Introduction to Problem Solving in the Information Age

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Brief Abstract of Book

> "Never doubt that a small group of thoughtful committed citizens can change the world: indeed; it's the only thing that ever has." (Margaret Mead)

In this book, the term *problem solving* includes posing and solving problems, posing and accomplishing tasks, posing and answering questions, and posing and making decisions. Problem solving is an integral component of every academic discipline.

The Information Age officially began in the United States in 1956 when the number of "white collar" workers first exceeded the number of "blue collar" workers.

The primary audience of this book is preservice and inservice teachers, and others who help students to learn. The goal of this book is to help K-12 students get better at problem solving in the various disciplines they study.

We get better at problem solving through informal and formal education, and through reflective practice. We also get better at problem solving through learning to make effective use of tools. In some sense, a tool incorporates the problem-solving insights of the inventor of the tool. When you learn to make effective use of a tool, you are building upon the knowledge and skills inherent to the tool.

This is true whether the tool is designed to aid your physical capabilities or your mental capabilities. A bicycle, motorbike, and a piece of factory machinery are aids to one's physical capabilities. Reading, writing, and a library are aids to one's mental capabilities.

This book explores how Information and Communication Technology (including calculators and computers) aid both your physical capabilities and your mental capabilities. By learning to make effective use of ICT tools, you can improve your problem-solving capabilities.

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About Dave Moursund, the Author

"The wisest mind has something yet to learn." (George Santayana)

- Bachelor's degree in mathematics, University of Oregon.

- Master's degree and doctorate in mathematics (specializing in numerical analysis) from the University of Wisconsin-Madison.

- Instructor, Department of Mathematics, University of Wisconsin-Madison.

- Assistant Professor and then Associate Professor, Department of Mathematics and Computing Center (School of Engineering), Michigan State University.

- Associate Professor, Department of Mathematics and Computing Center, University of Oregon.

- Associate and then Full Professor, Department of Computer Science, University of Oregon.

- Served six years as the first Head of the Computer Science Department at the University of Oregon, 1969-1975.

- Full Professor in the College of Education at the University of Oregon for more than 20 years. Currently retired with rank Emeritus Professor.

- In 1974, started the publication that eventually became *Learning and Leading with Technology*, the flagship publication of the International Society for Technology in Education (ISTE).

- In 1979, founded the International Society for Technology in Education). Headed this organization for 19 years.

- Author or co-author of about 50 books and several hundred articles in the field of computers in education.

- Presented about 200 workshops in the field of computers in education.

- Served as a major professor for about 50 doctoral students (six in math, the rest in education). Served on the doctoral committees of about 25 other students.

- Founding member of the Math Learning Center. Served on the MLC Board of Directors since its inception in 1976, and chaired the board for several years.

- For more information about Dave Moursund and for free online, no cost access to 20 of his books and a number of articles, go to http://uoregon.edu/~moursund/dave/.

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

Preface

"What is written without effort is in general read without pleasure." (Samuel Johnson)

"In short, learning is the process by which novices become experts. " (John T. Bruer)

This short book provides an overview of a large and complex field—problem solving and roles of Information and Communication Technology (ICT) in problem solving. Quoting from the Wikipedia:

> Problem solving forms part of thinking. Considered the most complex of all intellectual functions, problem solving has been defined as higher-order cognitive process that requires the modulation and control of more routine or fundamental skills (Goldstein & Levin, 1987). It occurs if an organism or an artificial intelligence system does not know how to proceed from a given state to a desired goal state. It is part of the larger problem process that includes problem finding and problem shaping.

Reading, writing, and arithmetic are powerful aids to problem solving. These aids have been available for more than 5,000 years. They are so important that they are considered the *basics* of education.

We now have computer technology that builds upon and extends uses of reading, writing, and arithmetic. ICT tools have become routine aids to problem solving in every discipline. However, our educational system has been slow to thoroughly integrate ICT aids to problem solving into the everyday curriculum. While many people argue that ICT aids to problem solving should now be part of the basics (as are reading, writing, and arithmetic), we are a long way from achieving this in our schools.

The book has three main audiences:

1. It is intended for use in computer in education courses. Many computer in education courses focus mainly on the computer tools, rather than the deeper idea of computers as an aid to solving problems and accomplishing tasks that are part of "doing" or using a discipline. Use of this book in such courses will help redress this imbalance.

2. It is intended for use in non-ICT courses for preservice and inservice teachers. Thus, for example a person taking a Social Science, Science, or Math Methods course would benefit by reading it. Solving problems, accomplishing tasks, answering challenging questions, and making difficult decisions lie at the heart of every discipline. Thus, every discipline teaches problem solving, and every discipline benefits by having ICT available as an aid to representing and solving problems.

3. 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 in each discipline they are studying.

The single most important idea in problem solving is building on the previous work and learning done by ones self and others. ICT bring some new dimensions to these endeavors.

For example, we now have the Web, the world's largest library. It substantially helps in providing access to the previous work of others. Moreover, personal computers and connectivity allow a person to build their own virtual library, putting into it content that they find particularly useful in solving problems and accomplishing tasks that they encounter in their everyday lives.

We now have computers that can solve or help solve a wide variety of problems. In essence, we are automating many mental tasks that used to be done using simpler tools, such as pencil, paper, and calculators. More and more problems can be solved by just appropriately presenting the problem to a computer.

Computers have given us a new way of thinking about problems, called computational thinking. Computational thinking involves using one's own thinking abilities, those of other people, and those of computer systems. Many complex problems are now being attacked by developing computer models and computer simulations of the problem situation. The world's most powerful computers are being used to model weather and global climate (including global warming) and various aspects of proteins and genes in the study of genetics.

This book is divided into a number of short chapters. Each contains some suggestions for immediate actions (implementations) for teachers. Each chapter ends with a set of activities that are suitable for self-study, use in a workshop, or use in a course's class meeting, and use in homework assignments.

Chapter 1

Introduction and Overview

"Learning without thinking is labor lost; thinking without learning is dangerous." (Chinese Proverb)

"Once you have learned how to ask relevant and appropriate questions, you have learned how to learn and no one can keep you from learning whatever you want or need to know." Neil Postman and Charles Weingartner. Teaching as a Subversive Activity.

This chapter contains some general background that lays foundations for the rest of the book. Keep in mind that this is a scholarly, "academic" book. This means that you need to read it while you are mentally alert and your mind is in gear. It means that after you read a paragraph, you should stop and reflect about what the paragraph means to you. Learning comes from the concentrated, alert mind reading process and from careful reflection about what you are reading. Learning comes from using what you are learning and from seeking possible uses of what you are learning.

Improving Education

This book focuses on improving education by helping preservice and inservice teachers, and their students, to get better at problem solving. Problem solving is certainly core to a good education. Thus, better curriculum, instruction, and assessment in this area can lead to improvements in our overall educational system.

However, there are some still larger issues than can be addressed our educational system. From time to time over the years, I have attempted to make a short list of **Big Ideas** that help me as I work to improve our educational system. Here is my current list:

1. Empower and enable the learner and those who directly help learners to learn.

2. Help students learn to sell-assess and to take a steadily increasing level of responsibility for their own learning.

3. Help students get better at asking researchable question and in learning to do the various types of research that are used to answer such questions. The Web plays a significant role in this endeavor, since a literature search is an important component of trying to answer a researchable question.

4. Help all people to get better at being both teachers of themselves and others, and learners. (We are all lifelong teachers and learners.)

5. All technology (not just computers) plays a role in the above list. Any particular technology is potentially more empowering and enabling for some

than for others. Indeed, any particular technology has the potential to be disempowering and disenabling for some people.

Please work with me as I briefly explore the first item —about empowering and enabling— on the list from a combination of your point of view and from our educational system's point of view. You, a learner, already know a great deal. You have good insights into what your want to learn, and why. You want your new learning to empower and enable you as you work toward achieving goals that you set for yourself.

Contrast this self-centered point of view with that of our educational system, your course instructors, book authors, and so on. The "establishment" feels that it know what is best for you. It develops requirements, courses, tests, and so on—hoops that you must jump through to achieve a degree, certification, a job, and so on. At the precollege level, these hoops include high stakes tests at the regional, state, and national levels. This assessment system has grown so powerful that it is shaping the lives of students and their teachers.

You, and all other students, are thus faced with the problem of dealing with these two different approaches to education. Some students find it easy to give in to the establishment. They develop an attitude summarized by the statement: "Just tell me what to do and I will do it." Indeed, there is some evidence that this is a growing trend in our educational system. It is accompanied by increased efforts on the part of teachers to carefully specify what it is a student is to do and learn, and increased efforts on the part of students to challenge the teachers who do not provide detailed specifications of what they want students to learn and how they will assess this learning.

My personal opinion is that this is a poor approach to improving education. I much prefer to see an educational system that is more strongly student centered, that empowers and enables students from their personal points of view. I much prefer an educational system in which teachers are empowered and enabled in a quest to empower and enable individual students, working to achieve an appropriate balance between the needs and wants of students, and the needs and wants of the establishment.

Most readers of this book are preservice or inservice teachers and others involved in our overall educational system. I hope that each of you will think about the how you can empower and enable yourself through your studies, and how you can do the same thing for your current and future students.

Academic Disciplines

This book is intended for students who are studying many different disciplines. You might wonder why we have so many different academic disciplines. Indeed, you may wonder what distinguishes one discipline from another, or the extent to which the various disciplines one can study in precollege and higher education overlap each other.

Each academic discipline can be defined by a combination of:

- The types of problems, tasks, and activities it addresses.

- Its accumulated accomplishments, such as its results, achievements, products, performances, scope, power, uses, impacts on the societies of the world, and so on.

- Its history, culture, methods of communication, and language (including notation and special vocabulary).

- Its methods of teaching, learning, assessment, and thinking, and what it does to preserve and sustain its work and pass it on to future generations.

- Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, and recording and sharing accumulated results.

- The knowledge and skills that separate and distinguish among (a) a novice, (b) a person who has a personally useful level of competence, (c) a reasonably competent person, (d) an expert, and (e) a world-class expert. Each discipline has its own ideas as to what constitutes a high level of expertise within the discipline and its subdisciplines.

Notice that this list emphasizes solving problems and accomplishing tasks. It emphasizes gaining an increasing level of expertise in "doing or accomplishing."

One of the major issues in getting better at doing or accomplishing (solving problems, accomplishing tasks, etc.) is discipline-specificity versus discipline-independence. Does gaining an increased level of expertise in playing chess automatically make you better at solving math problems, or vice versa? Does learning how to solve chemistry problems make you better at solving the types of problems faced by a performing artist, or vice versa?

Clearly some cognitive tools cut across many disciplines. Reading and writing are useful in every academic discipline. Math is an old, broad, deep discipline in its own right, but also a component of many other disciplines. Math provides a language and a way of thinking that is useful in many other disciplines.

Information and Communication Technology is somewhat analogous to math in that it is both a broad and deep discipline in its own right, and it has become an important component of many other disciplines.

Thus, as you work to improve your knowledge, skills, and "doing" abilities in almost any discipline, you will find that you are continually drawing on your current levels of expertise in disciplines such as reading and writing, math, and ICT.

Subconscious Thinking and Problem Solving

Your brain and body are highly skilled in solving the problems of keeping you alive. Most of this goes on at a subconscious level. You do not have to consciously think about telling your heart to beat regularly, your lungs to keep breathing regularly and to oxygenate blood, or your digestive system to digest the food that you eat. You do not have to consciously tell your immune system do deal with infections.

You are also highly skilled at solving problems at a conscious level. When you carry on a conversation or read a book, you are solving complex communications problems. Interestingly, much of what you are doing as you carry on a conversation or read a book occurs at a subconscious level. For example, you think a thought and your brain somehow puts together the sequence of muscle, vocal cord, and other physical activities needed to deliver sentences about the idea. You look at small squiggly drawings on a page (that is, at letters, words, and sentences) and your brain turns these into silent sounds, pictures, and meaning in your head.

The conscious and subconscious processes of talking, listening, reading, and writing give us considerable insight into teaching and learning for problem, solving. You learned speaking and listening from our informal education system. You have an innate ability to learn oral

communication—it is built into your genes. (Of course, some people's genes don't work correctly or physically injuries damage parts of their body that are necessary to oral speaking and listening.)

You probably learned reading and writing from our formal educational system. Reading and writing were developed just a little over 5,000 years ago. Learning to read and write is a major cognitive challenge for most people. It takes a relatively long period of instruction, learning, and practice to become skilled at reading and writing. Indeed, I find it somewhat surprising that with appropriate formal education, most people can learn to read and write relatively well.

Much of the initial learning of reading and writing is done at a conscious level. However, eventually much of what you do in reading and writing is carried out at a subconscious level. It is through considerable practice that the initial reading and writing learning becomes automatic at a subconscious level. That is, formal education and practice produce important results at both a conscious and subconscious level.

Your brain has considerable plasticity. When you are learning through our informal and formal education systems, your brain is changing. Your brain is forming new neural connection, strengthening some connections, and weakening others. If part of your brain is damaged, the overall brain plasticity helps to repurpose other parts of your brain to carry out tasks previously done by the damaged parts.

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 Formal Educational System

Our PreK-12 and higher formal education systems are designed to develop the capacity of your brain to deal with the problems that our society (that is, the establishment) feels a person might encounter in 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 home, work, school, play, and in other parts 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. However, that is one (useful) way to think about our informal and formal education systems. Thus, 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 book.

This book gives a brief overview of the subject or discipline 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 book can be woven into instruction in almost any curriculum area.

What is Problem Solving?

In this book, I use the term **problem solving** to include all of the following activities:

- posing, recognizing, clarifying, and answering questions

- posing, recognizing, clarifying, and solving problems

- posing, recognizing, clarifying, and accomplishing tasks

- posing, recognizing, clarifying, and making decisions

- using higher-order, critical, and wise thinking to do all of the above.

This broad definition is intended to encompass the critical thinking and higher-order thinking activities in every discipline. An artist, mathematician, musician,scientist, and poet all do problem solving.

Critical Thinking

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?" 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. (Educational Psychologist. 36(4), 253-256)

Indiana University Purdue University Indianapolis provides a student-oriented definition of critical thinking (IUPUI, 2007).

> [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;
>
> - use knowledge and understanding in order to generate and explore new questions.

Higher-Order Thinking

The term "higher-order" thinking is often used in discussing critical thinking and 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.

Probably you have heard about Benjamin Bloom's six-part taxonomy of cognitive learning. This was developed in 1956, and its focus was mainly on college education. However, it is applicable to education at all levels. . Quoting from Donald Clark (n.d.), the six levels are:

- **Knowledge:** Recall data or information.

- **Comprehension:** Understand the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.

- **Application:** Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.

- **Analysis:** Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.

- **Synthesis:** Builds a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.

- **Evaluation:** Make judgments about the value of ideas or materials.

Bloom's taxonomy is designed to help differentiate between the lowest order (knowledge; recall data and information) and the highest order (evaluation) of human cognitive activity. One way to think about the scale is that it starts at rote memory of data and information with little or no understanding, and it ends at the highest level of understanding and critical thinking.

Our educational system attempts to differentiate between lower-order cognitive (thinking) skills and higher-order cognitive 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).

Some Important Aspects of Problem Solving

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 lower-order goals. Learning to write in a manner that communicates effectively is a higher-order, critical thinking goal. In some sense, each writing task is a new problem to be solved.

Moreover, writing is a powerful aid to the brain. George Miller (1956) discusses the magic number 7 ± 2. He and many others have observed that a typical person's short term memory is limited to about 7 ± 2 pieces or chunks of information. Thus, probably you can read a seven-digit phone number and remember it long enough to key it 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 using 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. Some are much more explicit in this endeavor than others.

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 students to master the basics (fundamentals) of problems solving and then the new problem-solving topics that the teacher wants to cover.

This book covers the basics 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 book 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 book places particular emphasis on several important problem-solving ideas:

1. Posing, recognizing, clarifying, 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. Some traditional tools (for example, reading and writing) 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, recognizing, clarifying, 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, recognizing, clarifying, representing, and solving problems that cut across many or all domains, and so there can be considerable transfer of learning among domains. Transfer of learning is discussed in Chapter 5. 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 Chapter 1

Chapter 1 suggests that every teacher teaches problem solving, lower-order skills, higher-order skills, and critical thinking. Every teacher teaches for 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, critical thinking, and transfer of learning.

Activities for Chapter 1

1. Select a discipline that is a standard part of the PreK-12 curriculum. List several important lower-order skills within the discipline. List 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. List 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 Chapter 1 of this book 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 Chapter 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.

Chapter 2:

What is a Formal Problem?

"All progress is precarious, and the solution of one problem brings us face to face with another problem." (Martin Luther King Jr.)

See how a smart squirrel deals with a difficult problem. View the short video: http://www.youtube.com/watch?v=nWU0bfo-bSY.

Each of us has our own concepts as to what constitutes a problem. People wanting to share their thoughts and do research on the topic need to agree on a definition. This chapter presents both a general overview and a formal definition of *problem.*

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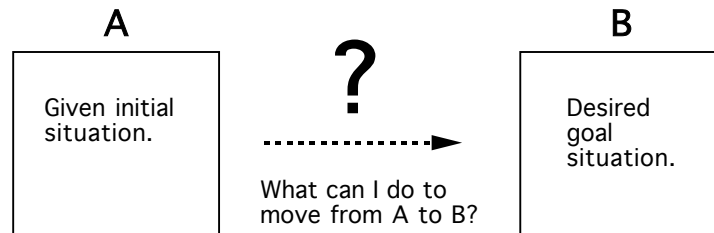
Figure 2.1. Problem-solving—how to achieve the final goal?

There is a substantial amount of research literature as well as many practitioner books on problem solving. A recent Google search on the quoted expression *"problem solving"* produced over 9 million hits.

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, time, money, and so on to achieve the desired final goal.

More Detail About the Four-Component Definition

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 (that is, a 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.

This is a key idea. Through study, practice, and access to appropriate tools, you can increase your level of expertise in solving a particular category or type of problem. One way to think about informal and formal education is that the purpose or goal is to increase your level of expertise in various problem-solving areas.

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. 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, suppose that 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. However, 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. An employee may have ownership "assigned" by his/her supervisor in a company. That is, the company or the supervisor has ownership, and assigns some of this ownership it to an employee or group of employees. An employee accepts ownership of a problem as being part of the job, and is expected to function in a manner consistent with having personal ownership.

The idea of ownership can be confusing. In this book 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 and learning. From a teacher point of view, it would be nice if students would accept ownership of the problem of learning or the problem of doing assignments. Certainly one can draw a parallel with an employee having some ownership of a company's problem. Here however, the employee is being paid to accept this ownership.

For the most part, we want students to accept ownership of their overall problem of obtaining a good education. This works well for some students, but it is certainly not uniformly successful. Teachers, parents, and others expend considerable efforts in trying to get students to have ownership of their education.

If a student creates or helps create the problems to be studied and solved in school, 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.

Dealing With Problem Situations

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 a 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 problem situation—you may begin to think about and clarify the problem situation. 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.

Finally, you need to know that just because you have a clearly defined problem does not mean that you (or indeed, anyone else) can solve it. Many problems have no solution.

Did you just "bleep" over the previous paragraph, or did you stop to think about the possibility of a clearly defined problem not having any solution? Did you attempt to think of such a problem?

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.

Solvable and Unsolvable Problems

Find two even integers whose sum is an odd integer. Find two chemicals, neither containing atoms of gold, that when mixed together and heated over a Bunsen burner will produce gold.

The point is, just because one has a clearly defined problem does not mean that one has a solvable problem. Probably you can give a good argument that the first of the two problems listed above does not have a solution. The second of the problems confounded alchemists for many years. The Bunsen burner restriction is an important part of this problem. Gold can be produced by the heat and pressure inside a sun.

It is easy to find clearly defined problems that have no solution. It is easy to find clearly defined problems that have exactly one solution, and it is easy to find others that have two

solutions, three solutions, or still more solutions. Thus, one of the things to think about when faced by a clearly defined problem is that it might not have solution, it might have exactly one solution, or it might have more than one solution.

Are you having trouble thinking of a problem that has exactly five solutions? Here is an example from math. Find a positive integer that is greater than 2 and less than 8.

The world of problem solving also faces the situation of situations in which one is seeking a "good" solution or "the best" solution. Suppose that I am trying to decide what clothes to wear to work today. There are lots of possible solutions, since I have a variety of clothes. Some of my possible choices are likely to be better than others. Thus, for example, it typically is not considered "good" to wear mismatched socks or a dress shirt with a hole in one elbow and a large stain on the front. However, if this happens to be a freaky Friday day, either or both of these choices might be good. How does one decide which of a number of possible good solutions is "the best?" Indeed, what is there about a real world problem such as choice of clothing that suggests that there is one "best" solution? Is there a best way to raise a child or a best way to teach students how to read?

To further complicate this situation, there are problems that are undecidable. This topic is beyond the scope of this book. You can find more information on the topic by doing a Web search on *undecidable*.

Immediate Actions for Chapter 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 their overall education and of the formal education part that we call *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 Chapter 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 of 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. Think back to when you were a secondary 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.

4. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Chapter 2 of this book from the point of view of applicability to students at that grade level and/or in that content area.

5. Drawing upon the full range of your current ICT knowledge and skills, analyze roles of ICT within the ideas discussed in Chapter 2. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 3

Information and Problem Overload

"When people cannot see the need for what's being taught, they ignore it, reject it, or fail to assimilate it in any meaningful way. Conversely, when they have a need, then, if the resources for learning are available, people learn effectively and quickly." (Brown & Duguid, 2000)

"What information consumes is rather obvious: it consumes the attention of its recipients. **Hence a wealth of information creates a poverty of attention**, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it." (Computers, Communications and the Public Interest, pages 40-41, Martin Greenberger, ed., The Johns Hopkins Press, 1971.)

It is common to talk about information overload. The totality of information that is being stored and made available to people is increasing quite rapidly. Far more information is being gathered and created in a year than a person can learn in many lifetimes of study.

However, a different way to look at this situation is that we have a problem overload, and we do not yet have easy access to enough information to help solve or to solve the problems. This chapter explores information overload and problem overload.

Problem Overload

Think about a typical television ad. It presents a problem situation and tries to convince you that you, personally, have a problem. It then presents a possible solution—"buy and use our product."

Think about a typical television or radio news broadcast. It describes problem situations in your community, state, nation, and the world. There is a strong effort to have you accept some ownership of these problem situations.

Think about browsing through a large grocery store, doing the grocery shopping for a week. The number of decision-making situations you face is immense. What do I really need versus what do I want? Which of the various brands of a product should I buy?

It is easy to extent the list of problem situations you may encounter in a typical day. Some of these will catch your attention and you may take some ownership. Thus, it is possible that you will acquire far more problems in a day than you can possibly solve. You are faced by problem overload.

People deal with this problem overload situation in a variety of ways. One way is to refuse to accept ownership of most of the problem situations you encounter. Perhaps you find it "interesting" that hundreds of thousands of children are starving in a particular country, or that

hundreds of thousands of people have been killed in an "ethnic cleansing" in another region of the world. In both cases, you might make a conscious or subconscious decision that you are unwilling or unable to devote your personal time and other resources to do anything about these situations.

Similarly, you may be very good at tuning out television, radio, and other ads. Just turn off your audiovisual input system when an ad begins. This is a way to help solve your personal problem of problem overload. The general idea is to carefully choose the problem situations that you want to accept as problems. Filter out problem situations that you don't want to attempt to solve.

Now, think about this in terms of a precollege or college student. Besides all of the types of problem situations being encountered in every day life, a student is bombarded with problem situations presented by teachers and textbooks. A student may consciously or subconsciously refuse to take ownership in many of these problem situations. The same skills used to tune out television ads can be used to tune out a teacher. Indeed, this is a common occurrence.

Okay, let's think this through. You are a teacher who is personally committed to solving the problem of helping students to learn and paid to solve this problem. Thus, you have ownership. You have the resources that come from your teacher education program of study, your experience of being a student, and your experience of being a teacher. There are many other resources in a school setting that you can draw upon, such as other teachers, school administrators, consultants, and so on.

You can think of the problem presented by each individual student, each class, each subject area you are teaching, and so on. These are constantly changing and very challenging problems. It is no wonder that most teachers feel overworked and under appreciated. Their job is always one of problem overload.

If there were easy and simple solutions to this overload problem, teachers would have found them. However, it seems to many teachers that their problem overload is increasing.

My personal opinion is that just doing more of what we have been doing in education will not ameliorate the overall situation of teachers having problem overload. We need a major paradigm shift. I believe that this shift will eventually occur and will include:

1. A very large increase in computer-assisted learning. This tends to shift part of the problem of teaching to CAL systems and part of the problem of being responsible for student learning to CAL systems and to students.

2. A very large increase in students learning to make routine use of powerful ICT systems as part of the content of each discipline they study and being assessed in authentic environments in which they use these ICT aids to knowing and using one's knowledge.

3. A large shift in moving the problem to individual students. Each student needs to learn to take much more individual responsibility for his or her own learning.

4. Continued research progress in brain theory, teaching theory, and learning theory. This ties in with (1) above, as much of this progress can be incorporated into computer-assisted learning systems.

These are powerful, large ideas. They cannot be adequately treated in this short book. However, they can help guide teachers and our educational system as it attempts to deal with the ongoing problem of teachers' having problem overload.

Who or What Should Do the Solving of a Problem?

One of the big ideas in problem solving is the need to convert an ill-defined problem situation into a well-defined problem. Consider the three ideas:

1. The most important idea in problem solving is building upon the previous work of oneself and others. Thus, we place considerable emphasis in school on learning about what problems people know how to solve and how to solve them.

2. If a problem is sufficiently clearly defined (sufficiently well defined), then work on solving the problem and actual processes of solving the problem can be stored and then communicated to others. In some cases a tool (perhaps a computerized tool) can be built that can automatically solve the problem. Then, in essence, the problem is no longer a problem, but merely a simple situation that is easily dealt with when it occurs.

3. Many problems are not solvable. Many others are not solvable within the limits of the resources that one has available.

These three ideas combine in many individual and group research projects, product design projects, and product development projects throughout the world. Government, large companies, and philanthropic foundations often fund large problem-solving efforts. Creative, inventive people are providing us with a continual stream of products and services that solve or help to solve problems.

What should students be learning about problems that people know how to solve? I am reminded of a time when I was doing a workshop on problem solving. A person in the workshop told us that she was not good at problem solving. She then went on to explain her weaknesses. These included needing to use a income tax preparation service to do her income tax, needing to use a car service to maintain her car, needing to use her physician to take care of routine medical problems, and so on.

This was a wonderful example. The woman had accepted ownership of a variety of standardly occurring problem situations. She understood the problems at a level of knowing why they needed to be solved and the results of solving the problems. She solved these problems by using her financial resources. We all do this! Most of us don't consider this as evidence of not being good at problem solving.

A Story About Building on Work of Others

Here is a short personal story. It is about a time when I was five years old. I was playing with friends in the alley outside my house. We were playing cops and robbers, and there was a lot of running and shouting. As I run down the ally, I glance back to see if I was being chased. I turn my head forward again and run smack into the steel railing around the bed of a large lumber truck. My next awareness was of trying to sit up and of reaching up to feel a spot on my forehead that hurt. The "feeling" process resulted in me putting a finger into a hole and touching my skull bone!

I didn't think about this in terms of the four components of a well-defined problem. However, in retrospect it is clear that the given situation was pain, blood, and a hole in my head allowing me to touch my skull bone. My goal was to do something about this bad situation. It quickly occurred to me that my goal was to seek help. I found that I could stand up, walk, and yell. (Those were resources). I certainly had ownership!

I ran into my house, screaming bloody murder. This produced a response from my parents. They wiped off some of the blood, set me down, and calmed me down. They quickly reframed the problem. From their point of view, I had a bleeding scalp wound that needed to be fixed. They made use of a telephone to call a doctor. (This was back in the days when doctors still made house calls.)

Eventually the doctor drove himself to my home, cleaned me up, sewed me up, and bandaged my wound. Over time the wound healed, the stitches were removed, and a scar slowly decreased its prominent redness.

Notice that I was able to take action to change my problem into a problem that was jointly owned by my parents and me. They, in turn, turned the problem into one that was owned by my parents, and our family doctor, and me. My parents used their knowledge of the telephone system to accomplish this task. The doctor made use of resources such as his car and the street infrastructure leading from his office to my home. He carried along a "black bag" of medical resources that he used in dealing with my medical problem. He also carried along his brain that had years of training and experience is dealing with medical problems.

This is a simple story. However, it illustrated how my parents and the family doctor drew upon their previous knowledge, the infrastructure, and other problem-solving aids that had been developed by others. The story illustrates some roles of technology (telephone, car, road, medical equipment) in solving a problem. All of this happened well over 60 years ago.

In this story, I am sure that my parents had not gone to school to learn to use a telephone. Moreover, I am sure that they had never previously had to deal with a screaming child who had a bleeding scalp injury.

However, the family doctor had many years of formal education along with many years of on the job experience. He had an appropriately high level of expertise that he could draw upon to solve my medical problem.

The story illustrated use of informal and formal education and the previous work and learning of others in order to solve a problem. During the decades since then, technology and infrastructure have changed. Other things have changed, such as doctors making house calls. However, the basic ideas of problems and problem solving have not changed.

Should We Drop Some Content from the School Curriculum?

Consider "what to learn" situation from the point of view of schooling and students in our schools. A lot of educational time is spent helping students to learn about problems that other people know how to solve. What problems should a person learn to personally solve with out help from others? We need to think very carefully about what we want students to learn about problems that have been carefully studied and solved in the past.

As a simple example, consider the general topic of square root. Students may well encounter this topic while in elementary school, perhaps learning that 5 x 5 = 25, so that the square root of

25 is five. Later in elementary school them will learn that -5 x -5 = 25, so that -5 is also a square root of 25. From a mathematics point of view, this is an interesting topic.

There are (at least) two square roots of 25. Are you interested in the question of whether a positive number has more than two square roots? This is an example of a higher math problem. Note that mathematicians call this a problem because the discipline of mathematics has ownership. You, personally, may have little or no interest in this square root topic. In that case, you can merely consider it as a problem situation and dismiss it.

Continuing the square root example, in first or second year high school algebra it used to be common for students to learn a paper and pencil algorithm for calculating square root. The commonly algorithm is somewhat more complex than long division, but has some of the same characteristics. This topic has almost disappeared from the curriculum because inexpensive handheld calculators have a square root key—that is, an algorithm for calculating square root is built into the calculator circuitry.

There is a substantial difference between understanding the meaning and use of square root, versus learning a paper and pencil algorithm for calculating square root by hand. Memorizing a computational algorithm and practicing it repeatedly to gain in speed and accuracy does very little to help one understand the underlying problem that is being solved.

The square root example illustrates that computer technology can lead to a change in the curriculum content. Now, think about all of the things that are part of the school curriculum. Schools, school districts, states, and nations have ownership in a huge collection of well-defined problems that they feel all students should be learning about. They feel so strongly about this that they mandate inclusion of these topics in the curriculum, assess students on their learning of these topics, and perhaps even "punish" teachers, schools, and school districts whose students perform poorly on these tests.

In the more general school curriculum, the issue illustrated by square root plays itself out on a daily basis. Consider it from a student point of view. What should I memorize just because it might be on a test? What should I learn that I feel will be of lasting, long-term value to me? What should I learn how to look up and read about (with understanding) versus memorize (with or without understanding)? How much of what I am being expected to learn is so out of date and irrelevant that it will make little difference in my life?

These are very difficult questions. It is unreasonable to expect that individual students should have to or be encouraged to make individual, personal decisions in each case. Teachers, curriculum developers, test makers, and others should be continually in the process of rethinking curriculum content, instructional processes, and assessment. That is because appropriate answers change as progress occurs in accumulating and storing knowledge in machines such as calculators, computers, and automated factory equipment.

Summary

All of us are faced by the possibility of having both problem overload and information overload. Indeed, in our current "rush, rush" society, it seems inevitable that many people will frequently have such problems.

One way to help deal with problem and information overload is to become award of these problems. Learn to screen problem situations to reduce the number that you accept as problems. Learn to screen information sources and information so that you can avoid being overloaded.

Don't take it upon your self to need to know so much information. Develop better skills in using a computer and other information retrieval tools.

A substitute for knowing information consists of:

1. Knowing that the information exists and some of the potential uses of the information. In particular, it is important to know potential uses in solving problems and accomplishing tasks where you currently have ownership or are likely to have ownership in the future.

2. Having the research and understanding knowledge and skills so that when you need particular information, you can find, understand, and use it.

Immediate Actions for Chapter 3

Talk to your students and colleagues to see what they know about the general ideas of information and problem overload. Strive to gain an increased level of understanding of how they view or experience information and problem overload. Ask about how they deal with these two types of problems.

Activities for Chapter 3

1. In your own words, explain what information overload means to you. Give examples in which you have experienced information overload, and what you have done about the situations.

2. In your own words, explain what problem overload means to you. Give examples in which you have experienced problem overload, and what you have done about the situations.

3. Think about your personal formal education. From this, extract examples of when this educational process seemed to produce problem overload, and information overload for you. Discuss how the teaching and learning situations might possibly have been changed to produce less stress on you, but still produce equally good or better learning of long-term value to you.

4. This chapter gives the example of learning to calculate square root by hand versus learning to use a calculator that has a key to press to calculate square root. Based on your current knowledge of calculators, computers, and various other tools, give additional example of school time being spent to help a student learn to do what machine can do better.

5. Analyze several of the examples you provided in (4) above. In each case, provide arguments for continuing to have the current content in the school curriculum and arguments for substantially decreasing or removing the content from the curriculum.

6. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Chapter 3 of this book 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 Chapter 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.

Chapter 4

Problem and Task Team

> Of all the things I've done, the most vital is coordinating those who work with me and aiming their efforts at a certain goal. (Walt Disney)

> If I have seen further it is by standing on the shoulders of giants. (Isaac Newton, English mathematician & physicist 1642–1727. Letter to Robert Hooke, February 5, 1675.)

When you are attempting to solve a problem, you draw upon your personal knowledge, skills, experience, and other resources. There are many problem situations where a team of people work together, each contributing their knowledge, skills, and experience. One of the reasons that ICT is such a powerful aid to problem solving is that it facilitates communication and sharing among a group of people working on a challenging problem. Another reason is that a computer can be thought of as a member of a team working on a problem. A computer brings certain types of capabilities that people do not have.

Introduction

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 smarter. 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. This is certainly a **Big Idea** that is important in both informal and formal education.

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 book I 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 4.1 illustrates the P/T Team. The concepts that make up the diagram are explained in subsequent paragraphs.
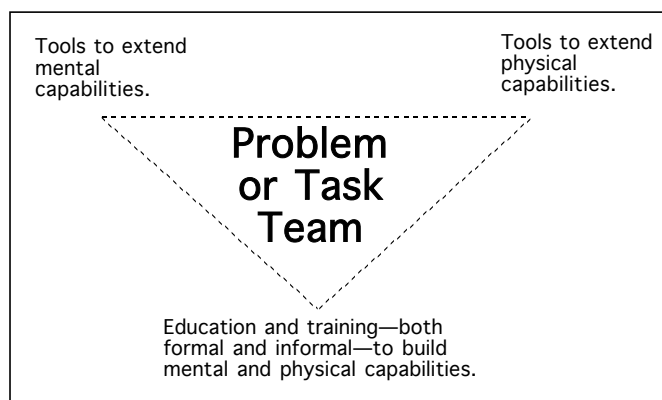
Figure 4.1. The P/T Team—People aided by physical and mental tools.

Figure 4.1 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 5,200 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 extent capabilities of a person's mind. In some sense, they can be thought of as an auxiliary brain.

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. 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 a relatively short time. The pace of change of ICT seems breathtaking to most people (Moursund, 2005).

On the other hand, our formal educational system has a relatively slow pace of change. This has led to the interesting and perhaps troubling 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. Many children routinely use computer games and Web-based social networking systems that are far outside the experience of many of 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

Project-Based Learning (PBL) is mentioned a number of times in this book. In PBL, an individual or a team works on a project over an extended length time. This work leads to a product, performance, and/or presentation. PBL is one way to create a problem-solving environment in which a P/T Team works to accomplish a task that is too large for an individual person to accomplish in the time available.

Teams-based PBL is a challenge both to the teacher and to the team. If a team of people work together to product a product, how does one assess the individual effort of each student? To what extent should the teacher attempt to assess learning to be a contributing and facilitating member of a team? How does a teacher deal with a student who would rather be a "loaner?" How can one give a test to a class in which different teams of students work on different topics?

Often a project to be undertaken is not very well defined. Thus, one of the tasks of a team is to decide on the nature and scope of the project they will attempt to accomplish. This requires learning about the capabilities and limitations of individual team members and the resources that are available to the team.

Many students find it is hard to learn to be a team "player." Indeed, it is often argued that learning to be a member of a sports team is a very valuable experience—not only because one learns a sport, but because one learns to be a productive member of a team. Transfer of learning from one environment (a sport) into other environments (such as teamwork on a job) is discussed in the next chapter.

ICT-Assisted PBL can be used to create environments in which teams of students in diverse locations 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).

Another argument for increased use of PBL in schools is that projects are often interdisciplinary. Thus, students must draw upon the knowledge and skills they have learned in many different curriculum areas. Working together, learning from each other, students must review and probably relearn previous knowledge and skills.

Problem-Based Learning

A project in Project-Based Learning need not be rooted in a specific problem that currently interests a lot of people. Thus, a project might be an exploration of food or medicine available to soldiers from the South and the North during the US Civil War.

Problem-Based Learning (also abbreviated as PBL) has students or teams of students working on specific problems. Quite often, the problems are quite specific to the course being taught or the discipline being studied. The goal is to develop a good solution to a specific problem. Problem-based learning has a number of the characteristics of project-based learning, but the goal is to produce a workable solution to a specific problem.

For example, a team of architectural students might be assigned the problem of developing low cost and easily portable housing that can be made available to victims of a natural disaster. A class of students might be divided into teams, with each team assigned the same problem.

The problem might be quite difficult. The reference (Venkataramanan, 2007) provides an excellent example and an accompanying video:

> Inspired to reinvigorate his teaching after a yearlong sabbatical, electrical and computer engineering professor Giri Venkataramanan decided to try an experiment. During spring semester 2007, he challenged the freshman in his introductory engineering class to build a functioning wind turbine from scratch. The stated goal was to generate power. But by the course's end, the students had also gained critical hands-on skills, team experience—and a powerful understanding of what it means to be an engineer.

Problem-based learning is extensively used in the professional schools in higher education. This approach to teaching and learning allows students to get hands on experience in solving "real world" problems.

Precollege students can address many real world problems. For example, suppose that a rural family of four has $300 to buy food and other supplies that will help to sustain them through a snow storm that will blanket their region, cutting of all power and transportation for four days. What should they purchase and what other preparation should they make?

Problem Solving as a Process

Suppose that you are faced by the problem (the task, the assignment, the project) of writing a four-page essay on a specified topic. The chances are that producing a high quality solution will take considerable time and effort. It will also take careful thinking and planning.

Over thousands of year, people have studied different ways to approach this problem. In the mid 1970s, a group of people got together to share their collective knowledge about how to teach and learn how to write. This led to the creation of the Bay Area Writing Project.

> BAWP is a collaborative program of the University of California at Berkeley and Bay Area schools, dedicated to improving writing and the teaching of writing at all grade levels and in all disciplines. The Project includes an expanding network of exemplary classroom teachers, kindergarten through university, who, throughout the summer and school year, conduct professional development programs for teachers and administrators.

…

The Bay Area Writing Project was established in 1974 in the Graduate School of Education on the Berkeley campus. Each year close to 4,000 teachers participate in BAWP summer and school-year programs. For many, BAWP remains a resource throughout their teaching careers. BAWP's commitment to the professional growth of teachers is key to the high-level of interest by classroom teachers and to their enduring support. (BAWP, n.d.)

In brief summary, the BAWP work has led to a clear understanding that writing is a process (now called process writing), and that students can learn to do process writing. The six steps involved in process writing are:

1. Brainstorming ideas.

2. Organizing the brainstormed ideas. Often this involves getting more information about the ideas, such as by doing library research and talking to others.

3. Developing a draft.

4. Obtaining feedback from oneself and from others.

5. Revising, which may involve going back to earlier steps.

6. Publishing. Polishing the final product and then making this available to others.

A similar set of steps is used in composing music, doing drawing or painting, designing a building, and in many other problem-solving situations. In many problem-solving situations, it is helpful to think of problem solving as a process that leads to a product, performance, or presentation. Notice the similarity of this statement with the previous discussion of Project-Based Learning.

Immediate Actions for Chapter 4

Talk to your fellow teachers and 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.

Each academic discipline has developed ways of teaching and learning the discipline. Often, a teaching, learning, and "doing" methodology is one of the Big Ideas, or Unifying Ideas in a discipline. Think about Scientific Method in the sciences. Do a mental compare and contrast with process wiring in the discipline of writing.

Activities for Chapter 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 Chapter 4 of this book 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 Chapter 4. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 5

Transfer of Learning

"An individual understands a concept, skill, theory, or domain of knowledge to the extent that he or she can apply it appropriately in a new situation." (Howard Gardner)

"I am not a teacher. . . I am an awakener." (Robert Frost)

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 a key aspect of getting better at problem solving. The problems one will encounter in the future will most often be somewhat different from and in somewhat of a different environment than the problems that one has learned to solve while in school.

Quoting from Bransford et al. (1999):

Processes of learning and the transfer of learning are central to understanding how people develop important competencies. Learning is important because no one is born with the ability to function competently as an adult in society. It is especially important to understand the kinds of learning experiences that lead to transfer, defined as the ability to extend what has been learned in one context to new contexts. **Educators hope that students will transfer learning from one problem to another within a course, from one year in school to another, between school and home, and from school to workplace.** Assumptions about transfer accompany the belief that it is better to broadly "educate" people than simply "train" them to perform particular tasks. [Bold added for emphasis.]

We All Do Transfer of Our Learning

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. The next hour, 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, employers, and employees.

One of the difficulties or challenges in transfer of learning is that people forget—that is, their ability to retrieve and use learned knowledge and skills decreases over times of not using the knowledge and skills. Thus, it is desirable for students to learn in a manner that facilitates long-term retention as well as rapid and effective relearning.

Transfer of Learning Theories

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 be used by teachers and writers to 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.

In near transfer, 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. All other transfer situations were called far transfer.

However, even automaticity degrades over time if it is not used. Let me share a personal story with you. In the early days of my professional career, I wore a necktie. I learned how to tie a necktie, and I used this knowledge practically every day. Later in my career, I gave up wearing a necktie, only putting one on for very special occasions. I remember being in a hotel room, just before I was to go to an important meeting. I wrapped the necktie around my neck and "told" my automatic neck tying procedural memory to do the task. My hands went through a process, but the result was not successful. I did it again, still with no success. Panic! Fortunately, slow and careful thought eventually reconstructed the tying process, and I made it to the meeting on time.

It is appropriate to learn or train for near transfer in many situations. For example, take the situation of shooting free throws in a basketball game. Shooting free throws can be practiced repeatedly. A high level of automaticity can be developed. How to shoot a free throw can be stored in the procedural, muscle memory part of one's brain. Even then, basketball players routinely practice shooting free throws in order to maintain and perhaps improve their skill.

The necktie and basketball stories indicate that it may take a lot of practice (with appropriate training or coaching and feedback) to develop automaticity. Even, then, it may take continuing practice to maintain one's skills. Thus, near transfer tends to be a relatively time consuming way of learning to solve problems.

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.

Now, with the terms near transfer and far transfer in mind, think about learning to read. One aspect of reading is decoding. I look at a word, puzzle over it, and sound it out. Perhaps I draw upon context, such as the book, pictures in the book, earlier parts of the story, and so on. Eventually I decode the word, silently "hearing" the word in my mind. With enough practice, this decoding becomes fast and automatic. Eventually I can look at a word and quickly decode it, not having to draw on contextual aids. I have learned the word so well that near transfer occurs.

However, automaticity in decoding lots of words does not, by itself, make a person into a good reader. One must mentally create meaning and understanding from the words, sentences, and paragraphs. With a lot of instruction and practice, a majority of students learn to read well enough by the end of the third grade so that they can have reasonable success in using their reading skills as an aid to learning in areas whey they already have a significant amount of knowledge.

The transfer from this situation to being able to learn a new area by reading is a large step— we can call it far transfer. The reading challenge is building an understanding of the new area, learning to decode and understand the new words, and learning to tie the new knowledge in with one's current knowledge. For most students, it takes many years of instruction, practice, and learning a variety of disciplines to become skilled at this far transfer task.

Getting better at solving novel, challenging problems requires getting better at both near transfer and far transfer in tasks and skills related to problem solving. Since people vary considerably from each other, the near transfer and far transfer aspects of problem solving and how to get better at problem solving vary considerably among students.

High-road and Low-Road Transfer of Learning

The theory of near and far transfer has somewhat limited value in a theory of teaching and learning. 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 and/or skill to a high level of automaticity. It usually requires a great deal of practice in varying settings. Shoe tying, keyboarding, driving 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 academic 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 simpler 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, 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 pieces that are more manageable. That is, you want them to make use of 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.

Hugging and Bridging

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 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 any of your strategies 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.

Final Remarks

Transfer of learning is certainly one of the most important ideas in education. Education can be improved by helping students better understand the concept of transfer of learning and how to learn for transfer.

The types of problems that students encounter in courses tend to be ones that have be previously encountered (and solved) by many thousands of students. From a student's point of view, the goal is to solve the problem. However, from a teacher point of view the goal is to learn about solving a general type of problem in a manner that will transfer to other problems. All teaching should be done in a manner that increases transfer of learning.

Immediate Actions for Chapter 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 Chapter 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. Discuss what you do to maintain a high level of automaticity.

    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 the low-road transfer given above. 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 a person can achieve the conditions for low-road transfer. Higher-order skills are ones in which a person strives to meet the conditions for high-road transfer. From your point of view, discuss the merits of this way of thinking about lower-order and higher-order skills. 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 Chapter 5 of this book 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 Chapter 5. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 6

Expertise and Domain Specificity

"An expert is a person who has made all the mistakes that can be made in a very narrow field." (Niels Bohr)

"In short, learning is the process by which novices become experts. " (John T. Bruer. Schools for Thought, 1999, page 13.)

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's level of expertise can increase through learning and practice. Thus, all informal and formal education can be examined through a lens of how it contributes to a person gaining in expertise.

Expertise and being an Expertise

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.
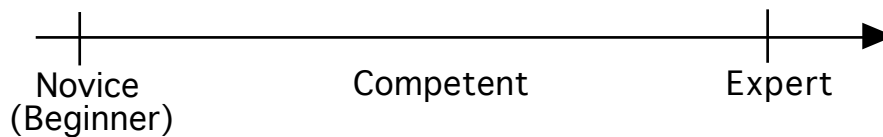
Figure 6.1. An "expertise" scale.

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 (Gardner, n.d.). 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 quite hard for 10 to 15 years within that specific area, they are apt to achieve national or even world-class expertise in that area. Of course, good teaching (coaching, training, educating) 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.

Consider the general practitioner versus the specialists in medicine, or professors who write and do research in two relatively different academic disciplines.

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. However, 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 and 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 an educational 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. That is, we expect students to become generalists and we encourage students to also specialize in one or more narrower areas.

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 success of Tiger Woods (golf) and Serena and Vanessa Williams (tennis) illustrate this point. Music, chess playing, and math, are also rich sources of examples.

To a large extent, our formal PreK-12 educational system is not well set up to help a student become a high level expert at a relatively young age. Even with talented and gifted students, it is unusual to advance a student more than one grade level. This is in spite of the fact that profoundly gifted students learn more than twice and fast and a lot better than average students (Moursund, 2006). For example, if such a student is interested in math and has appropriate instruction, the student can easily learn two years of the traditional school math curriculum per year.

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 computers provide math productivity tools that 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 the 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.

Music provides an interesting example. Consider a young student who has a potential to gain a high level of expertise in musical performance and a different student who has a high level of potential to become a composer. Via the route of private lessons, the performance-oriented student can gain a high level of expertise in playing an instrument such as violin or piano at a relatively young age.

The potential composer faces the challenge of needing to learn to perform and needing to learn to compose. Historically, the performance knowledge and skill is needed in order to have an outlet for what the student composes. Now, however, we have computer systems that can perform music. A young composer can compose and have a computer perform the composition.

Another interesting and somewhat similar example comes from computer animation. Computer programming languages have been developed that are powerful aids to developing characters and other objects that can be animated, and then (under directions specified by the programmer) become animated. Relatively young students can learn to make use of such animation-oriented programming languages. See, for example the programming language Alice available free at http://www.alice.org/.

Immediate Actions for Chapter 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 Chapter 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; and so on).

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 through the schools.

   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 Chapter 6 of this book from the point of view of applicability to students at that grade level 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 Chapter 6. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 7

Some Problem-Solving Strategies

"If I had eight hours to chop down a tree, I'd spend six sharpening my axe." (Abraham Lincoln)

"Don't saw with a dull saw." (Old adage)

"Mathematics consists of content and know-how. What is know-how in mathematics? The ability to solve problems." (George Polya)

The first two quotations given above provide strategies for approaching certain types of problems. Both are profound, as they are applicable in many setting other than chopping down a tree of sawing a board. Practice your insights into high-road transfer of learning by thinking of some examples where these problem-solving strategies are applicable.

A strategy can be thought of as a plan, a heuristic, a rule of thumb, or 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.

Introduction

We all make use of strategies in our everyday lives. Some are quite specific to narrow areas, and others are quite general, possibly applicable to a wide range of different situations. Research suggests:

1. There are relatively few strategies that are powerful and applicable across all domains. Because each subject matter 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 subject area.

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 in a domain, it might make a significant difference in the person's overall problem-solving performance in that domain.

3. The typical person has relatively few domain-independent (that is, quite general) effective strategies. This suggests the value of helping students to learn strategies that cut across (transfer, via high-road transfer) many different domains.

Information Retrieval as a General-Purpose Strategy

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 almost 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. However, all students can gain considerable facility for retrieving information from the Web and other sources. That is, an important goal in education is to help students gain an increased level of expertise in information retrieval. An important goal in any domain-specific course of study is to gain increased expertise in retrieving and using information within that domain.

Retrieving information from a library or other resource materials can be thought of as an *ask an expert* problem-solving strategy. It is also called the *don't reinvent the wheel* strategy. There are three clear challenges in using this strategy:

1. Knowing what to look for (what to ask). What problem are you trying to solve?

2. Knowing what vocabulary and search terms to use in a search. In essence, you are attempting to communicate your problem to computer.

3. Being able to understand and make use of the materials that the computer search engine finds for you.

An alternative ask an expert approach is to actually ask a human expert. You do this, for example, when you go to a medical doctor's office and seek help with a medical problem. A student does this by asking a teacher a question about the subject matter being taught. A child does this when asking a parent for help on homework.

Learning how to effectively ask questions of human experts and of computers is a key aspect of a good education. It is not easy to learn to ask good questions. One aspect of asking a good question is thinking before asking. Think about what one already knows about possible answers and what one wants to learn from the expert.

Many computer Discussion Groups (often referred to as ListServs) are commonly used in an ask an expert mode. A person on the list who has a problem or a question asks the list for help. Often, a person on the list has some knowledge that can help.

There are also a number of "Ask an Expert" Websites. A 10/19/07 Google Search of the quoted term "ask an expert" produced about 1.75 million hits.

Other General-Purpose Strategies

This section gives examples of some general-purpose strategies that cut across many domains. While a student may first encounter one of these strategies in a specific domain, each strategy is amenable to teaching for higher-road transfer. A teacher who is teaching one of these strategies within a particular domain can teach it for high-road transfer and help 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. It was discussed in Chapter 5. 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. The task of wiring a paragraph can be broken down into writing an introductory sentence, writing the "body" of the paragraph, and writing a concluding sentence.

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.

It takes quite a lot of time and effort to learn to solve a building-block problem to a relatively high level of automaticity, speed, and accuracy. (We discussed this idea when we were exploring low-road transfer of learning.) 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.

Think about statistical procedures. You probably have a sense or mental picture of what it means for two variables to be linearly related. Your mental picture might be of a child's height and age being somewhat linearly related, with the height increasing as the child grows older. For most people, that sense or mental picture of correlation is not helped by seeing a mathematical formula for correlation or doing a sequence of by-hand calculations of correlation.

It is common for a scientific calculator to have a built-in correlation procedure. Also, of course, statistical programs to computer correlation are readily available on computers. Thus, our math educational system has had to think about what it wants students to learn about correlation. Is it an important goal to have students memorize a formula for correlation and practice this computational procedure a number of times using pencil and paper? An alternative is to spend the time gaining an understanding of the meaning of correlation, when it is appropriate to make use of correlation in analyzing data, and how to use a calculator or computer to do the calculation.

This second approach treats correlation as a building-block problem. Many statistics courses treat a variety of statistical procedures as building block problems that can easily be solved in the overall task of making meaning from (analyzing) data that has been collected. This approach has led to many departments creating their own statistics courses, as they feel that the traditional math department approach to teaching statistics does not appropriately meet the needs of their students.

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. An oral input computer system or a computer system that accepts phonetic spelling provide another approach.

For another example, consider the problem of cropping a photograph. This can be done with a pair of scissors. However, if the photograph is in a computer, the computer can be used both for cropping and for a range of other manipulations.

In brief summary, there are steadily growing collections of building-block computer programs in various disciplines. Our precollege and higher education systems are struggling with how to appropriately integrate this powerful aid to problem solving into the everyday curriculum.

Scientific Method Strategy

The various fields of science share a common strategy called scientific method. Quoting from Barrow, 1991):

> The scientific method has four steps:
>
> 1. Observation and description of a phenomenon or group of phenomena.
>
> 2. Formulation of an hypothesis to explain the phenomena. In physics, the hypothesis often takes the form of a causal mechanism or a mathematical relation.
>
> 3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
>
> 4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.

The scientific method 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.

The research of a scientist typically starts with posing a problem or question. The researcher then thinks about what he or she already knows about possible answers. That is, their researcher asks an expert—himself or herself. Next, the researcher may discuss the problem with colleagues, either face to face or through use of telephone, email, and so on. Probably at roughly the same time, the researcher begins to explore the literature, trying to find out what others know n the topic.

Using the information garnered by these various ask an expert approaches, the researcher may then reformulate the problem or question and repeat the processes described above. At the same time, the researcher will begin to think about how to design and carry out an experiment— what empirical research is needed—that will help solve the problem or answer the question.

The term *scientific method* suggests that the ideas given above are only applicable in science. That is incorrect. It is a methodology of careful thinking, research based on what is already known, and empirical research that is being talked about. The goal is to produce answers that the researcher and others can use (build upon) with confidence. In some sense, each well-done piece of research in any discipline can be thought of as creating a building block that others can use in their problem solving.

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 you 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. 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.

Strategies Applicable to the Problem of Learning

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, through formal education, each person gains an increasing level of expertise in attacking various learning 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. Each person is also faced by the situation that a strategy that is quite useful in one type of learning task might not be very good in another type of learning task.

From a teacher point of view, we thus want to help each student gain personally effective approaches to attacking the problem of learning in the various domains that are taught in school. In addition, we want each student to acquire learning skills that will prove effective as the student encounters learning tasks in the future—even learning tasks in domains the student has not previously encountered.

To me, this situation suggests the importance of actively engaging students in analyzing their learning strategies. Each learning task provides an opportunity for reflection on the personal effectiveness of the strategies used in the learning task.

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.

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 general 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."

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.

Still More Strategies

The following free book on games in education includes a major focus on learning problem-solving strategies through use of games, and then doing high-road transfer to make these strategies useful in other settings. An Appendix contains a large number of strategies.

Moursund, D.G. (June 2006). Introduction to Using Games in Education: A Guide for Teachers and Parents. Access at http://uoregon.edu/~moursund/Books/Games/games.html.

Immediate Actions for Chapter 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 Chapter 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.

4. 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. Practice doing transfer of learning of this strategy from math into the other domains you use in your discussion.

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 Chapter 7 of this book 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 Chapter 7. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 8

Representations of a Problem

"Not everything that can be counted counts, and not everything that counts can be counted." (Albert Einstein)

Could you restate the problem? Could you restate it still differently? (George Polya [1957], *How to Solve It.)*

There are many different ways to represent a particular problem. A problem might be represented in words, in an audiovisual format, in your head, and so on. A problem involving numbers might be represented using Roman Numerals or Hindu-Arabic Numerals. Each way of representing a problem may have some advantages and/or some disadvantages to a person trying to solve the problem.

Notice the second of the two quotations given above. A standard strategy to use when faced by a challenging problem is to consider different ways to represent the problem.

Introduction

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 (Goleman1995). 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, a play to be written and performed, and a math or science problem situation. Clearly there are many steps from an initial conception—perhaps a mental model—of a problem situation to 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. However, a problem 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). This might include words, diagrams, drawings, and so on. 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, perhaps using handwriting or a word processor. Characters are first hand drawn, and repeatedly revised and redrawn. 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. However, 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. The two rooms are connected, with an 8 foot opening between the two rooms. How much will the carpeting cost for the two rooms?
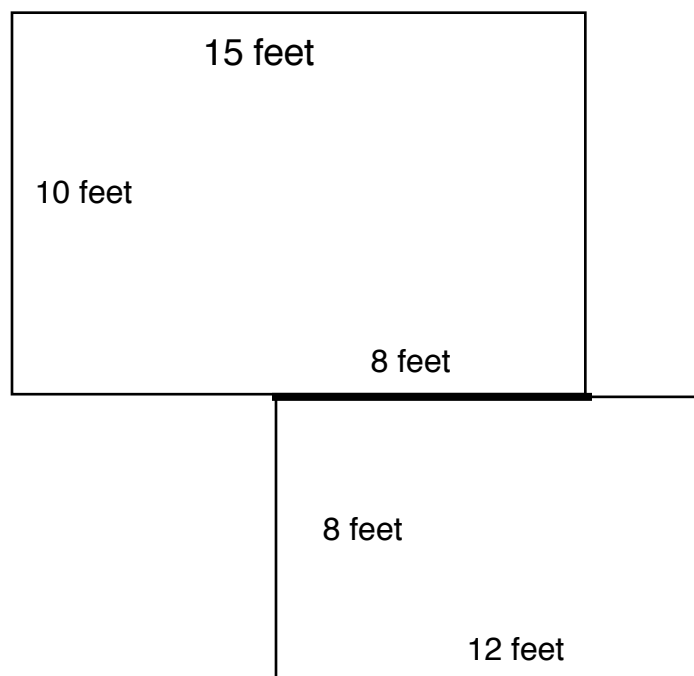
Figure 8.1. Two rooms to be carpeted.

Conceptually, the problem is not too difficult. You can form a mental model or do a drawing of the two rooms. As you do a drawing, you might realize that there are a number of different layouts that meet the problem specifications. Figure 8.1 provides one example. You can think about whether each of the different possible layouts will take the same amount of carpeting.

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 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 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 book 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 Various 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, basketball, and other team sports.
5. Architectural drawings, such as blueprints.
6. A spreadsheet with numbers and formulas used in business.
7. Maps.

Part of learning to solve problems in a discipline is learning to read, write, speak, and listen in the vocabulary and notation of the discipline. A high level of communication fluency—and learning to think in these communications systems—is an important aspect of having a high level of expertise in a discipline.

Immediate Actions for Chapter 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 Chapter 8

1. Discuss advantages and disadvantages of Roman Numerals versus Hindu-Arabic Numerals for young children learning to write numbers and do simple addition and subtraction.

2. Before the development of reading and writing, "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 as 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 hears 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 Chapter 8 of this book 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 Chapter 8. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 9

Representing & Solving Problems Using Computers

"Civilization advances by extending the number of important operations which we can perform without thinking of them." (Alfred North Whitehead)

"A clever person turns great troubles into little ones and little ones into none at all." (Chinese proverb)

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.

However, many problems involve such a large amount of detail that they overwhelm mental modeling. Mental modeling provides a general overview, but the brain needs help in dealing with the details.

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.

A computer model combines some of the "big picture" and easy to change characteristics of mental modeling with the types of details and symbolic manipulation possible in other types of models. Developing a computer model and then using a computer in an interactive manner to ask and seek answers to "What if" questions, is a very powerful aid to problem solving.

Computational Thinking

The term computational thinking is used to describe people and computers working together to solve problems and accomplish tasks. As Jeannette Wing (2006), a highly respected computer scientist, says:

Computational thinking builds on the power and limits of computing processes, whether they are executed by a human or by a machine. Computational methods and models give us the courage to solve problems and design systems that no one of us would be capable of tackling alone. Computational thinking confronts the riddle of machine intelligence: What can humans do better than computers, and what can computers do better than humans? Most fundamentally it addresses the question: What is computable? Today, we know only parts of the answer to such questions.

Computational thinking is a fundamental skill for everybody, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability.

In terms of ideas presented previously in this book, computational thinking is the type of thinking used when using both one's brain and the brain augmentation provided by computer systems. It involves representing and thinking about a problem in terms of the capabilities of both brain and computer. It typically involves developing both mental and computer models of the problem.

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. Once a spreadsheet model of a problem has been developed, the computational capabilities of a computer can be brought to bear in solving the problem.

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. Indeed, this is such an important and powerful aid to solving geographical problems that special software— geographic information system (GIS) has been developed to aid in developing such computer models.

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. Chapter 4 contains a discussion 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.

Spreadsheet Models

Before the development of microcomputers, bookkeepers and accountants made extensive use of bookkeeping ledgers that consisted of sheets divided into rows and columns. Information was entered by hand. Calculations were done by hand or by use of a calculator.

As microcomputers began to become available, it was soon discovered that a relatively simple computer program could store a table of data consisting of row headings, column heading, and numbers. The computer program could perform calculations such as adding the numbers in a row, multiplying a pair of numbers from two successive columns and placing the products in a third column, and so on.

These relatively simple uses of a computer wee so powerful from the point of view of bookkeepers and accountants that hundreds of thousands of microcomputers and the spreadsheet software were sold.

Quoting from the Wikipedia:

> The spreadsheet concept became widely known in the late 1970s and early 1980s because of Dan Bricklin's implementation of VisiCalc.

> Bricklin has spoken of watching his university professor create a table of calculation results on a blackboard. When the professor found an error, he had to tediously erase and rewrite a number of sequential entries in the table, triggering Bricklin to think that he could replicate the process on a computer, using the blackboard as the model to view results of underlying formulas. His idea became VisiCalc, the first application that turned the personal computer from a hobby for computer enthusiasts into a business tool.

> VisiCalc went on to become the first "killer application", an application that was so compelling, people would buy a particular computer just to own it. In this case, the computer was the Apple II, and VisiCalc was no small part in that machine's success.

A modern spreadsheet program includes a large number of built-in mathematical formulas and easy provisions for creating graphs of data. Spreadsheets are still widely used for business modeling and simulation. However, they are now also widely used for developing computer models in the sciences and in other disciplines.

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, military operations, movie making, science, and sports. 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.

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. Moursund (10/30/06) is free 80-page book on AI written specifically for preservice and inservice teachers.

Here are two definitions of AI. The first is from Marvin Minsky, a pioneer in the field. The second is a 1990 definition from Eric Horvitz.

> In the early 1960s Marvin Minsky indicated that "artificial intelligence is the science of making machines do things that would require intelligence if done by men." Feigenbaum and Feldman (1963) contains substantial material written by Minsky, including "Steps Toward Artificial Intelligence" (pp 406-450) and "A Selected Descriptor: Indexed Bibliography to the Literature on Artificial Intelligence" (pp 453-475)

> What is artificial intelligence? It is often difficult to construct a definition of a discipline that is satisfying to all of its practitioners. AI research encompasses a spectrum of related topics. Broadly, AI is the *computer-based* exploration of methods for solving challenging tasks that have traditionally depended on people for solution. Such tasks include complex logical inference, diagnosis, visual recognition, comprehension of natural language, game playing, explanation, and planning (Horvitz, 1990).

One approach to AI is to develop models of the human brain and mind, or models of how humans solve particular categories of problems. A second approach is more pragmatic—just working to develop computer programs that solve problems that humans consider to be quite challenging.

Both approaches have made significant progress during the past 50 years. The idea of using a computer as an auxiliary brain was mentioned in Chapter 4. As computer capabilities continue to be increased, it become more possible to represent (model) problems in a computer and to have a computer system work to solve the problems. That is, work in AI can be thought of as work to develop models or representations of complex problems in a form that computer capabilities can be used to solve or help solve the problems.

Consider the following quote from Economist.com (6/9/06):

> "In a partnership announced on June 6th [2006], the two organisations said they would be working together to build a simulation of a structure known as a neocortical column on a type of IBM supercomputer that is currently used to study the molecular functioning of genes. If that works, they plan to use future, more powerful computers to link such simulated columns together into something that mimics a brain."

> The goal is to develop a computer simulation of 10,000 neurons in the grey matter of a human brain. The IBM supercomputer to be used has enough processors to devote several processors to each neuron. It is currently the world's fastest supercomputer. The Ecole Polytechnique Fédérale de Lausanne is a world leader in brain research.

What this says is that it is now feasible to develop a computer model of a small piece of human brain. If this turns out to be a productive line of research and development, than the faster

computers we expect to have available in the future will be able to model a much larger piece of a human brain.

Even a simple handheld calculator can be thought of 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 spot 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.)

Highly Interactive intelligent CAL

Artificial Intelligence is being routinely applied in many different areas of problem solving. Computer-assisted learning provides a good example. A very common type of CAL is little more than an automated flash card system. The learner is provided with a sequence of questions where there is only one right answer. The learner keys in an answer and the computer system determines if it the one correct answer. The computer provides some sort of feedback on the correctness and keeps track of the number of right answers.

It is relatively easy to add a little "intelligence" to such a system. Program the computer so that it remembers the questions that are incorrectly answered, and intersperses them into the stream of questions being asked. The computer system is programmed to generate a random integer between 0 and 99, and then another random integer between 0 and 99. The computer can easily calculate the sum. The problem is presented, the student enters an answer, and the computer determines if it is the correct answer.

However, the computer can also measure the time the leaner takes to enter in a response. The instructional goal might be for a learner to gain both increased speed and increased accuracy in tow-digit additions.

If a wrong answer is input, the computer can be programmed so that it analyzes the question. Perhaps the calculation involves carrying from the one's "column" to the ten's column, and from the ten's column to the hundred's column. The program could determine if an incorrect answer appears to come from an error is the second of these two carrying steps. The program could then provide instruction on this particular type of computation. More of this type of computation might then be interspersed in the sequence of problems being presented to the student.

This "just in time" or "context-specific" one-on-one instruction is quite effective. Quite a bit of research effort has gone into developing CAL systems that have these features. Progress in AI has made possible increasingly "intelligent-like" CAL systems.

Ideally, a good CAL system would have characteristics similar to a highly qualified human tutor. Highly interactive intelligent computer-assisted learning (HIICAL) is now good enough in some instructional areas that it is leading to a significant improvement in education. Carnegie Mellon University, one of the world's leaders in AI research, is a leader in this area.

A key component of HIICAL is the development of computer models of what a student already knows, what educators want the student to learn, and the progress that the student is making. Notice that this involves: modeling a student's knowledge, understanding, and performance; modeling desired knowledge, understanding, and performance; and developing a HIICAL system that effectively moves the student toward the desired knowledge, understand, and performance levels.

Another type of computer-assisted learning is based on use of computer simulations. Suppose, for example, that you want educate and train an airplane pilot. There is a huge amount to be learned. HIICAL is helpful in this endeavor.

However, a substantial amount of hands on training is necessary, and flight simulators have been developed to aid in this training. Quoting from the Wikipedia:

> A flight simulator is a system that tries to replicate, or simulate, the experience of flying an aircraft as closely and realistically as possible. The different types of flight simulator range from video games up to full-size cockpit replicas mounted on hydraulic (or electromechanical) actuators, controlled by state of the art computer technology.
>
> Flight simulators are extensively used by the aviation industry for design and development and for the training of pilots and other flight deck crew in both civil and military aircraft.
>
> Engineering flight simulators are also used by aerospace manufacturers for such tasks as:
>
> • development and testing of flight hardware. Simulation (emulation) and simulation techniques can be used, the latter being where real hardware is fed artificially-generated or real signals (simulated) in order to make it work. Such signals can be electrical, RF, sonar and so forth, depending on the equipment to be tested.
>
> • development and testing of flight software. It is much safer to develop critical flight software on simulators or using simulation techniques, than development using aircraft in flight.
>
> • development and testing of aircraft systems. For electrical, hydraulic and flight control systems, full-size engineering rigs sometimes called 'Iron Birds' are used during the development of the aircraft and its systems.

Virtual Reality

The Web can be thought of as a virtual library. This virtual library is very large and is continuing its rapid growth. There are a number of large-scale projects going on throughout the world to digitize the holdings of physical libraries and make them available on the Web. More than a dozen of these are discussed briefly at http://iae-pedia.org/Open_Source_Libraries.

Computer simulations of real or imagined reality are commonly called virtual reality. This is a very large and growing field of research and development. Quoting form the Wikipedia:

> Virtual reality (VR) is a technology which allows a user to interact with a computer-simulated environment, be it a real or imagined one. Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. Some advanced, haptic systems now include tactile information, generally known as force feedback, in medical and gaming applications. Users can interact with a virtual environment or a virtual artifact (VA) either through the use of standard input devices such as a keyboard and

mouse, or through multimodal devices such as a wired glove, the Polhemus boom arm, and omnidirectional treadmill. The simulated environment can be similar to the real world, for example, simulations for pilot or combat training, or it can differ significantly from reality, as in VR games. In practice, it is currently very difficult to create a high-fidelity virtual reality experience, due largely to technical limitations on processing power, image resolution and communication bandwidth. However, those limitations are expected to eventually be overcome as processor, imaging and data communication technologies become more powerful and cost-effective over time.

Computer games provide good examples of use of virtual reality. Moursund (June 2006) is a free book that explores teaching and learning problem solving in a game environment. There are many games available in both "hard copy" and virtual formats. For example, one can play a computerized version of many different solitaire games, and one can play the same games using one or two physical decks of cards.

The online gaming world is huge. Some of the games have millions of people who sign up and pay a monthly fee. In such environments, one often plays as a member of a team of humans. This creates a type of social networking system where one develops a type of friendship with people and their computerized characters.

Immediate Actions for Chapter 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? In what sense can a computer program model human intelligence? Will computers eventually be smarter or more intelligent than people? What do they feel about such a possibility?

Activities for Chapter 9

1. What are some similarities and differences between a physical model (for example, a wooden or medal 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. Probably 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 Chapter 9 of this book 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 Chapter 9. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 10

Computer Programming

"In their capacity as a tool, computers will be but a ripple on the surface of our culture. In their capacity as intellectual challenge, they are without precedent in the cultural history of mankind. " (Edsgar Dijkstra)

"Humans are allergic to change. They love to say, 'We've always done it this way.' I try to fight that. That's why I have a clock on my wall that runs counter-clockwise." (Grace Hopper)

A significant part of the process of gaining expertise in a discipline is learning to think in and communicate in the language and ideas of the discipline. The term *computational* thinking has been used a number of times in this book. Here is a short definition of computational thinking It is the type of thinking that involves using the capabilities of one's brain/mind with the capabilities of ICT to represent and solve problems.

This chapter focuses on computer programming, one the underlying computer-oriented aspects of computational thinking. In the early days of electronic digital computers, many of the users learned to write computer programs or r had computer programmers at their beck and call. They had to understand quite a bit about the inner workings of a computer.

The development of large libraries of computer software, as well as huge improvements in the human-computer interface, have greatly reduced the need for a computer user to understand the inner workings of a computer.

What this means, however, is that the vast majority of computer users have a large hole in their understanding of computational thinking. One does not need to be a computer programmer to understand and make use of computational thinking, but it sure helps!

Procedural Thinking

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. Thus, computer programming and problem solving are closely related topics. Any modern course on computer programming has a strong focus on problem solving.

Programmers use the term *procedure* to refer to a program or a piece of a program designed to accomplish some specific task. Thus, for example a computer program might include a procedure to input names of workers and hours worked during a week, a procedure for retrieving information about each worker from a disk storage unit, a procedure for calculating the pay due each worker, a procedure for storing these results on a disk, a procedure for printing out checks for the workers who want to receive a check, and a procedure for automatic bank deposit for those who want their wages deposited in a bank. The whole program might be called a payroll

program or a payroll procedure. It consists of a number of procedures that work together to accomplish the payroll-processing task.

A computer programmer learns to think about problems solving in terms of a using a collection of procedures. The programmer designs the program, figuring out what procedures are needed to solve the problem. Some of the procedures have already been created by others and are available in a program library. The programmer creates other procedures. The programmer puts the procedures together in a manner so that they work together, and tests the program for correctness.

This is, of course, an overly simplified presentation of what a programmer does. However, it is easy to see that the overall task requires procedural thinking.

Types of Computer Programming

In this chapter, I use the somewhat simplified definition that computer programming is telling a computer what to do. In computational thinking, you tell your brain what to do and you tell a computer system what to do. To tell your brain what to do, it is not necessary to know the fine details of how the neurons in your brain store and process information. In computer programming, you do not need to know the details of how transistors and integrated circuits work. In either case, however, it is helpful to know the capabilities and limitations of the storage and processing "machinery" (brain and computer).

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., Algol, BASIC, C++, COBOL, FORTRAN, Java, Logo). 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 one's 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 microcomputer 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 later actions by the computer. later time.

Productivity-tool Programming

When you are creating a spreadsheet using spreadsheet 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 computer system. 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.

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 execute (carry out) several billion instructions per second. Supercomputers are many thousands of times this fast. Such speed is one key to the valued 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 35,001. 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 35,001 and 35,002. If the value in memory location 35,002 is the larger, then do instruction # 4 next. Otherwise, do instruction # 35 next. This simple "If … Then" decision-making capability of a computer is a fundamental idea in computer programming. A very short computer program can keep a billion operations per second computer busy for a very long time!

As another simple example, here is a very short program written in the language BASIC. It consists of four statements (four lines of code) that have been numbered 1, 2, 3, and 4.

1 For X = 1 to 1000000

2 Print X, "I will not chew gum in class."

3 Next X

4 End

This program tells the computer to print out a million line list numbered 1 to 1,000,000, with each line containing the message: I will not chew gum in class. The first three lines of the program are a loop, with the value of X starting at 1 and being automatically incremented by 1 over and over again until instruction 2 has been executed a million times.

A key aspect of procedural thinking is finding and making use of repetitive patterns in the solving of a particular problem or a general category of problems. You have memorized such patterns for doing paper and pencil addition, subtraction, multiplication, and division.

Testing and Debugging

Suppose that you issue an immediate action command to a computer. For example, you tell the computer to check the spelling of a document or to print a copy of the document. You can quickly determine if the computer has carried out your instruction.

If the computer fails to correctly carry out the instruction, then there might be something wrong with the computer hardware and software. However, there may be something wrong with the instruction that you have issued. For example, you may have selected an incorrect menu item when issuing an instruction, or you may have made a keyboarding error.

Similarly, suppose you are telling your telephone system to make a connection to a person you want to talk to. You do this by keying in a telephone number. If you make an error in keying in the number (or, if you don't remember the correct number), you will receive feedback that tells you something has gone wrong. You can then take action to solve this problem. Of course, if the problem is that the telephone system is out of order or very overloaded, you will not be able to solve the problem.

When writing using a computer. I frequently make keyboarding errors. I use a word processor that placed a wavy red line underneath words that are not in its spelling dictionary, and a wavy green line under phrases of sentences that it "thinks" might be poor or incorrect

grammar. Also, of course, I can often detect when I have made a keyboarding error just from the "feel" of what my fingers have done, of by looking at the words as they appear on my display screen. In word processing, a combination of what my machine can do and what I can do tends to detect and correct a high percentage of my errors.

Certain keyboarding error I make repeatedly. For example, my fingers often interchange the i and o in the word education. I have instructed my word processing system to automatically correct these errors without even bothering to tell me it has done so. That is an interesting idea. I trust the computer so much that I allow it to detect and automatically correct some of my errors.

Errors in computer hardware of software are often called *bugs*. As hardware has gotten more reliable over the years, the term has come into common usage as an error in a computer program. Finding and correcting such errors is called *debugging*. Testing and debugging are major aspects of developing large complex programs such as word processor, spreadsheet, and operating systems.

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. 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 quite 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 easy to make a mistake of telling the computer to use a number that is stored in memory location 3867 when you really mean to use the number in memory location 3876. 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, 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 discipline can build on this knowledge through learning a programming language specifically designed to help solve problems in that discipline.

That is, there is transfer of learning from a discipline into learning to use a programming language that is specifically designed to help solve problems within the discipline. 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 bookkeeping. However, if the spreadsheet instruction is designed to help one solve certain types of science problems, the learner will probably not learn much abut business bookkeeping.

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 In particular, many of the ideas of computational thinking readily transfer among different programming languages.

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 developed more than 40 years ago, 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.

Over time, people found the need to deal with other types of data structures. They found that FORTRAN and COBOL were not as well suited as one might like in dealing with the data structures that occur in working with graphics, animation, music, maps, and so on.

For 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.

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 so far in this chapter. In many problems, the needed control structure and data structures tend to merge. 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 models and 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 are 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 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, the programming language Logo, designed for use by children, makes use of objects.

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 computers 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.

Final Remarks

Computational thinking involves drawing upon your brain's knowledge and processing capabilities, and a computer's "knowledge" and processing capabilities. A human brain and a computer have different capabilities and limitations. In many problem-solving situations, a person who has expertise in both use of his or her brain and in use of computers has a substantial advantage over a person with weak computer knowledge and skills.

Immediate Actions for Chapter 10

Begin using the term *computational thinking* in your everyday vocabulary. Tell your colleagues and students about this idea. Help them learn to recognize when they are doing computational thinking.

Activities for Chapter 10

1. Make a list of immediate action instructions that you routinely instruct computers to do. Think broadly, so that you list includes telling an ATM machine to process a deposit or withdrawal for you, and telling a telephone system to establish a connection between your phone and another person's phone.

2. Make a list of computer applications software that you routinely use. For each application package, briefly discuss how it helps you to solve problems and accomplish tasks that are important to you.

3. Think about some of the things you do over and over again during a typical day or week. Discuss the possibility of developing machines (perhaps computerized, machines that make use of artificial intelligence) to carry out some of these tasks. In your analysis, see if you can come up with a simple set of criteria that separate the tasks that require human intelligence and a human body versus what a computerized robot might eventually be able to do.

4. Both BASIC and Logo used to be widely taught in elementary and middle school. Students at these grade levels are quite capable of learning to write computer programs to solve problems. While there are still many small pockets of such instruction, for the most part instruction computer programming has mostly disappeared from the elementary and middle school curriculum. Discuss possible reasons why this has occurred.

5. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of Chapter 10 of this book 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 Chapter 10. Identify your current strengths and weaknesses in ICT from this point of view.

Chapter 11

Summary of Important Ideas

"Be the change you want to see in the world" (M. Gandhi)

"Technology is a gift of God. After the gift of life it is perhaps the greatest of God's gifts. It is the mother of civilizations, of arts and of sciences." (Freeman Dyson)

ICT provides powerful aids to problem solving in every academic discipline. The number of such aids and their power is steadily growing. The idea of helping students learn to do computational thinking, where they build upon their mental capabilities and the capabilities of computers, is gradually taking hold throughout the world.

Some Key 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 through this ownership and by other means.

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. Use of mental, physical, paper and pencil, and computer models.

    C. Building on the previous work of self and others.

    D. Transfer of learning, using the high-road, low-road model.

    E. Mindfulness, metacognition, and reflection. When a student routinely uses these mental activities before, during, and after solving a problem, the student will get to be better at problem solving.

    F. Computational thinking, with an emphasis on human intelligence and machine intelligence (artificial intelligence) working together to solve problems and accomplish tasks.

G. Capabilities and limitations of ICT.

H. Roles of ICT in each discipline being taught. Roles include being part of the content, an aid to instruction, and aid to making use of the material being learned, and an aid to assessment.

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 Chapter 11

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 Chapter 11

1. Select a specific grade level and/or subject area that you teach or would like to teach. Analyze the content of this book 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 book. Revise the lesson plan so that it better incorporates the ideas from this book.

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 book. Identify your current strengths and weaknesses in ICT from this point of view.

Appendix A

Brain/Mind Science and Problem Solving

"Imagination is more important than knowledge." (Albert Einstein)

"... pedagogy is what our species does best. We are teachers, and we want to teach while sitting around the campfire rather than being continually present during our offspring's trial-and-error experiences." (Michael S. Gazzaniga, 1998, p 8)

"Man's mind, once stretched by a new idea, never regains its original dimensions." (Oliver Wendell Holmes)

The Appendix briefly discusses 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. Thus, it can be integrated into a course, or just used as an add-on for those students who have an interest in brain science.

Introduction

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. In this appendix, I 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.

This section introduces three Big Ideas emerging from progress in mind/brain science.. Later sections explore these ideas in more detail.

Human 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 combined strengths of their brains and ICT systems. We need to help students gain an increased level of knowledge and skill in computational thinking and working in a Problem/Task Team environment.

Human Memory

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. There is a section about chunks and chunking given later in this appendix.

- Long-term memory has large capacity and stores information for a long time.

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 time. The human brain can memorize large amount of poetry or other text. However, 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. A 160-gigabyte hard drive (typical on many microcomputers) can store well over a hundred thousand 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 tactile sensation) 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. Constructivism can be thought of as building on—enriching, expanding, modifying—chunks stored in long-term memory.

In essence, reading and writing provide an augmentation to short-term and long-term memory. 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. Our educational system is faced by the challenge of educating students to work in environments in which the capabilities of physical and mental aids are steadily being improved.

Brain/Mind Science

Brain science is one of the current buzzwords 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 his 1999 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).

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 x 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.
>
> …
>
> 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. 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 of 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 ± 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 are relatively good 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 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.

This same set of ideas applies in learning any discipline. Each discipline has its own special vocabulary and notation. Part of the process of increasing one's expertise in a discipline is learning (with considerable understanding) the vocabulary. This is akin to developing fluency in a foreign language, where one eventually learns to think in the language without having to do a conscious translation of each word or phrase.

This analysis suggests the value of stressing depth rather than breadth in learning. It is better to have a small vocabulary in a discipline, with great fluency and understanding of the vocabulary, than to have a large vocabulary with little understanding and fluency.

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. Sensory input data 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.
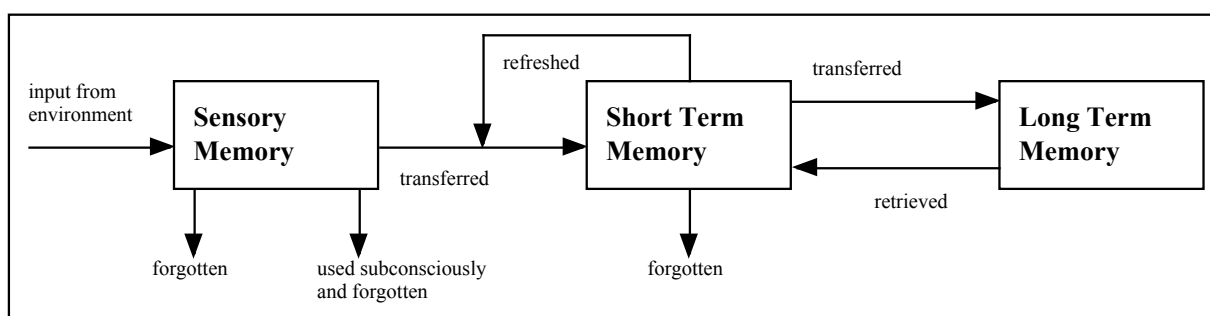
Figure A.2. An Information Processing Model for human memory.

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. However, 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 is 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. If the stream of input contains a lot of new information, it will overwhelm the brain's processing capabilities.

This observation helps explain how difficult it is for a teacher to effectively communicate to a group of students. Each student has different stored knowledge and understanding. Each student processes new information—some much slower or faster than others—making use of his or her stored knowledge and understanding. For some students, the rate of input will be far too slow, while for others it will be far too fast.

This also helps to explain why individual tutoring or very small classes are more effective than large classes.

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 and communicate. 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 sometimes also 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. They computer automatically corrects some of my keyboarding or spelling errors. Some possible spelling and grammatical errors are brought to my attention by the computer underlining the word or text in question. I then use my declarative and procedural knowledge to deal with these suggestions from my computer.

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 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 discovers 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 8 years of undergraduate and graduate study brings this person to age 26. Hmmm. 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 genetically 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 in a typical elementary school class 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 in a typical class.

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 a personal example, my logical/mathematical IQ is well above average, but my spatial IQ is below average.

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 part 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). This is not 50,000 rotely 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 of study and practice to develop this high level of expertise.

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 speak and understand 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 and 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 curricula that place 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.

Our increasing research base in nature-based and nurture-based difficulties in gaining reading fluency has led to a variety of interventions. We now know enough to substantially reduce the percentage of students who are not making good progress in moving from learning to read into reading to learn.

Other Learning Differences and Disabilities

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.
>
> …
>
> 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 10/23/07: 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 some place in the 4th to 5th 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.3 (Huitt and Hummel, 1998).

Approximate Age	Stage	Major Developments
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. Research suggests that only 35% of children in industrialized societies have achieved formal operations by the time they finish high school.

Table A.3. 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:

I must admit that I was astounded when I first encountered this piece of information in the bottom right corner of the table. 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 statements 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 what we are attempting 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.4.

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.4. Van Hiele developmental scale for geometry.

The van Hieles also concluded 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.

The majority of high school geometry courses is taught at Level 3 (Deduction). It is interesting to compare Level 3 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 9th or 10th 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.

3. It is likely that a rigorous freshman math course (.College Algebra provides an example of such a course)in a college or university is above the math cognitive developmental level of a great many (perhaps a majority) of the students who take such a course.

These three observations do not say that a typical student cannot be educated to the math developmental levels needed to be successful in high school and college math. Rather, they say that our current math education system is not successful in accomplishing this task.

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 and legacy. That is, they want students to learn to develop and test relationships (causality) among historical events. We want them to understand how legacy strongly influences us. 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. 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 ICT is important in problem solving because:

1. 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.

2. 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.

3.   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.

In summary, from a teaching and learning point of view we now have the human brain/mind, the human brain/mind augmented by reading and writing, and the brain/augmented by ICT. We have long understood the value of reading and writing, and have thoroughly integrated it course content, instruction, and assessment. We have made relatively little progress in a similar approach to ICT.

We have little evidence that the typical human brain has changed appreciably over the past hundred thousand years. We have ample evidence that the typical ICT system is becoming more capable over the years. The future of education lies in helping people learn to make effective use of their intellectual capabilities in a world where ICT systems will steadily become more and more capable.

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 ± 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. Glance at this note from time to time, and you still have the full capability of your short term memory as you do your lesson planning processes.

You also know quite a bit about roles of ICT as an aid to problem solving. Name this chunk *augmented memory*. Hold it your short term memory or add it to your "cheat sheet." If you place both chunking and augmented memory in your short term memory while doing lesson planning, you are then down to 5 ± 2 chunks of short-term memory to use in focusing on content, pedagogy, and assessment. Continuing, 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? Let's restate the suggestions. Get a sheet of paper and make a short list that includes brain chunking, augmented memory, constructivism, transfer of learning, lower-order and higher-order thinking, cognitive development, and other major ideas from this book. Keep this list in front of you as you prepare

lesson plans and get ready to teach your classes. Eventually you will have used your list so many times that it will become part of your daily lesson planning and preparation.

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Imagine a school with children that can read or write, but with teachers who cannot, and you have a metaphor of the Information Age in which we live. (Peter Cochrane)