 15 years or so that these theoretical barriers have fallen. Now scientists called cognitive neuroscientists are beginning to study how our neural hardware might run our mental software, how brain structures support mental functions, how our neural circuits enable us to think and learn. This is an exciting and new scientific endeavor, but it is also a very young one. As a result we know relatively little about learning, thinking, and remembering at the level of brain areas, neural circuits, or synapses; we know very little about how the brain thinks, remembers, and learns (Bruer, 1999).

In this book we use the term *brain/mind science* to designate the combined psychology and neuroscience discipline that focuses on the study of the brain and the mind. *Cognitive science* is a still broader term that adds relevant work being done in the field of computer and information science, philosophy, linguistics, and still other fields.

## The Human Brain

An average adult brain weighs about three pounds and contains more than 100 billion neurons. These neurons communicate with each other via a network averaging perhaps 5,000

synapses per neuron. The numbers 100 billion and 500 trillion (which is  $5,000 \times 100$  billion) are impressively large numbers.

The human brain controls memory, vision, learning, thought, consciousness and other activities. By means of electrochemical impulses the brain directly controls conscious or voluntary behavior. It also monitors, through feedback circuitry, most involuntary behavior and influences automatic activities of the internal organs.

During fetal development the foundations of the mind are laid as billions of neurons form appropriate connections and patterns. No aspect of this complicated structure has been left to chance. The basic wiring plan is encoded in the genes.

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The brain's billions of neurons connect with one another in complex networks. All physical and mental functioning depends on the establishment and maintenance of neuron networks. (Elert, n.d.).

The human brain is immensely complex, and even the brains of identical twins are not identical at birth. Moreover, the human brain is continually changing, because learning produces change in the brain. Finally, we know that the human brain has great plasticity, allowing major changes in the human brain (often thought of as rewiring) to occur over time, even in adults.

Your brain is active all of the time, even when you are asleep. Your brain functions at a subconscious level to direct a wide range of activities to keep your body alive and functioning well. That is, your brain is constantly detecting and solving problems at a subconscious level. (Some people find it helpful to develop an analogy with a thermostat that controls the heating and air conditioning in a room. While such a thermostat does not have consciousness, it has enough “intelligence” to perform a useful task.) However, these are not the types of problems that we have in mind when we explore the development of a school curriculum to help students get better at problem solving.

### **Chunking: Seven Plus or Minus Two**

In a 1956 article, George Miller noted, “Everybody knows that there is a finite span of immediate memory and that for a lot of different kinds of test materials this span is about seven items in length.” The article then goes on to explore how  $7 \pm 2$  seems to be a magical quantity, appearing in many different measures of human sensory and brain processing capabilities. The article includes a heavy emphasis on how to make more effective use of short-term memory by chunking information (putting a number of individual items into a chunk, that is then deal with as a single item).

It turns out that short term memory span is very important in problem solving and other higher-order cognitive tasks. Thus, there has been a lot of research on short-term memory and how to “enhance” its capabilities.

The contrast of the terms *bit* and *chunk* also serves to highlight the fact that we are not very definite about what constitutes a chunk of information. For example, the memory span of five words that Hayes obtained when each word was drawn at random from a set of 1,000 English monosyllables might just as appropriately have been called a memory span of 15 phonemes, since each word had about three phonemes in it. Intuitively, it is clear that the subjects were recalling five words, not 15 phonemes, but the logical distinction is not immediately apparent. We are



dealing here with a process of organizing or grouping the input into familiar units or chunks, and a great deal of learning has gone into the formation of these familiar units

In order to speak more precisely, therefore, we must recognize the importance of grouping or organizing the input sequence into units or chunks. Since the memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before (Miller, 1956).

The building of “larger and larger chunks” is a fundamental concept in learning and problem solving. For example, suppose you want to memorize a long sequence of binary digits (a sequence of 0’s and 1’s). Table A.1 contains conversions between binary numbers and base 10 numbers. Suppose as you view the string of binary digits to be memorized, you divide them into groups of three and then memorize the corresponding base 10 number. In that way, memorizing 21 binary digits is like memorizing 7 base 10 digits. However, this only works if you have a high level of automaticity in converting groups of three binary digits into a base 10 digit, and then back again.

Binary number	Base 10 number
000	0
001	1
010	2
011	3
100	4
101	5
110	6
111	7

Table A.1 Binary to base 10 conversion table.

George Miller describes this chunking process as a recoding, or translation scheme. Miller (1956) notes, “Apparently the translation from one code to the other must be almost automatic or the subject will lose part of the next group while he is trying to remember the translation of the last group.”

Let’s use math to help illustrate this situation. Math is a language with its own vocabulary. If the vocabulary being used in a “conversation” (for input orally or in writing) is sufficiently familiar to the receiver, then a great deal of information can be communicated in a small number of chunks. Without the automaticity, this cannot occur. Moreover, for many students, math is learned by rote memory, with little or no understanding. For such students, a sequence of math words and symbols is much like a sequence of nonsense words and symbols. Such sequences are difficult to learn, difficult to chunk into smaller numbers of units, and difficult to recall from memory.

Thus, one of the most important ideas in learning mathematics (gaining in math maturity, math expertise) is learning chunks that have meaning. Storing and retrieving math information, and thinking, reading, writing, and talking in math involve rapid (automatic) chunking and unchunking.

### Processing Sensory Input

As you carry on your everyday activities, your five senses input a steady barrage of data into your brain. In very simplified terms, this is what happens with the sensory input data. It is temporarily stored at a subconscious level, where one of three things happens.

- Your brain may pay attention to the data at a subconscious level and use it at a subconscious level.
- Your brain may bring the data to a conscious level, allowing the brain/mind to then process it at a conscious level.
- Your brain may ignore the data, and it is quickly forgotten. This is what happens to the vast majority of sensory input data.

Figure A.2 is an information processing model showing what happens to sensory input data.

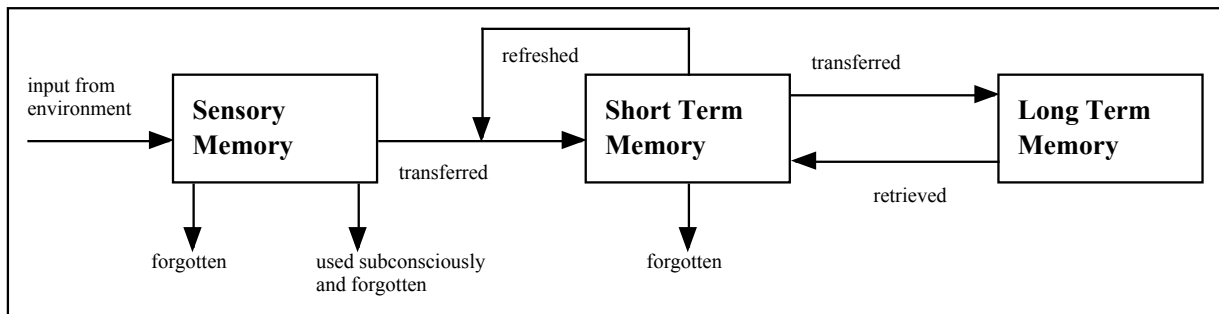


Figure A.2. An Information Processing Model for human memory.

Think about what happens as you talk to a class of students. For many, their minds will wander—their attention will shift from you to other things. You will try to keep your students’ attention focused on what you are saying, what you are showing them, and so on. But, it is likely that most of what you are presenting goes into auditory and visual sensory memory and is forgotten.

Now, suppose that you are presenting (by talking and through use of slides) quite a bit of information. A student pays attention to the visual and auditory information stream, pulls off an occasional chunk that attracts special attention, and moves it into short-term memory. If the chunks going into short-term memory make sense in light of what the student already knows, this is a big help in moving the chunks into long-term memory. If the chunks don’t make sense (don’t tie in well with what one already knows), then the likely result that new incoming chunks quickly replace them, and little or no meaningful long-term learning occurs.

This helps to explain constructivism. If the chunks that move into a student’s short-term memory have little or no meaning to the student, then this creates a situation in which the student

is being expected to quickly memory nonsense syllable and words. Constructivism is a theory that says new learning is built on what one already knows. If there is a significant gap between what a student knows and understands, and what is being presented, little or perhaps no learning will occur.

### **Procedural and Declarative Memory**

Long-term memory can be divided into two categories—procedural and declarative. For the most part, these are stored in different parts of the brain.

Declarative memory is our memory for facts—chunks of information that we can consciously retrieve and use. Declarative memory can be further broken down into episodic memory (memory for past and personally experienced events), and semantic memory (memory for knowledge of the meaning of words and how to apply them).

Procedural memory is our memory for rules of action that are carried out rapidly and accurately at a subconscious level. For example, if you are a fast keyboarder, you do not consciously think about the various neural signals that need to be sent to cause your fingers to rapidly and accurately move to and depress the appropriate keys. Indeed, if I ask you where the “r” key is on the keyboard, you may have to mentally keyboard it (using subconscious procedural memory) and look where your finger has moved to, in order to provide me with a conscious answer.

In very simple terms, declarative memory stores information we can retrieve and process consciously, while procedural memory stores information (sets of directions) that we perform at a subconscious level. Often, a person uses a combination of declarative and procedural memory in solving a problem or accomplishing a task. As I sit writing this book, I am using my knowledge of facts, I am consciously processing these facts, I am creating sentences, and my procedural memory keyboarding skills are moving my sentences to my computer’s memory.

However, as I sit writing this book, I also make use of the Web. Here is what happens. I retrieve chunks of information from my declarative memory. I think about how this stored information fits with the message that I am trying to develop. Quite often I find that I don’t have sufficient stored information in my brain to appropriately describe or represent the message. I quickly make use of a search engine and then browse a number of Websites. I often browse some of the hardcopy books that are near at hand in my personal library. When I feel I know enough, I continue with my writing. Thus, for me, writing a book draws upon my declarative memory, the Web, my personal library of books and magazines, and procedural memory.

Moreover, as I am writing, my computer’s spelling and grammar checkers are continually checking what I write. The computer automatically corrects some of my keyboarding or spelling errors. Other possible errors are brought to my attention by the computer underlining the word or text in question. A slightly different way of saying this is that for me, writing a book is like taking an open book, open computer exam. This is authentic assessment.

## **Gaining a High Level of Expertise**

Problem solving is part of each discipline that we teach in K-12 education. We want to help our students increase their level of problem-solving expertise in each area that they study.

As you know, it takes many years of study and practice to gain a high level of expertise in a discipline or in a narrow part of a discipline. This observation has led a number of researchers to explore the question of how long it takes for a person to get really good in a particular area. For example, how many hours of practice does it take for a person to get about as good as they are capable of being in a sport, in playing chess, in playing a musical instrument, in solving math problems, and so on? Answers vary with the discipline, but tend to be a minimum of 10 to 12 years, and often much longer.

Thus, for example, suppose that you have the genetic disposition, personality, drive, and so on to be a world-class chess player. Once you are old enough to learn and understand the rudiments of the game, you can figure on at least 12 years of full time effort—full time meaning perhaps 50 to 60 hours a week—to come close to reaching your potential.

Now, suppose that a child has a goal to be as good a research scientist as he or she can be. Evidence suggests that most research scientists do their best work before they are 30 years of age. While they can continue to do good work later in life, in some sense most peak in terms of groundbreaking highly original discoveries by age 30.

Suppose that a person who has the potential to do such groundbreaking science research enrolls in our traditional school system and progresses through an ordinary program of study before entering college at age 18. Then 10 years of undergraduate, graduate, and postgraduate study brings this person to age 28. Hmm. That doesn't leave much time before reaching the age of 30. An analysis of this situation reveals that many such people start their intensive study well before the traditional age for entering college, often graduating from high school several years earlier than average. You can see advantages of acceleration programs for the talented and gifted!

## **Nature and Nurture**

This section continues our exploration of the human brain. In very simple terms, people talk about those aspects of mental development that are due to “nature” and those that are due to “nurture.” What is built in, and what is developed through education and life experience?

This is an over simplification because of the interaction of nature and nurture. However, both nature (such as one's genetic makeup) and nurture (such as avoidance of alcohol or other drug poisoning while in the womb, one's home environment, appropriate food, avoidance of lead poisoning) are quite important.

There has been extensive research on issues about nature versus nurture over the past hundred years and more. In addition, we now have brain imaging equipment and a knowledge of the human genome that is beginning to allow us to pinpoint genetic differences that are related to learning (for example, slow/poor learning versus fast/good learning). The next few subsections provide examples of the findings in this type of research.

## Rate of Learning

Elementary school teachers know that there are large differences in how fast various students learn. Research indicates that this difference may be as large as a factor of five (MacDonald, n.d.). Stated in simpler terms, this means that a typical class may have one or more students that learn less than half as fast as the average, and one or more that learn more than twice as fast as average. The combination of one-half and twice produces a factor of four between the slower and faster learners.

You know, of course, that students differ significantly in their interests, their areas of relative strength, and their areas of relative weakness. Howard Gardner's and other researchers' work on multiple intelligences suggest that a student's intelligence in different areas may vary considerably. As an example, my logical/mathematical IQ is well above average, but my spatial IQ is below average. And, my children decided that I am "tune deaf," which was a nice way of suggesting that my musical IQ leaves much to be desired.

Rate of learning is tied in with gaining increasing skill in problem solving within a discipline. For example, a world-class chess player has committed to memory perhaps 50,000 chess-information chunks. Each chunk is knowledge of a complete chessboard position or a significant piece of a position that has a reasonable chance of occurring in a game, and information about that position (for example, is it a weak position, to be avoided, or a strong position to be sought after, and then exploited). That is, this is not 50,000 rote memorized organizations of pieces on a board. Each position has meaning. A world-class chess player can look at a chess game in progress and very rapidly recognize (recall from long term memory and bring into short term memory) and make use of the memorized information. It takes tens of thousands of hours for a person who is fast at this endeavor to accomplish such a memory feat.

## Reading and the Brain

This short section is about students learning to read a natural language. Remember that building on the previous work of yourself and others is one of the most important ideas in problem solving. Reading and writing are very powerful aids to accomplishing the task of building on previous work.

A normal human brain is "wired" to be able to learn to a natural language. Throughout the world children learn to understand spoken language and to talk—without going to school! Indeed, if raised in a bilingual or trilingual environment, children become bilingual or trilingual.

The situation for learning to read is certainly not the same as the situation for learning to speak and listen. It takes years of informal instruction, formal instruction, and practice to develop a reasonable level of skill in reading. One benchmark for progress in learning to read is making a transition from learning to read to *reading to learn*. In the current education system in the United States, approximately 70-percent of students reach or exceed this stage by the end of the third grade. Such students tend to transition relatively smoothly into a fourth grade and higher grade level curriculum that places more and more emphasis on reading to learn. In our current educational system, the expectation is that by approximately the seventh grade students will be using reading as their dominant aid to learning.

The 70-percent figure stated above means, however, that approximately 30-percent of students have not yet met the reading to learn benchmark by the end of the third grade. Some of these students are diagnosed as being dyslexic. Historically, this term was applied to students with normal or above normal IQ who had a great deal of difficulty in learning to read. Recent brain research has discovered that the brains of many students are wired differently than those of students who make “normal” progress in leaning to read (Shaywitz, 2003). Sally Shaywitz estimates that perhaps as many as 20-percent of all children have a significant level of dyslexia.

There are neurological explanations for why some students have reading difficulties. At the current time brain scientists are just beginning to identify some of the genetic sources of reading difficulty. Here is an example of such findings, quoted from the abstract of Mikko Taipale et al. (2003). You will notice that the “language” of a gene researcher is quite a bit different than the language of a typical elementary school teacher.

We report here the characterization of a gene, *DYX1C1* near the *DYX1* locus in chromosome 15q21, that is disrupted by a translocation t(2;15)(q11;q21) segregating coincidentally with dyslexia. ... We conclude that *DYX1C1* should be regarded as a candidate gene for developmental dyslexia. Detailed study of its function may open a path to understanding a complex process of development and maturation of the human brain.

### Math and the Brain

Brain imaging techniques now provide us with information about which parts of the brain are involved in accomplishing different sorts of tasks, such as reading versus doing math. For example:

Through separate studies involving behavioral experiments and brain-imaging techniques, the researchers found that a distinctly different part of the brain is used to come up with an exact sum, such as 54 plus 78, than to estimate which of two numbers is closer to the right answer. Developing the latter skill may be more important for budding mathematicians.

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In addition to shedding light on how mathematicians' brains work, the researchers' results may have implications for math education. If the results of these studies on adults also apply to children, the studies imply that children who are drilled in rote arithmetic are learning skills far removed from those that enrich mathematical intuition, Professor Spelke said.

"Down the road, educators may look harder at the importance of developing children's number sense"—for example, their ability to determine a ballpark answer rather than a specific answer, she said. Number sense is considered by some to be a higher-level understanding of mathematics than rote problem-solving (Halber, 1999).

There has been quite a lot of research on the learning of students classified as having general learning disabilities. The term learning disability has been given a legal definition:

The regulations for Public Law (P.L.) 101-476, the Individuals with Disabilities Education Act (IDEA), formerly P.L. 94-142, the Education of the Handicapped Act (EHA), define a learning disability as a "disorder in one or more of the basic psychological processes involved in understanding or in using spoken or written language, which may manifest itself in an imperfect ability to listen, think, speak, read, write, spell or to do mathematical calculations."

The Federal definition further states that learning disabilities include "such conditions as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia." **According to the law, learning disabilities do not include learning problems that are primarily the result of visual, hearing, or motor disabilities; mental retardation; or**

**environmental, cultural, or economic disadvantage. Definitions of learning disabilities also vary among states.** [Bold added for emphasis.] Accessed 3/4/04:  
[http://www.kidsource.com/NICHCY/learning\\_disabilities.html](http://www.kidsource.com/NICHCY/learning_disabilities.html).

Research on learning by LD students has been conducted in many different disciplines. We know, for example, students with learning disabilities tend to learn math much slower than students without such disabilities. Here are a few poignant points from Miller and Mercer (1997).

1. LD students experience difficulty in learning computation, math problem solving, and other math starting at the earliest grade levels and continuing throughout their schooling.
2. LD students tend to make one-half of a grade level of math learning progress per school year.
3. The math learning of LD students tends to plateau at some place at the 4<sup>th</sup> to 5<sup>th</sup> grade levels as they continue through secondary school. After that, the rate of forgetting tends to equal the rate of learning.

Studies of students with learning disabilities help provide insight into the types of difficulties that a broad range of students (who are not classified as learning disabled) face as they encounter coursework that is highly focused on problem solving and higher-order cognitive activities. The next section provides more insight into this issue.

### **Piaget’s Developmental Theory**

Piaget’s developmental theory discusses various stages of development and his work has proven to be quite important in education. Very roughly speaking, Piaget thought of these stages as being driven by “nature” rather than by “nurture.” The brain of a newborn child is about 350 cc in size, and that of an adult is about 1,500 cc in size. This brain development is, to a great extent, programmed by genetics. Piaget’s developmental theory is summarized in Table A.2 (Huitt and Hummel, 1998).

<b>Approximate Age</b>	<b>Stage</b>	<b>Major Developments</b>
Birth to 2 years	Sensorimotor	Infants use sensory and motor capabilities to explore and gain understanding of their environments.
2 to 7 years	Preoperational	Children begin to use symbols. They respond to objects and events according to how they appear to be
7 to 11 years	Concrete operations	Children begin to think logically. In this stage (characterized by 7 types of conservation: number, length, liquid, mass, weight, area, volume), intelligence is demonstrated through logical and systematic manipulation of symbols related to concrete objects. Operational thinking develops (mental actions that are reversible).

11 years and beyond	Formal operations	Thought begins to be systematic and abstract. In this stage, intelligence is demonstrated through the logical use of symbols related to abstract concepts. Only 35% of children in industrialized societies have achieved formal operations by the time they finish high school.
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Table A.2. Piaget's Stages of Cognitive Development

The Piagetian scale of cognitive development does not refer to any specific area of cognitive development. Here is a slight expansion of the bottom right corner of the table:

**Formal Operations.** In this stage, intelligence is demonstrated through the logical use of symbols related to abstract concepts. Early in the period there is a return to egocentric thought. Only 35% of high school graduates in industrialized countries obtain formal operations; many people do not think formally during adulthood (Huitt and Hummel, 1998).

I must admit that I was astounded when I first encountered this piece of information. Further Web research produced the following statement about college students (Gardiner, 1998):

Many studies suggest our [college] students' ability to reason with abstractions is strikingly limited, that a majority are not yet "formal operational."

The information given in the two quotes is consistent—we expect the percentage of college students at formal operations to be higher than percentage who are high school graduates. Such information suggests that some (perhaps quite a bit) of our attempts to have students learn while in school may be far above their developmental level. This is illustrated in the next sub section.

### Developmental Theory in Math

Piaget's work on developmental theory is general purpose, not focusing in any particular discipline or area of human intellectual endeavor. It is possible to pick a specific discipline (or, a narrow area of human intelligence) and study developmental theory for this specific area. This section provides an example from geometry.

During the 1950s, Dutch educators Dina and Pierre van Hiele focused some of their research efforts on developing a Piagetian-type scale just for geometry (van Hiele, n.d.). It is a five-level scale, and it does not provide approximate age estimates. See Table A.3.



Stage	Description
Level 0 (Visualization)	Students recognize figures as total entities (triangles, squares), but do not recognize properties of these figures (right angles in a square).
Level 1 (Analysis)	Students analyze component parts of the figures (opposite angles of parallelograms are congruent), but interrelationships between figures and properties cannot be explained.
Level 2 (Informal Deduction)	Students can establish interrelationships of properties within figures (in a quadrilateral, opposite sides being parallel necessitates opposite angles being congruent) and among figures (a square is a rectangle because it has all the properties of a rectangle). Informal proofs can be followed but students do not see how the logical order could be altered nor do they see how to construct a proof starting from different or unfamiliar premises.
Level 3 (Deduction)	At this level the significance of deduction as a way of establishing geometric theory within an axiom system is understood. The interrelationship and role of undefined terms, axioms, definitions, theorems and formal proof is seen. The possibility of developing a proof in more than one way is seen.
Level (Rigor)	Students at this level can compare different axiom systems (non-Euclidean geometry can be studied). Geometry is seen in the abstract with a high degree of rigor, even without concrete examples.

### A.3. Van Hiele developmental scale for geometry.

The majority of high school geometry courses is taught at Level 3. The van Hieles also identified some characteristics of their model, including the fact that a person must proceed through the levels in order, that the advancement from level to level depends more on content and mode of instruction than on age, and that each level has its own vocabulary and its own system of relations. The van Hieles proposed sequential phases of learning to help students move from one level to another. Their point of view tends to lie on the nurture side of nature/nurture. If the geometry curriculum is properly designed and properly taught starting at the early grade levels, students will steadily move up the geometry developmental scale.

It is interesting to compare Level 3 (Deduction) in the van Hiele scale with the top level (Formal Operations) of the Piaget scale. To me, it appears that these two levels are about the same. This suggests to me:

1. A formal proof-oriented secondary school geometry course is beyond the cognitive and geometric developmental level of the great majority of high school students. This statement becomes even more important if we consider students at the 9<sup>th</sup> or 10<sup>th</sup> grade level, when such a course is frequently taught.

2. It is likely that more advanced rigorous high school math courses are beyond the cognitive and mathematical developmental level of the great majority of high school students.

This type of analysis can be done in other disciplines. For example, some people think that the study of history is mainly memorizing dates, names of people, names of Wars, and so on. However, historians suggest that the main theme in studying and understanding history is to understand causality. That is, they want students to learn to develop and test relationships (causality) among historical events. They want students to learn to make carefully reasoned argument to support or argue against positions that they and others posit. However, this type of study of history is based on students functioning at a formal operations level. Or, if we look at it from a developmental point of view, we need a history-oriented curriculum that slowly but steadily increases the history developmental level of students, moving them towards formal operations in history.

## **Augmentation of Brain/Mind**

We know that:

1. Paper, pencil, and printing (for example, books, libraries) are powerful aids to problem solving. One way to examine these aids is from the point of view of how they aid and supplement (augment) capabilities of long-term memory and short-term memory.
2. Still and motion picture cameras and a wide range of audio recording devices provide a very useful augmentation to short-term and long-term memory of visual and audio information.
3. ICT is important in problem solving because:
  - A. It has a number of the characteristics of paper, pencil, printing still pictures, and motion pictures. The Web, for example, is a global library that can store digitized versions of print materials, sound, still pictures, and motion pictures.
  - B. It has some characteristics of the human brain. A computer can rapidly and accurately carry out a set of directions that have been written as a computer program. Such a set of directions contains or represents a certain type and level of intelligence. Even a very modest amount of this “machine intelligence” (often called “artificial intelligence”) is a very powerful aid to problem solving. For example, computer software can remove the “red eye” from a photograph, and computerized animation has become a routine aid to filmmakers. For under \$5 one can purchase a solar battery handheld calculator that “knows” how to add, subtract, multiply, divide, and take square roots of decimal numbers.
  - C. It can greatly enhance human productivity in solving some types of problems and accomplishing some types of tasks. The editing of audio and video provides an excellent example.

Thus, we now have the human brain/mind, the human brain/mind augmented by reading and writing, and the brain/augmented by ICT. The paper and pencil augmented brain depends on the

human reader/writer for its intelligence. The actions or problem-solving activities that are aided by paper and pencil must be carried out by humans.

ICT builds upon and expands the usefulness of reading and writing—for example, by making possible a global library that can be simultaneously accessed by many millions of people. But ICT adds a new dimension to reading and writing, by making possible the automation of some cognitive tasks that previously were carried out by humans, or humans aided by much less powerful tools. My thesis is that ICT-based auxiliary brain should already be an important part of education, and that it will continue to grow in importance.

## Concluding Remarks

Collectively, the human race knows a lot about brain/mind science and how it relates to teaching and learning. Moreover, we are living at a time of rapid growth in the field of brain/mind science.

However, brain/mind science is a field where it is difficult to translate theory into practice. As the adage says, “When you are up to your neck in alligators, it's hard to remember the original objective was to drain the swamp.” When a teacher is facing a classroom full of young students, he or she tends to be in survival mode rather than in the mode of learning, understanding, and implementing current ideas from brain/mind science.

This provides an excellent opportunity to practice “chunking.” You know quite a bit about brain and mind—indeed, probably quite a bit more than your students. You have knowledge about some of the capabilities and limitations of brain/mind within the disciplines that you teach. Consider brain/mind science as a single chunk that you hold in short term memory as you think about designing a lesson for your students. That still leaves you about  $6 \pm 2$  chunks of short-term memory space to deal with the key ideas you need to think about as you develop the lesson. A low technology variation of this is to write your self a note, “**Remember to take brain/mind science into consideration.**” that you place near the top of a page you are using to develop a lesson plan.

You also know quite a bit about roles of ICT as an aid to problem solving. Name this chunk *augmented memory*. As you develop a lesson plan, hold this chunk in your short-term memory. Now you are down to  $5 \pm 2$  chunks of short-term memory to use in focusing on content, pedagogy, and assessment. But, surely you need to think about constructivism, transfer of learning, lower-order knowledge and skills, higher-order knowledge and skills, the overall curriculum goals in the discipline, and various other things.

Oh oh! Do you see how easy it is to exceed short-term memory capabilities? Fortunately, you have a useful level of expertise in making use of paper, pencil, books, and computers to augment the capabilities of your brain/mind!

## **Appendix B: Computer Programming and Problem Solving**

**This Appendix discusses some general ideas about computer programming. A computer program is a set of instructions that a computer can follow. The instructions are used to represent a problem and the steps needed to solve the problem.**

**A computer program may be designed to interact with a person, so that the person and a computer work together to solve a problem. Or a program may be designed to interact with a machine, such as an automated production facility or data-gathering instrumentation equipment. These ways of storing and processing information add a dimension to information storage and retrieval that is not available through books and similar static media.**

### **Types of Computer Programming**

A computer program is a detailed set of step-by-step instructions that a computer can interpret and carry out. That is, a computer program tells the computer hardware what to do. The process of creating a computer program is called computer programming. The terms computer program and computer software are used interchangeably.

Traditionally, computer programming has meant the process of designing and writing a computer program in a general-purpose programming language, such as a machine language, an assembler language, or a higher level programming language (e.g., BASIC, C++, COBOL, Java, Logo FORTRAN). There are hundreds of different higher-level programming languages designed to fit the specific needs of programmers working in different problem domains (Kinnersley, n.d.).

It takes a great deal of study and practice to gain a high level of expertise in programming in a general-purpose programming language. That is because two general activities are involved. First, one must understand the problem to be solved and how to solve it. Second, one has to know the discipline of computer programming, and how to program well enough to develop a computer program that implements your problem-solving ideas.

The next three sub sections give brief introductions to three different levels of types of computer programming.

#### **Command-level Programming**

Essentially all computer users do some command-level programming. Here are some examples of command-level programming that you have probably done.

- You specify the general appearance of your desktop and you tell your computer what files to open up when it starts up.
- You specify a number of preferences to your word-processing software, such as what printer to use and a variety of printer options that the computer is to follow.

- You change the font that is being used by your word processor, and you change the margin settings of a page.
- You use menu selections and/or a keyboard to tell the computer to spell check a document, determine its length, and print it out.
- When playing a computer game, you use a mouse and the keyboard to issue instructions to the game software.

Some of the commands that you issue to a computer result in immediate action that you can see. Other commands, such as specifying a printer to be used, resulting in visible actions at a later time.

### **Productivity-tool Programming**

When you are creating a spreadsheet using spread software, or creating a database using database software, you are doing productivity tool programming. Spreadsheet software and database software are examples of productivity tools.

To illustrate, suppose that you are creating a spreadsheet to help solve a personal budgeting problem. The spreadsheet software provides you with a two dimensional table. You specify labels for the rows and columns of the table. You specify values for data to be placed in various cells in the table. You specify computations to be performed to create values that will go into other cells. For example, you might specify that a value at the end of a row is to be computed by adding up all of the preceding numbers in the row.

Spreadsheet software includes a number of built-in functions designed for use in business, science, and other areas. The software also contains a number of different graphing utilities to be used for outputting graphs of data.

A spreadsheet environment can be used to illustrate and learn a number of the rudiments of using a general-purpose programming language. Examples of key ideas include:

- Developing a computer model (a computer representation) of a problem.
- Developing a solution procedure for a problem in a form that can be used by you and others in the future, and in which a computer does a significant part of the work in solving a problem.
- Developing a human-computer interface that is comfortable and convenient for a human to use.
- Testing the correctness of the spreadsheet implementation of the model, including debugging (correcting errors).

### **Programming Using a General-purpose Programming Language**

BASIC, C++, COBOL, Java, Logo, and FORTRAN are some of the many general-purpose programming languages that are not specific to any particular productivity tool. Generally, they

are available for a variety of different computer platforms, such as IBM-compatible and Macintosh microcomputers. These languages are often used to write sophisticated programs to be used by yourself and/or other people. Traditionally, computer programming has meant writing programs in such programming languages.

We have previously mentioned that a computer program is a step by step set of instructions to be carried out by a computer. A modern microcomputer can carry out many millions of instructions per second. Such speed is one key to the value of a computer. A second key is the ability of a computer program to make decisions based on results that have been stored in a computer memory by a person or by a computer.

For example, suppose that a computer is following a list of instructions, instruction # 1, instruction # 2, etc. Suppose that instruction # 1 tells the computer to perform a certain computation and place the result in computer memory location 35,0001. Instruction # 2 tells the computer to carry out a specified computation and place the result in computer memory location 35,002. Computer instruction # 3 tells the computer to compare the results in memory locations 25,001 and 35,002. If the value in memory location 25,0021 is the large, then do instruction # 4 next. Otherwise, do instruction # 35 next. This simple "If ... Then" decision-making capability of a computer is what allows a relatively short computer program to keep a computer busy for hours or indefinitely.

## **Some History of Programming Languages**

The earliest electronic digital computers were designed to help solve math, science, and engineering types of problems. For the earliest computers, programming consisted of rewiring the machine. A computer was rewired to be able to solve a particular specific problem. Plug boards were used, much like the plug boards used in early telephone systems. There are many fine Websites on the history of computers (Computer History Museum, n.d.; History of Computers, n.d.).

It was a major breakthrough when the idea of storing a computer program in the computer memory was developed. Just changing the contents of the computer memory could then change a program. Indeed, the instructions in a computer program could be designed to make changes to the computer program! This "stored program" change in the human-machine interface made it easy to store computer programs for reuse at a later date and for transporting them to other computer sites.

The mechanics of programming in the early days of computers were not simple because the human-machine interface was not well developed. Programming was done at the machine-language level. A machine is constructed to "understand" about 100 to 200 different instructions, and the instructions were each identified by a number such as 001, 002, 003, 004, and so on. The instructions are designed to work on the contents of individual computer memory locations, and each instruction accomplishes a small, specific task. For example, an instruction might change the sign of a number. A different instruction might compare two different memory locations to see if they are equal. Still another instruction might add the number 1 to a given memory location. The smallest error in indicating what instruction is to be done or what memory locations it is to affect can lead to completely wrong results. It is really easy to make a simple mistake, such as telling

the computer to do instruction 187 when you really want the computer to do instruction 178. It is difficult to detect and correct errors when one is programming at the machine-language level.

Very early on, the human-machine interface in computer programming was improved. A simple example was the development of mnemonics for the instructions and variable names for memory locations. Instruction names such as ADD, SUB, MUL, and DIV, are easier to remember than numeric codes for instructions. Variable names, such as LENGTH and WIDTH, are easier to work with than memory location addresses, such as memory location 21834 and memory location 02642. Computer programs were developed that translated the mnemonic instructions and the variable names into appropriate machine-language instructions and specific memory location addresses. The translating programs were called assemblers, and the languages themselves were called assembler languages or assembly languages.

During the early to mid-1950s, still better human-machine interfaces were developed to help programmers. These were called higher level programming languages. FORTRAN (standing for FORMula TRANslation) was developed over a period of several years, from 1954 to 1957. This language was specifically developed for use by scientists and engineers. Many different versions of this language have been developed since then, and FORTRAN is still a widely used programming language in the science and engineering fields.

The FORTRAN programming language is representative of a key idea in the computer field. Not only can people develop better human-machine interfaces but they can also develop interfaces to suit the needs of specific domains. COBOL (COMmon BUSINESS ORiented Language) was developed for programmers working on business problems. BASIC (Beginners All-purpose Symbolic Interchange Code) was developed as a math tool for college students. The key idea is that a person who has considerable knowledge in a domain can build on this knowledge through learning a programming language specifically designed to help solve problems in that domain.

That is, there is transfer of learning from a domain into learning to use a programming language that is specifically designed to help solve problems within the domain. It is interesting to consider the opposite direction of transfer. Suppose that one has never studied business accounting. One learns to use a spreadsheet. By doing so, one may learn something about business accounting.

Over the years, more and more higher-level programming languages have been developed. Now there are hundreds of different programming languages. Superficially, these general-purpose, higher-level programming languages seem to differ quite a bit from each other. However, in many ways, they share much in common. Some of the commonality is discussed in the following section.

## **Data Structures and Control Structures**

Here is a somewhat simplified way to think about a computer program. A computer program consists of two major parts. First, it contains a representation of the problem, including the data that is to be input, stored, manipulated, and output. This is called a data structure. Second, it contains detailed instructions telling the computer exactly what to do with the problem

representation and the data. This is called a control structure. Thus, a computer program consists of a combination of a data structure and a control structure.

The initial higher-level programming languages, such as FORTRAN and COBOL, were oriented toward somewhat specific domains of problem solving. FORTRAN was designed to help a programmer create the types of data structures and control structures needed to solve math, science, and engineering problems. COBOL was designed to help the programmer create the types of data structures and control structures needed to solve business problems. However, both languages are general-purpose. They can be used to write programs to solve any kind of problem that can be solved by a computer.

As use of computers spread to other fields, people began to develop software to fit the specific needs of problem solvers in these fields. As timeshared computing and then microcomputers became available, people developed a variety of software such as spreadsheet, database, and graphics that can be thought of as somewhat limited purpose, but still relatively general purpose.

For example, a spreadsheet is based on a two dimensional table as a data. Obviously such a data structure is useful in representing a wide range of business accounting problems. However, it is also useful in representing table of data in any discipline that makes use of tables of data.

As another example, a graphic artist needs to represent figures that contain lines, rectangles, circles, text, and other geometric shapes. Thus, a productivity tool designed for graphic artists contains good provisions for representing these types of figures. The graphic artist may want to view a figure from different perspectives, enlarge or shrink a graphic or piece of a graphic, and so on. Thus, a productivity tool designed for graphic artists contains good provisions for manipulating a figure in a variety of ways..

The data structures and control structures needed by a graphic artist are certainly different from those needed by a musician. The musician uses musical notation to represent music. A musician needs to hear the music in addition to viewing its score. The musician needs easy provisions for manipulating and combining the sound from a number of different musical instruments. Thus, a productivity tool designed for musicians contains provisions to make it easy to accomplish all of these tasks.

## **Procedures and Procedural Thinking**

Computer programming is a discipline in which a person can gain a very high level of expertise. It takes a special type of talent to learn to be a good computer programmer, and some programmers develop a much higher level of expertise than others. Indeed, some of those at the world class end of the scale are perhaps ten times as productive as the mid level professional programmer.

As with any discipline, learning “meaningful chunks” and learning to think and solve problems using these meaningful chunks is an important aspect of increasing one’s level of expertise in computer programming.



Earlier parts of this book discuss the strategy, break a big problem into smaller, more manageable pieces. This is one of the most important ideas in computer programming. A programmer needs to break a problem solution process into pieces (chunks) that the programmer can understand, manipulate, and write program code for. Moreover, a programmer needs to keep in mind that programming code has already been written for many thousands of different sub problems (chunks), and that this code is available in a form that can easily be reused.

Now we are getting to the heart of procedures and procedural thinking. Think of a computer program as a procedure (a set of instructions to be carried out by a computer). A programmer creates a procedure by developing some of the needed sub procedures, by making use of sub procedures developed by others, and by putting them all together in a way that will solve the specified problem. The overall thinking and problem-solving process is called *procedural thinking*.

Thus, computer programmers learn to think in terms of developing cognitively manageable chunks or pieces of procedures. They learn to solve problems by using such chunks (procedures). Procedural thinking is such an important idea that some definitions of computer literacy include the specification that to be computer literate, a person has to understand and make use of procedural thinking.

## **Object Oriented Programming**

In the past few decades, computer programming languages and computer programming have moved beyond the general ideas of control structure, data structure, and procedural thinking described above. In many problems, the needed control structure and data structures tend to merge together. The following early history of object-oriented programming illustrates this situation. It describes the reasons for the development of a programming language named Simula in the mid 1960s. (Pawson and Matthews, n.d.). In developing computer simulations:

Sometimes the data is fixed and the programmer manipulates the functional characteristics of the system until the output meets the required criteria. For example, the data might represent the roughness of a typical road and the programmer might alter the design of a simulated truck suspension system until the desired quality of ride is achieved. Sometimes it is even difficult to tell data and functionality apart: when you add another axle to your simulated truck, for example, are you changing the data (the number of wheels) or the functionality (the way in which the truck translates road bumps into ride quality)?

The inventors of Simula had the idea of building systems out of 'objects', each of which represents some element within the simulated domain. A simulation typically involves several classes of object - a Wheel class, a Spring class, a Chassis class, and so forth. Each class forms a template from which individual instances are created as needed for the simulation.

Each software object not only knows the properties of the real-world entity that it represents, but also knows how to model the behaviour of that entity. Thus each Wheel object knows not just the dimensions and mass of a wheel, but also how to turn, to bounce, to model friction, and to pass on forces to the Axle object. These behaviours may operate continuously, or they may be specifically invoked by sending a message to the object.

Object-oriented programming is now commonplace. Some examples of objects that a programmer might want to include in a program could be a pull-down menu, a button, and a scrolling field. Each of these objects varies in physical size, placement on the screen, and how it is to interact with the computer user. An object-oriented programming language contains a

number of built-in objects. With a few keystrokes, the programmer designates the specifics of an object that possesses an underlying computer programming code of possibly thousands of lines in length. In an object-oriented programming language, the programmer can also easily create new objects.

Initially, object-oriented programming was considered to be an esoteric subject. We now have reached the stage where a number of programming languages and computer applications contain object-oriented provisions that are easy to use. For example, in an engineering drawing program there are good provisions to create objects consisting of combinations of circles, rectangles, text, and other geometric shapes. These objects can easily be sized, rotated, and positioned as needed when undertaking a drawing task.

Now, object-oriented programming has come to the forefront, proving to be an important key to building on the previous work of other people. It is a powerful aid to amplifying the capabilities of a computer programmer.

## **Transfer of Problem-Solving Skills From Programming**

Computer programming can be thought of as a type of problem solving in which the main resources are a computer and the computer programmers. You might think that the problem-solving skills needed in this environment easily transfer to solving problems in other environments that do not depend on computer programming.

There have been many research studies on the transfer of problem-solving skills from computer programming to other environments. In the typical study, some students (the experimental group) learn computer programming while other students (the control group) spend their time on some other learning tasks. The groups are matched on the basis of their initial overall skills in problem solving that do not involve the use of computers. After the "treatment," both groups are tested for their general non-computer problem-solving skills.

The early researchers were puzzled by the rather consistent results indicating that little or no transfer of problem-solving learning surfaced in such studies. Salomon and Perkins (1988) and Perkins (1995) summarize the early research literature in this field. They describe a low-road/high-road transfer theory. They analyze the research studies on the basis of whether the treatment was powerful enough to lead to low-road and/or high-road transfer. Their conclusion is that the treatment in these types of studies has seldom been adequate to lead to either low-road or high-road transfer.

Based on an analysis of the research literature and their own studies, Salomon and Perkins conclude that there will be transfer of learning in problem solving if computer programming is taught in a manner that helps transfer to occur. That is, transfer of learning will occur if the instruction meets the conditions that are needed for either low-road transfer or high-road transfer.

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