Introduction to Using Games in Education: A Guide for Teachers and Parents

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Dave Moursund

Teacher Education, College of Education

University of Oregon 97403

Email: moursund@uoregon.edu

Web: http://uoregon.edu/~moursund/dave/index.htm

About Dave Moursund, the Author

Dave Moursund
Teacher Education, College of Education
University of Oregon
Eugene, Oregon 97403
Email: moursund@uoregon.edu
Web: http://uoregon.edu/~moursund/dave/index.htm

- Doctorate in mathematics (numerical analysis) from 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 Professor 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.
- 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.
- Full Professor in the College of Education at the UO for more than 22 years.
- Author or co-author of about 40 books and several hundred articles in the field of computers in education.
- Presented about 200 workshops on various topics 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.
- 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/.

Preface

All the world's a game,
And all the men and women merely players:
They have their exits and their entrances;
And each person in their time plays many parts, …

(Dave Moursund—Adapted from Shakespeare)

The word *game* means different things to different people. In this book, I explore a variety of board games, card games, dice games, word games, and puzzles that many children and adults play. Many of these games come in both non-electronic and electronic formats. This book places special emphasis on electronic games and the electronic versions of games that were originally developed in non-electronic formats.

There are many other types of games that are not explored in this book. For example, I do not explore sports games, such as Baseball, Basketball, Football, and Soccer, or any of the sports in the summer and winter Olympic Games.

Since my early childhood, I have enjoyed playing a wide variety of games. Indeed, at times I have had a reasonable level of addiction to various games. In retrospect, it is clear that I learned a great deal from the board games, card games, puzzles, and other types of games that I played as a child.

In recent years, a number of educators and educational researchers have come to realize that games can be an important component of both informal and formal education. This has become a legitimate area of study and research.

There are oodles of games that are now available in electronic format. While many of these are distributed commercially, many others are available for free play on the Web, and some can be downloaded at no cost. In this book, I am especially interested in games that are available at little or no cost and that have significant educational value.

Some electronic games are merely computerized versions of games that existed long before computers. Others only exist in a computer format. Computer networks have made possible games that allow many thousands of players to be participating simultaneously. The computerized animation and interaction in these games bring a dimension to games.

Learning Through Game Playing

This book is written for people who are interested in helping children learn **through** games and learn **about** games. The intended audience includes teachers, parents and grandparents, and all others who want to learn more about how games can be effectively used in education. Special emphasis is given to roles of games in a formal school setting.

As you know, education has many goals, and there is a huge amount of research and practitioner knowledge about teaching and learning. This book is well rooted in this research and practitioner knowledge. Five of the important ideas that are stressed include:

- Learning to learn.
- Learning about one's strengths and weaknesses as a learner.
- Becoming better at solving challenging problems and accomplishing challenging tasks. Learning some general strategies for problem solving is a unifying theme in this book.
- Transfer of learning from game-playing environments to other environments.
- Intrinsic motivation—students being engaged because they want to be engaged. This idea is illustrated by the following quote from Yasmin Kafai, a world leader in uses of games in education.

> If someone were to write the intellectual history of childhood—the ideas, the practices, and the activities that engage the minds of children—it is evident that the chapter on the late 20th century in America would give a prominent place to the phenomenon of the video game. The number of hours spent in front of these screens could surely reach the hundreds of billions. And what is remarkable about this time spent is much more than just quantity. **Psychologists, sociologists, and parents are struck by a quality of engagement that stands in stark contrast to the half-bored watching of many television programs and the bored performance exhibited with school homework.** Like it or not, the phenomenon of video games is clearly a highly significant component of contemporary American children's culture and a highly significant indicator of something (though we may not fully understand what this is) about its role in the energizing of behavior (Kafai, 2001). [Bold added for emphasis.]

Computational Thinking

Your mind/brain learns by developing and storing patterns. As you work to solve a problem or accomplish a task, (as you think) you draw upon these stored patterns of data, information, knowledge, and wisdom.

Beginning more than 5,000 years ago, reading and writing have become more and more important as a mind/brain aid. In the past few decades, computers have contributed substantially to mind/brain processes by providing improved access to information, improved communication, and aids to automating certain types of human "thinking" processes.

Notice how the thinking of mind/brain and the thinking (information processing) of computers are melded together in the following brief discussion of *computational thinking*.

> 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. (Wing, 2006)

Games provide an excellent environment to explore ideas of computational thinking. The fact that many games are available both in a non-computerized form and in a computerized form helps to create this excellent learning environment. A modern education prepares students to be productive and responsible adult citizens in a world in which mind/brain and computer working together is a common approach to solving problems and accomplishing tasks.

Puzzles

A puzzle is a type of game. To better under the purpose of this book, think about some popular puzzles such as crossword puzzles, jigsaw puzzles, and logic puzzles (often called brain teasers). In every case, the puzzle-solver's goal is to solve a particular *mentally challenging* problem or accomplish a particular mentally challenging task.

Many people are hooked on certain types of puzzles. For example, some people routinely start the day by spending time on the crossword puzzle in their morning newspaper. In some sense, they have a type of addiction to crossword puzzles. The fun is in meeting the challenge of the puzzle—making some or a lot of progress in completing the puzzle.

Crossword puzzles draw upon one's general knowledge, recall of words defined or suggested by short definitions or pieces of information, and spelling ability. Through study and practice, a person learns some useful strategies and can make considerable gains in crossword puzzle-solving expertise. Doing a crossword puzzle is like doing a certain type of brain exercise. In recent years, research has provided evidence that such brain exercises help stave of the dementia and Alzheimer's disease that are so common in old people.

From an educational point of view, it is clear that solving crossword puzzles helps to maintain and improve one's vocabulary, spelling skills, and knowledge of many miscellaneous tidbits of information. Solving crossword puzzles tends to contribute to one's self esteem. For many people, their expertise in solving crossword puzzles plays a role in their social interaction with other people.

Brief Overview of Contents

Each chapter ends with a set of activities for the reader of the book, and a set of activities that might be useful with students of varying backgrounds and interests.

Chapter 1 illustrates the idea of thinking outside the box. This idea is important is solving puzzle problems, but it is also essential in solving many real-world problems.

Chapter 2 provides some general educational background needed in the rest of the book.

Chapter 3 uses a puzzle called Sudoku to explore some aspects of puzzles and their roles in education.

Chapter 4 explores some additional puzzles and sources of free puzzles on the Web.

Chapter 5 explores solitaire card games that can be played with ordinary decks of 52 playing cards, or that can be played on a computer.

Chapter 6 explores competitive 2-person games such as checkers, chess, and backgammon. Nowadays, many people play these games using a computer as an opponent.

Chapter 7 explores games that typically involve more than two players, but only a modest number of players. Examples include Poker, Bridge, and Hearts.

Chapter 8 discusses the development of game-based lesson plans.

Chapter 9 provides very brief introductions to a miscellaneous collection of ideas related to the topic of games in education. If I were writing a longer book, some of these topics would be individual chapters.

Appendix 1 summarizes the problem-solving strategies explored in the book. It also provides additional information about effective ways to use games in education.

The References section of this book includes links to many relevant Websites.

David Moursund

Chapter 1

Thinking Outside the Box

We can't solve problems by using the same kind of thinking we used when we created them. (Einstein, Albert)

The vertical thinker says: 'I know what I am looking for.' The lateral thinker says: 'I am looking but I won't know what I am looking for until I have found it.'" (Edward de Bono)

Consider the following two statements:

- Education has many goals. Few people would list "to be fun" as one of the main goals of education. Instead, people tend to say "no pain, no gain."
- Many games are used as a form of play. Games are for fun.

Now, think back to your childhood. I'll bet that you can think of games that you played that were fun **and** made significant contributions to your learning. A personal example that comes to mind is the game of Monopoly. I probably spent hundreds of hours playing this game.

Indeed, as a child I enjoyed playing many different card games, board games that involved dice or spinners, and board games such as Checkers, Chess, and Go that do not depend on randomness. As a young adult I learned to play Bridge, and in more recent years have learned to play a wide variety of computer games.

Games have contributed significantly to my informal and formal learning. Playing games that involved two or more people was an important component of my social development and social life. Game playing was such an important part of my childhood that I made sure it was a part of my children's childhoods.

In recent years, computers have made possible some new types of games. In addition, computers have made many older games more accessible.

As you read this book, I want you to think outside of the box. Suspend some of your suspicions and beliefs about educational and other values of games. Open your mind to new possibilities. For example, as a child I enjoyed interacting with a small group of people playing Monopoly and other board games. Now, there are computer-based games in which tens of thousands of people simultaneously play in a combination of cooperative and completive manners. This is made possible by the Internet and by the development of games designed to accommodate huge numbers of simultaneous players. Whether it is just a few people, or a few thousand people playing a computer-based game, they are learning to communicate and interact in a computer-supported environment. What can education learn from such games?

Think outside the box! Our children are growing up in a world in which it is common for teams of people, with members located throughout the world, to work together on complex problems and tasks. You have undoubtedly heard the African proverb, “It takes a whole village to raise a child.” Combine this idea with that of *global village* and you can see that nowadays, the whole world is involved in raising and educating our children. Our children need an education that prepares them to be effective participants in this global village.

Puzzle Problems

This book will expose you to a variety of games. One type of game is called a puzzle. A puzzle is a problem or enigma mainly designed for entertainment. Often one can solve a puzzle without having to draw upon deep knowledge of any discipline. A jigsaw puzzle and a Rubrics cube provide good examples of this.

A child doing a jigsaw puzzle is engaged in tasks that involve looking for patterns, using spatial visualization skills. This puzzle playing may be done individually or in a small group. In the latter case, there is a strong social education aspect of putting together a jigsaw puzzle.

Other types of puzzles require a broad and deep background. Contrast a jigsaw puzzle or a Rubric cube with a crossword puzzle from the New York Times newspaper. The crossword puzzle draws upon reading, spelling, word definitions, and word-suggestion clues.

In some cases, there will be a large number of variations on a particular type of puzzle. There are lots of different interlocking jigsaw puzzles, and there are lots of different crossword puzzles.

In other cases, a puzzle will be one-of-a kind. Once you have figured out how to solve the puzzle, it is no longer a challenge. Here is an example of a brain-teaser puzzle that you may have seen before.

> **Problem:** You are at a river that you want to cross with all of your goods. Your goods consist of a chicken, a bag of grain, and your large dog named Wolf. You have to cross the river in your canoe but can only take one passenger (chicken, dog, bag of grain) with you at a time. You can't leave the chicken alone with the grain, as the chicken will eat the grain. You can't leave your dog Wolf alone with the chicken, as Wolf will eat the chicken. However, you know that Wolf does not eat grain. How do you get everything across the river intact?
>
> **Solution:** Take the chicken across the river first and leave it on the other side. Return to where you have left Wolf and the grain.
>
> Next, take Wolf across the river, and leave him there, but bring the chicken back with you.
>
> Next, leave the chicken where you started. Take the bag of grain across the river and leave it with Wolf.
>
> Finally, go back and get the chicken, and take it with you across the river.

This brain teaser requires you to think outside the box. Many people do not think about the idea that in solving this puzzle you might bring something back on a return trip. They never consider this possibility, and they are unable to solve the puzzle problem.

Here is another brain-teaser puzzle that requires thinking outside the box.

> **Problem:** Using pencil and paper, arrange nine distinct dots into a three by three pattern as illustrated in Figure 1.1. The task is to draw four straight line segments with the beginning of the second starting at the end

of the first, the beginning of the third starting at the end of the second, and the beginning of the fourth starting at the end of the third, and so that the total sequence of line segments passes through each dot.

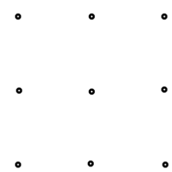


Figure 1.1. Nine dots in a 3x3 square pattern.

See if you can solve this puzzle before looking reading further.

To begin, you may think about how easy it is to complete the task using five line segments. A solution is given in Figure 1.2. After studying this solution, you can easily find other 5-line line segment solutions.

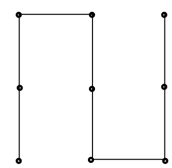


Figure 1.2. A 5-line segment solution for the 9-dots puzzle.

How can one possible complete the task with only four line segments? As with the river-crossing puzzle, it is necessary to think outside of the box. In this case, the layout of the puzzle tends to create a visual box. Many people do not think about drawing line segments that go outside of the visual box. A solution using four line segments is shown in Figure 1.3.

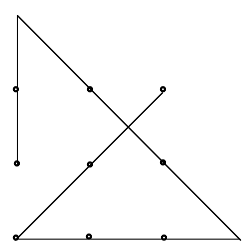


Figure 1.3. A 4-line segment solution for the 9-dots puzzle.

I suspect that most parents, teachers, and other adults really don't care whether students learn how to solve this 9-dots, 4-line segment puzzle problem. I don't ever recall encountering a similar real-world problem during my lifetime.

However, many people care about helping students learn to think outside the box. Thus, they want students to have an informal and formal educational system that will help students learn to think outside the box.

In this book, we will explore real-world problems and game-world problems. Of course, the games are part of our real world, so the distinction is somewhat silly. However, the goal in this book is to learn to make better use of the game world to learn about solving problems in the real world.

Thinking outside the box is illustrated by the two puzzles illustrated above. However, these two examples are useful in education mainly if the learner makes a connection between the examples and real-world problems. Young students will seldom make such connections on their own. Merely having students work to solve these two puzzles and then showing them solutions will not help the typical young student to make such connections.

This is where a teacher enters the picture. A good teacher can help students to discover personal examples of thinking outside the box. The teacher might be a parent, a schoolteacher, a sibling, or a peer. The point is that the teacher does a valuable service for the student. With proper instruction, most students can gain increased skill in making such connections by themselves. Clearly, this is an important goal in education!

Here is another 9-dot challenge. See if you can use just three connected line segments to draw through all of the dots. As before, think about this before going on. Think outside the box!

The chances are that you are like many other people, in that you have studied math for many years, starting in preschool or elementary school. Thus, you can probably tell me the difference between a dot and a mathematical point. A dot has size, while a point does not. The puzzle was stated in terms of using nine distinct dots (not nine points). A 3-line segment solution is illustrated in Figure 1.4. To make the illustration easier to understand, I have enlarged the dots in the puzzle.

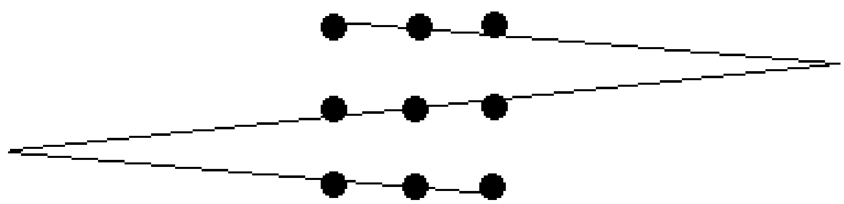


Figure 1.4. A 3-line segment solution for the 9-dots puzzle.

This solution not only illustrates thinking outside the box, it also illustrates the importance of precise vocabulary and the problem solver understanding the meaning of the precise vocabulary. This is a tricky puzzle problem, because many people tend to think of a dot as a (mathematical) point.

Here is a final challenge. Can the problem be solved using only two line segments? Prove your assertion!

The request for a proof is, of course, a standard thing in mathematics courses. However, proof is an important concept in many other disciplines. A lawyer works to prove a client is not guilty, and a researcher in science works to prove a scientific theory. One way to prove that a problem can be solved is to actually solve it. Demonstrate to other people how to solve the problem, and do so in a manner so that they can also solve the problem. That is what I did in the 3-line segment solution to the 9-dots problem.

Suppose, however, you suspect that a problem does not have a solution. Then, your task becomes one of proving that the problem does not have a solution. Your proof must be convincing to other people. See if you can prove that the 9-dots puzzle problem cannot be solved using only two connected line segments. [Hmmm. I wonder if the dots in this problem can overlap each other? That is not made clear in the statement of the problem.]

I suspect that as you thought about this puzzle problem, you forgot about the possibility of the dot pattern being on a sphere. There was no explicit statement in the problem that the nine dots are in a plane. Part of thinking outside the box is to think critically and carefully. What do you actually know about the facts of the problem, and what do you make up in your mind? As you work to understand and create meaning in a problem, you may well think yourself into a box in which the problem cannot be solved.

Problems and Problem Solving

Puzzle problems are a type of problem. A great deal of this book is about problem solving and what we can learn about problem solving through studying and using games.

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 1.5 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.

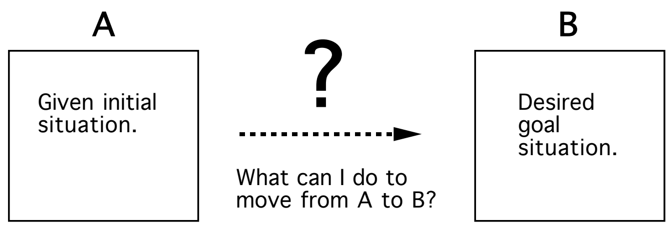


Figure 1.5. Problem-solving—how to achieve the final goal?

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 problem.
4. You have some ownership—you are committed to using some of your own resources, such as your knowledge, skills, and energies, to achieve the desired final goal.

These four components of a well-defined (clearly-defined) problem are summarized by the four words: givens, goal, resources, and ownership. If one or more of these components are missing, you have an ill-defined problem situation (frequently called a problem situation or an ill-defined problem) 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.

Consider some problem situations such as global warming, globalization of business, terrorism, homelessness, drugs, and the US scoring below some other countries in international tests. These are all problem situations because the givens, guidelines, and resources are not specified. You may or may not happen to care about specific problems that relate to these problem situations.

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

People are often 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. However, 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.

People often have access to computers as they work to solve a problem. They draw upon both the capabilities of their mind/brain and of Information and Communication Technology (ICT) systems. They routinely make use of computational thinking (see the Preface) as an aid to problem solving.

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

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

The idea of ownership can be confusing. In this 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. If a student creates or helps create the problems to be solved, there is increased chance that the student will have ownership.

Such ownership contributes to intrinsic motivation—a willingness to commit one's time and energies to solving the problem. All teachers know that intrinsic motivation is a powerful aid to student learning and success.

The type of ownership that comes from a student developing or accepting 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 or 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 encounter challenging problems that the students really care about.

Now, what does this formal definition of problem have to do with thinking outside the box? Plenty! In a game setting, the rules and regulations are usually carefully stated. Even then, however, there may be exceptions that allow thinking outside the box thinking. The 9-dots puzzle certainly illustrates this. Thinking outside the box and expanding the size of the dots, allowed us to see a 3-line solution. As you were working on the 2-line version of the puzzle, did it occur to you that perhaps the dots could overlap or that the dots could be on a sphere?

You know that students often develop personal interest in (ownership of) the problem of playing a game well. Now, if only such games had redeeming educational value … Wouldn't it be nice if students spent time in an intrinsically motivated state, working to learn to solve problems that they have ownership of, but that also tie in well with the contents of the regular school curriculum? I wonder what school would be like if students spent much of their time in such an environment?

The steam engine existed a long time before the internal combustion engine was developed. Imagine being an inventor studying a steam engine, and thinking about how to make a smaller and more fuel-efficient engine. Perhaps the firebox could be made a little smaller and better insulated? Perhaps one could find a fuel that is more concentrated than coal or wood? Thinking outside the box led to using a fuel such as gasoline, and having the "fire" occur right next to the piston, inside the cylinder that contained the piston. What a marvelous example of thinking outside the box!

Problem Solving is Part of Every Discipline

In general terms, each discipline or domain of study can be defined by its unique combination of:

1. The types of problems, tasks, and activities it addresses.
2. Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, and recording and sharing accumulated results.
3. Its accumulated accomplishments such as results, achievements, products, performances, scope, power, uses, impact on the societies of the world, and so on.
4. Its history, culture, unifying principles and standards of rigor, language (including notation and special vocabulary), and methods of teaching, learning, and assessment.

5. It particular sense of beauty and wonder. A mathematician's idea of a "beautiful proof" is quite a bit different than an artist's idea of a beautiful painting or a musician's idea of a beautiful piece of music.

Each discipline has its own ideas as to what constitutes a problem to be solved or a task to be accomplished. The following list is not all-inclusive, but is intended to emphasize that we are interested in general ideas of problem solving in all disciplines. We are interested in:

- Question situations: recognizing, posing, clarifying, and answering questions.
- Problem situations: recognizing, posing, clarifying, and solving problems.
- Task situations: recognizing, posing, clarifying, and accomplishing tasks.
- Decision situations: recognizing, posing, clarifying, and making decisions.
- Using higher-order, critical, creative, and wise thinking to do all of the above. Often the "results" are shared or demonstrated as a product, performance, or presentation.
- Using tools that aid and extend one's physical and mental capabilities to do all of the above. Examples of such tools include reading, writing, math, and computers.

Throughout this book we will be discovering and exploring various strategies for problem solving. The single most important strategy for problem solving is building upon the previous work of yourself and others. In this book, we will call this the *build on previous work strategy*. You may prefer to call it the *look it up strategy*. The development of the Internet and the Web have made it much easier to retrieve information from libraries and from other people. Moreover, tens of thousands of computer programs have been written so that computers can directly solve or help to solve many of the problems that people want to solve.

Cognitive Maturity

You make routine use of a number of different problem-solving strategies without giving much thought to them. As an example, often when you are about to make a decision, you think about the consequences of this decision. You mentally "play out" what might happen in the future if you make a particular decision or take a particular action. If you are impulsive—perhaps often acting without thinking of the consequences—you work to overcome this impulsiveness.

You have had years of informal and formal education in this *think before your act* strategy. It is now a well-ingrained component of your cognitive maturity. As a parent or teacher, you undoubtedly place considerable emphasis on helping children make progress in this aspect of cognitive maturity.

Another good example is the set of strategies you bring to bear when faced by a challenging learning task. You know a great deal about yourself as a learner. You can self-assess your progress in learning. You can set standards based on how well you have done other learning tasks. Your strategies in dealing with a challenging learning task are an important aspect of your current level of cognitive maturity. You certainly want to help children make progress in learning and using their own set of strategies in this area.

Notice that these aspects of cognitive maturity are not dependent on having learned any specific discipline. Cognitive maturity is a component of every discipline, and it cuts across all disciplines. Games can be used to help create an environment in which children can increase their levels of cognitive maturity. It is easy to see how an adult who has a higher level of cognitive maturity than a student can serve as a teacher and mentor in helping a student increase in cognitive maturity.

George Polya's General Problem-Solving Strategy

George Polya was a great mathematicians and teacher of the 20th century. He wrote extensively about problem solving. Polya's six-step problem-solving strategy is useful in math and in most other disciplines. The following version of this strategy has been modified to be applicable in many different domains. All students can benefit from learning and understanding this strategy and practicing its use over a wide range of problems.

1. Understand the problem. Among other things, this includes working toward having a 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.
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 because of this thinking.
4. Carry out your plan of action in a reflective, 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!

Modeling and Simulation

When you were a child, you may well have built and/or played with model cars, model airplanes, and model people (such as toy figures). A model car has some of the characteristics of a "real" car.

Models have long been used as an aid to representing and solving problems. For example, when the Wright brothers were in the process of developing their first airplane, they developed models of components of their airplane (such as a wing) and tested them in a wind tunnel they built.

The development and use of computer-based models is a valuable new addition to use of models to help solve problems. A computer model of a car or an airplane can be tested in a virtual wind tunnel (that is, in a computer model of a wind tunnel). In biology, chemistry, physics, and other sciences, computer modeling and then running simulations using the models has become a routine aid to research. Indeed, the three standard approaches to research in science are now experimental, theoretical, and computational. The term *computational* in this case means computer modeling and simulation.

Computational thinking includes thinking in terms of computer modeling and simulation. It also includes thinking in terms of mental modeling and simulation. When you are mentally considering the possible results of various decisions you might make, you are doing mental modeling. That is, you are doing a form of computational thinking.

Spreadsheet software was originally designed for modeling and simulation in business. A spreadsheet model was designed to represent a certain part of a business, such as inventory or payroll. "What if" types of questions could be answered by running the model (that is, doing a computer simulation based on the model) to help answer questions. Spreadsheet models are now a routine tool in business and a number of other fields.

How does this fit in with games? A game can be thought of as a model. Let's take Monopoly as an example. In this game, one buys and sells property, invests in houses and hotels on a property, and travels around the game board. Movement is determined by rolling a pair of dice, and various random events occur when your playing piece lands on certain board locations.

The game and its rules can be thought of as a model; playing the game is doing a simulation based on the model. Now, let's carry this one step further. While Monopoly was originally developed as a physical board game, it now also exists in a computerized form. Many people now play Monopoly using a computer model of the original game.

There are many advantages of computer models. In a game setting, the computer system can help take care of many of the details of playing the game. For example, instead of using physical dice, playing pieces, money, and so on, one uses computer representations (a virtual board, virtual playing pieces, virtual money) to play the game. Thus, none of these objects get worn out, damaged, or lost.

A second advantage of the computer model/simulation is that rules are strictly enforced. A player cannot "accidentally" move one space too far or pay less than the required rent.

A third advantage of computer models is in the easy setup and take down of a game. The computer does this for the players.

There are other advantages. Here is a quote from http://www.download-free-games.com/board_game_download/monopoly3.htm, a Website that sells a computerized version of Monopoly.

> **Monopoly 3 is an exact replica of the traditional board game—only better**! Animated tokens and property auctions, talking game announcer, the ability to customize rules and game boards, and online play all improve the classic game to make it even more fun than before.
>
> For additional challenge, choose from 3 different skill levels when playing [against] the computer. Have you always played with a cash bonus on the free parking space? No problem! Just **create your own customized rule and you can play Monopoly the way you always have**. Overall, Monopoly 3 is a great game for the entire family.

You know, of course, that Monopoly is a game for two or more players. Notice that with the software described above, your opponents can be virtual opponents (the computer plays these roles). Similar types of advantages hold for computerized versions of many traditional games.

Many computerized games have another provision that allows the player to take back or undo a move. For example, suppose that you are playing some version of a solitaire card game on a computer. The computer quickly shuffles the deck and lays out the cards. As you make your moves, you can easily undo a move or a sequence of moves. Indeed, provision is usually made so that a single keystroke allows the player to start over, using the same initial card layout. The undo feature allows you to explore "what if?"

Computer modeling and simulation is now one of the most important aids to problem solving. You and your students can lean about uses of this strategy through playing and studying games.

Games Can be Addictive

There are many different sources or types of addiction. Moreover, the term *addiction* is often used quite loosely. Thus, an observer might say that I am addicted to my morning cup of coffee. This observer might then go on to talk about caffeine being an addictive drug and that people experience headaches and other effects as they try to kick the caffeine habit.

Millions of people in this country are addicts. Types of addiction include heroin, morphine, amphetamines, tranquilizers, cocaine, alcohol, nicotine, and caffeine. Other addictions include work, shoplifting, gambling, computers, and **games**.

Games? When I was in graduate school, one of my friends flunked out of a Physics doctoral program because he was addicted to 2-deck games of solitaire. Some of these types of solitaire games are very mentally challenging, requiring deep concentration and careful thinking. The "thrill of victory and agony of defeat" is experienced repeatedly through playing such games. The immediate mental stimulation (the flow of dopamine and other endorphins) can be exhilarating. My friend found that such immediately available rewards overwhelmed the feelings of satisfaction gained through doing physics homework problems and attending physics classes.

I could provide some personal testimonial of addictive qualities of computer games—but I won't. Interestingly, I find that deep engagement in computer programming or in developing a spreadsheet has—for me—the same characteristics as game playing. For me, games, computer programming, spreadsheets and writing are all environments in which I can immerse myself, finding deep satisfaction in using my creativity and brain power. I experience what Mihaly Csikszentmihalyi calls *flow*.

Mihaly Csikszentmihalyi is a world expert and leader in Flow Theory. See http://www.brainchannels.com/thinker/mihaly.html. Quoting from that Website:

> Mr. Csikszentmihalyi (pronounced chick-sent-me-high-ee) is chiefly renowned as the architect of the notion of flow in creativity; people enter a flow state when they are fully absorbed in activity during which they lose their sense of time and have feelings of great satisfaction. Mr. Csikszentmihalyi describes flow as "being completely involved in an activity for its own sake. The ego falls away. Time flies. Every action, movement, and thought follows inevitably from the previous one, like playing jazz. Your whole being is involved, and you're using your skills to the utmost."

I have found Csikszentmihalyi's writings about flow to be quite interesting. Many people have decided that flow is a desirable state. Indeed, one might say that many people have become addicted to flow.

Here are two examples "outside the box" thinking related to addiction.

1. All children growing up in our world will encounter numerous addictive or addictive-like drugs, opportunities, and situations. Part of a good formal and/or informal education is to learn about how to deal with these situations. For some people, games are sufficiently addictive, or addictive-like, so they provide an opportunity to study themselves in an additive-like setting.

2. For many students, games are intrinsically motivating. Motivation—or the lack thereof—is a very important aspect of education. Teachers work hard to motivate their students; parents work hard to motivate their children. How can teachers and parents take advantage of the intrinsic motivation of games? Undoubtedly you have heard the adage, "If you can't beat them, join them." Outside the box thinking suggests that games be integrated into the ordinary, everyday school curriculum. Our informal and formal educational system should learn to take advantage of the addictive-like qualities of games. Quoting James Gee (2004):

    > For people interested in learning, this raises an interesting question. How do good game designers manage to get new players to learn their long, complex, and difficult games—not only learn them, but pay to do so? It won't do simply to say games are "motivating". That just begs the question of "Why?" Why is a long, complex, and difficult game motivating? I believe it is something about how games are designed to trigger learning that makes them so deeply motivating.
    >
    > …
    >
    > The answer that is interesting is this: the designers of many good games have hit on profoundly good methods of getting people to learn and to enjoy learning. Furthermore, it turns out that these methods are similar in many respects to cutting-edge principles being discovered in research on human learning.

Final Remarks

Games are a form of play. However, games provide an environment in which game players can learn about themselves. Games provide an environment in which one can interact with other people and develop certain types of social skills. Games provide an environment in which one can develop a variety of thinking and problem-solving skills that are useful in both non-game and game environments. Games provide an environment in which one can gain in mental maturity.

Many games have very long histories. Games that have survived over the years tend to have characteristics that fit well with the needs and interests of children and adults. Well before the advent of computers, many games had addictive-like qualities for some game players.

Computers have added new dimensions to games, and have provided more opportunities for a person to develop an addictive-like dependency on games. At the same time, computers are making possible games that have considerable educational value. The attention grabbing and attention holding characteristics of many of today's computer-based games are a challenge to our traditional formal educational system. At the same time, such games provide an opportunity for some changes that have the opportunity to improve our educational systems.

I recently used the quoted expression *"thinking outside the box"* as a search term in Google. I got nearly a million hits. It is clear that many people think about and write about thinking outside the box. However, our educational system experiences only limited success in developing this type of thinking in students. There is substantial room for improvement.

Activities for the Reader

This section contains some questions and activities for the person reading this book. Some are designed for people who are taking a workshop or course using materials from this book. The individual reader working alone may also find many of the questions and activities to be useful.

1. Think of some personal, real-world examples in which you thought outside the box. This book is one of my personal examples. Since I was a young child, I have played games for entertainment. Only recently, I have thought outside the box and begun to explore possible educational values of the games I played as a child.

2. Create a 16-dot (4 by 4 grid) puzzle problem akin to the 9-dot puzzle. Pose various goals associated and see if you can achieve these problem-solving goals. Many people enjoy creating puzzle problems and games. This is a different type of intellectual challenge than merely solving puzzles and playing games created by others. In the real world outside of games, problem posing (that is creating or defining problems) is an important component of each discipline of study.

3. Have you experienced flow, as described by Mihaly Csikszentmihalyi? If so, describe situations in which you have experienced flow and give your personal opinions on how this topic might fit in with informal or formal education. If you think that you have never experienced flow, then do some reading about Runner's High and discuss how it might relate to flow. See, for example, http://www.lehigh.edu/~dmd1/sarah.html.

4. Consider the following quotation:

> Comments from a student panel that my school district organized to investigate grading practices further elucidated the problem**. Students reported that they see their schoolwork as a game they play for grades—a game that at best treats learning as an incidental, and at worst distracts students from making meaning. One student referred to this grade game as academic bulimia:** Students stuff themselves with information only to regurgitate it for the test, with little opportunity for any thoughtful engagement that would produce deep understanding and

growth. Winger, Tony (November 2005). Grading to communicate. *Educational Leadership. Pp 61-65.* [Bold added for emphasis.]

Compare and contrast use of the term *game* in the quotation with the types of games and educational uses of games being discussed in this book.

5. Do some research on the topic *thinking outside the box*. Develop some ideas on how to improve your own ability to think outside the box, and how to improve the ability of students to do so.

Activities for use with Students

This section contains some ideas for use with students. It is assumed that the teacher, parent, or other person making use of these suggestions will adjust the activities to fit the needs of the students.

1. What are some games that today's students find to be fun to play? Engage an individual student or a group of students in a brainstorming activity designed to make a long list of games that they have played and enjoyed. As the list is being created, divide its items into three categories:

   a. Board games, card games, and other types of non-electronic games that are not physical sports games.

   b. Electronic games.

   c. Physical sports games

   d. Other (not fitting easily into any of the above categories.

   Use this activity to promote a discussion about whether a game can fit into more than one category, what is a game, is a puzzle a game, what makes a game fun, can a game be fun for one person and not for another, and so on.

2. Engage students in a discussion about what they have learned and other ways in which they have benefited by playing the various types of games from the list developed in (1).

3. Have each student select a game that they have played, and suggest some changes in the game that would make it more fun, or a better social experience, or a better learning experience. Encourage students to think outside the box. For example, is a game such as Monopoly more or less fun if one roles one die instead of a pair of die in making a move. How about rolling three dice to make a move? How about rolling three dice and selecting the two that add to the smaller total, and that is one's move. How about using a 12-sided die (is there such a thing)?

4. Lead your students in a brainstorming session about what it might mean to think outside the box. After your students reach a reasonable level of agreement on what this term means, engage them discussing the extent to which schools and parents place a lot of emphasis on thinking inside the box.

5. Talk with your students about cognitive maturity. Help them to develop examples in which one makes use of their cognitive maturity. Do whole class brain-storming on ways to increase one's level of cognitive maturity.

Chapter 2:

Background Information

> Men occasionally stumble over the truth, but most of them pick themselves up and hurry off as if nothing ever happened. (Sir Winston Churchill)
>
> A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty. (Winston Churchill)

This book is about some roles of games in informal and formal education. Many people see Games-in-Education as an opportunity to help improve our educational system. Others see the difficulties and downsides of using or increasing the use of games in education. (See the two quotes from Winston Churchill at the beginning of this chapter.)

For many people, games are intrinsically motivating. Educational research tells us that intrinsic motivation contributes substantially to learning. From an educational point of view, the issues are what does one learn through playing games, how does this learning relate to helping students achieve agreed upon goals of education, and what roles should teachers and other mentors play?

This chapter provides some background that will help us explore some possible roles of games in improving our informal and formal educational systems.

Types of Games Considered in this Book

In this book, the word *game* is taken to include both electronic and non-electronic games and puzzles. Many games are playable both in a computer mode and a non-computer mode. For example, many solitaire card games and Poker games require only a standard 52-card deck. Many of these can also be played on a handheld electronic game device, a game machine, or on a computer. In this book, the term *computer game* is taken to include all electronic games, whether they are played on inexpensive battery powered handheld devices, game machines, computers, or computer networks such as the Web.

The 84-page document *The use of computer and video games for learning* (Mitchell and Savill-Smith, 2004) is a British government-funded review of the computer game literature. The following quote from this document helps to define the words *play* and *game*.

> First, **play**: something one chooses to do as a source of pleasure, which is intensely and utterly absorbing and promotes the formation of social groupings (Prensky 2001, page 112). Fun, in the sense of enjoyment and pleasure, puts us in a relaxed receptive frame of mind for learning. Play, in addition to providing pleasure, increases our involvement, which also helps us learn (Prensky 2001, page 117).
>
> …
>
> Second, a **game**: seen as a subset of both play and fun (Prensky 2001, page 118). A game is recognised as organised play that gives us enjoyment and pleasure (Prensky 2001). Dempsey et al. (1996, page 2) define a

> game as: …a set of activities involving one or more players. It has goals, constraints, payoffs and consequences. A game is rule-guided and *artificial in some respects*.

The Mitchell and Savill-Smith document draws upon the work of Prensky (2001). Four chapters of that book can be accessed free on the Web.

The Mitchell and Savill-Smith survey of the literature is oriented toward learning and educational values of games. This may help explain the mention of learning that appears in the definition of play. As I think about this, I am reminded of a statement I have heard many times—that the "job" of young children is to play.

Here is another definition:

> Garris et al. (2002) define game play as "voluntary, nonproductive, and separate from the real world" (p.459). On the other hand, Jones (1999) points out that **for some people, computer and video games are real and sometimes, they are more engaging than reality**. Computer games can be categorized as adventure games, simulation games, competition games, cooperation games, programming games, puzzle games, and business management games (Hogle, 1996, citing from Dempsey et al., 1993; Jacobs & Dempsey, 1993). During the past 40 years, computer games have been played from a floppy disk, CD-ROM, with the use of email, or online through the Internet. Computer games can be played individually, against the computer, or against other people face-to-face or on-line. (Asgari & Kaufman, n.d.). [Bold added for emphasis.]

Notice the bolded statement in the above definition. For many people, games are attention grabbing and attention holding. They are intrinsically motivating, and they may be addictive. This is an important idea to keep in mind as you explore possible roles of Games-in-Education. I am interested in how games can be used to improve education. At the same time, I am fully aware that games can damage a person's education and other aspects of their life. For example, it is well known that gambling games have seriously damaged or destroyed many lives!

Here is another quite useful way to think about games (Costikyan1994):

> Games provide a set of rules; but the players use them to create their own consequences. It's something like the music of John Cage: he wrote themes about which the musicians were expected to improvise. Games are like that; the designer provides the theme, the players the music.
>
> A game is a form of art in which participants, termed players, make decisions in order to manage resources through game tokens in the pursuit of a goal.

My doctorate is in mathematics. Thus, it is not surprising that I pay particular attention to games that have been developed to help teach mathematics. For the most part, the examples that I have studied tend to have both poor attention-grabbing characteristics and poor entertainment value. They do not compete with games that children chose to play for entertainment. However, a later part of this book will explore some math games.

Goals of Education

Education has many goals, and each person tends to have their own ideas as to what constitutes a good education. David Perkins' 1992 book *Smart schools: Better thinking and learning for every child,* contains an excellent overview of education and a wide variety of attempts to improve our educational system. He analyzes these attempted improvements in terms of how well they have contributed to accomplishing three basic and enduring goals of education.

The following list of educational goals is an extension of his work.

1. **Acquisition and retention of basic, important, knowledge and skills.**
   There is considerable agreement that reading, writing, arithmetic, speaking,

listening, and information retrieval are basic and important for all students. Even then, however, there is disagreement about ways to achieve these goals in a cost effective manner that has a very high probability of success. There is less agreement on what students should learn in the fine and performing arts, health, science, social science, physical education, and other commonly taught disciplines.

2. **Understanding of one's acquired knowledge and skills.** *Understanding* tends to be difficult to define and measure. However, there is considerable agreement nowadays that education must proceed far beyond rote memorization.

3. **Active use of one's acquired knowledge and skills.** This includes being able to transfer one's learning to new settings, and being able to analyze and solve novel problems. We expect our educational system to:

    a. Provide challenging and rigorous programs of study designed to help each student become a literate, responsible, creative adult citizen.

    b. Help each student learn to learn, learn to take responsibility for their own learning, understand his or her capabilities and limitations as a learner, and to develop persistence and other lifelong habits of learning.

    c. Help each student learn to help others learn. In this, it is helpful to think of each student as a teacher. For example, students often help each other and their siblings to learn, and parents spend a lot of time working with their children in "teacher" mode.

    d. Help each student learn to cope with technological, social, and other forms of change that will be occurring during his or her lifetime.

This book explores a variety of games in terms of how they contribute to achieving the types of goals listed above. You will note that these goals are quite general—they do not speak to students gaining knowledge and skill in specific disciplines. In that sense, these goals fit in well with a student gaining in cognitive development and cognitive maturity.

However, learning in specific disciplines is an important aspect of getting a good education. There is quite general agreement that students should gain a substantial level of expertise in reading, writing, math, science, and social science. Many people support the idea that all students should acquire knowledge and skill in using calculators and computers as a general aid to problem solving. Even within these disciplines, however, there are considerable differences of opinion as to what students should learn and how they should demonstrate their knowledge and skills.

Games-in-Education as a Discipline of Study

The field of education can be divided into many different disciplines. Similarly, the field of games and gaming can be divided into many different disciplines. This book explores some of the overlap between education and games. As illustrated in Figure 2.1, the overlap can be thought of as a discipline called Games-in-Education.

Figure 2.1. Venn diagram illustrating Games-in-Education.

The Games-in Education discipline received increased legitimacy in October of 2003 when the Massachusetts Institute of Technology announced an initiative to study educational roles of computer games (Games-to-Teach Project, n.d.). Many colleges and universities now offer undergraduate and graduate degree programs in computer games.

Games-in-Education is a large and rapidly growing discipline. This book provides a limited introduction to some of the important ideas in this discipline.

Expertise

It is useful to think about learning in terms of how it contributes to increasing one's level of expertise in a discipline or in some particular more limited area. Figure 2.2 shows a general-purpose expertise scale.

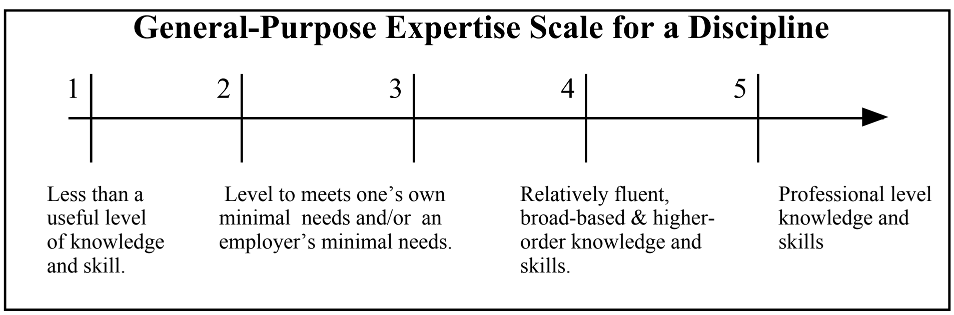


Figure 2.2. Expertise scale.

The words *expert* and *expertise* do not mean the same thing. From an informal and formal education point of view, through training, education, and experience, a person can gain increased expertise in a particular area. If the person has an appropriate level of natural ability and works long enough and hard enough at increasing his or her expertise in an area, the person develops a high level of expertise. If this level is sufficiently high, the person may be considered to be an expert. In comparing experts in a discipline, we sometimes talk about someone as being a national expert or world-class expert.

There has been substantial research on the natural ability, education and training, perseverance and determination, time and effort, and so on that it takes for a person to gain a very high level of expertise. As a rough rule of thumb, it takes 10,000 to 15,000 hours of hard work spread out over about 10 years to "be all you can be" in a particular area.

For example, consider a six-year-old girl who seems to have the physical ability to become a good gymnast, ice skater, or swimmer. Twelve years later, this girl (now a young woman) competes in the Olympics. She has probably put in about 10,000 hours achieving her current level of skill. She has had excellent coaches and training facilities for a good part of this time.

Many years ago I earned a doctorate in mathematics, and began to write papers that were accepted for publication in refereed journals and to work with doctoral students. I had probably put in 12,000 hours achieving my PhD level of mathematical research expertise. I was good, but by no means world class.

After completing my doctorate, I became interested in writing books to support my teaching interests. I have authored or co-authored about 40 such books. I estimate that I have spent more than 20,000 hours writing—developing, honing, and using my writing skills.

Chess players ranked in the top 10 in the world are likely have put in 15,000 to 30,000 hours or more gaining their chess skills. In 2006, the average age of the top 10 players in the world was about 30 years. People who play chess at this level usually put in well over 2,000 hours a year developing, honing, and maintaining their chess skills.

Benjamin Bloom (probably best known for Bloom's Taxonomy) was the editor of a 1985 book *Developing Talent in Young People*. The authors of this book studied 120 people in six different disciplines who rose to world-class levels. The time they had spent in their specialty areas varied somewhat with the specialty. The pianists who were identified and studied had a mean age of about 23 when they achieved world-class stature. On average, they had been begun taking piano lessons at age 6.

I find it interesting to compare these numbers with the amount of formal schooling that students receive in K-12 education. K-12 education in the United States is about 14,000 hours in length. Estimates are that only about 1/2 to 2/3 of this time is actually used productively. However, we can add to the total the time that is productively spent on homework and informal educational activities. Thus, we might conclude that the focused, productive time students spend in K-12 education is about the amount of time it takes for a person to develop a high level of expertise in a narrow discipline such as chess, gymnastics, math, piano, or swimming.

Bloom's analysis of young people achieving at a world-class level provides many examples of students doing well in school while putting in a thousand or more hours per year in their specialty area. This requires careful scheduling of time and a high level of sticking to the task. The single mindedness of purpose and high standards that these young people deal with tend to be very helpful in later careers.

K-12 formal schooling time is divided among a substantial number of different discipline areas that are taught in various schools around the country. Many of these disciplines have national standards that have been developed by professional societies and other groups. See, for example, the lists provided by the Mid-continent research for Education and Learning at http://www.mcrel.org/standards-benchmarks/.

The research data on how long it takes a person to achieve their potential in a discipline can be compared with data on how much time our K-12 schools are able to devote to teaching various discipline areas. Suppose, for example, that a school system places a very strong emphasis on reading and writing, with two hours per school day just in this area. This means that a student would get about 4,600 hours of formal schooling in this area during K-12 education. Suppose, at the same time, the school system devotes an hour a day to math. This amount to about 2,300 hours in total.

This sort of analysis suggests why college education is so helpful. It also suggests why schools tend to focus so much attention on the "core" basics, and downplay or eliminate the "frills." I hear many people say:

> How could we possible let a student who is struggling in math and reading spend any significant amount of school time on art, music, sports, or games? At the current time, many people are saying, "If it isn't on the state or national tests, then we should not be wasting school time on it. We need to spend all of our school time getting students to meet the state and national standards. We need to do a lot better in international competitions in the areas of these standards."

Indeed, there are continuing demands to increase the length of the school day and the length of the school year.

Two of the things missing from the above (in my opinion, quite short sighted) point of view are each individual student's intrinsic motivation, and striving to meet individual needs and interests of individual students. Intrinsic motivation and striving to meet the individual needs of different students are two of the most important ideas in education. The basics are important. However, there are many other important educational goals that are not on the state and national tests. A few examples include:

1. Learning to learn and to help others learn; learning about one's strengths and weaknesses as a learner.
2. Learning to work both individually and collaboratively with a team on a large, long, challenging project.
3. Learning for transfer of learning.
4. Learning to improve one's creativity.
5. Learning that helps increase one's level of cognitive development and cognitive maturity.
6. Learning to make effective use of new aids to solving problems and accomplishing tasks, such as computer modeling and other aspects of Information and Communication Technology.
7. Learning to make use of all of the above in doing things—developing products; doing performances and presentations; solving challenging, complex problems; and accomplishing challenging, complex tasks.

There are many ways to approach these important educational goals. This book presents ways in which Games-in Education can help.

Competition, Independence, Cooperation

Each game can be analyzed from a point of view of its:

- Cooperation/collaboration .
- Independence (not cooperative, not competitive) ,
- Competition leading to the determination of winners and losers.

Of course, a game may have components falling into each of the categories. Sometimes, it is not easy to decide which categorization best describes a particular game.

Let's use a crossword puzzle from the morning newspaper as an example. Suppose I work alone (independently) doing a crossword puzzle. I am not competing "head-to-head" with anybody, and I am not cooperating with anybody.

Later in the day, I might talk to a friend who also does the crossword puzzle from the same morning newspaper. We might talk about how hard or easy the puzzle seemed to be. We might talk about how long it took us to complete the puzzle, or how many clues we were unable to decipher. We might even discuss a particular clue, in a cooperative effort to figure it out.

Thus, we see how the independence of puzzle solving can be modified to being somewhat competitive and/or somewhat cooperative. Moreover, a social interaction dimension can be added to the overall activity. Often such social interaction can be considered as being cooperative/collaborative in nature.

Some games have a strong social interaction characteristic. This can be seen in many board and card games that children play. Many people play Bridge or Poker mainly for the social interaction. However, Bridge and Poker can also be played as highly competitive games. Thus, one might analyze a social Bridge-playing or Poker-playing event both in terms of its cooperation (for social purposes) and its competition (who wins; who loses).

The idea of independence is worthy of further exploration. Suppose I am a recreational bowler. I bowl alone, but I keep a careful record of my scores. Thus, I can tell if I am doing better, about the same as, or worse than I have in the past. This can be thought of as me competing with myself. However, in my opinion that is a poor use of the idea of competition. Competition is a win-lose situation.

This is a very important idea in education. Suppose education is considered as a type of game that is designed for independence, rather than for competition or cooperation. As a learner, my goals might be to learn, to get better at learning, to learn to use my learning, to better myself, and so on. I take satisfaction in the process of learning, in having learned, and in using what I have learned.

However, it is very helpful to have measures (for my own personal use) of how well I am doing. Am I a better reader than I was last month? Do I understand quadratic equations better than I did a week ago? Can I sight read music and play it on a piano better than I could two years ago?

Moreover, keep in mind that each person is different, and that there are quite large differences in abilities, interests, drive, and so on. I may well want to have some information about what others are doing and able to do, but my focus in upon myself as a learner. In some sense, I want to "be all I can be."

As an example, consider learning to keyboard for input to a computer. Personally, I can keyboard much faster than I can handwrite or print, and my keyboarded materials are far more legible than my handwriting or printing. Moreover, keyboarding in a word processing environment is a great aid to my writing, as the spell checker and grammar checker find many of my errors, and the word processor aids my in my revision efforts. From time to time, I feel a certain amount of envy of people who can keyboard faster and more accurately than me, or who are better at spelling. In essence, however, keyboarding for me is neither competitive nor cooperative. My (independent) expertise in keyboarding is at a sufficient level to be a great aid to achieving my writing goals.

Contrast independence this with a competitive model of education. The competition can be with other students, or it can be with "norms" that have been established for various state and national tests. The learner's goal becomes one of winning.

- "I got the top score in our class on this test!"
- "I am the best speller in my school!"
- "I am the fastest keyboarder at my grade level in our school!"

Another type of competition is scoring high enough to meet some specified requirements.

- "I have passed both the reading and math tests required for graduation!"
- "I scored high enough on my SATs to get into an Ivy League school!"

Still another way to look at competition-independence-cooperation is to consider competition versus cooperation. Competitiveness is a genetic characteristic, and all people are competitive. However, people vary considerably in the nature of their competitiveness, and competitiveness is strongly influenced by one's home environment, community environment, and culture.

Moreover, research suggests that males (on average) are more competitive than females. Put another way, the research suggest that on average, females are more cooperative/collaborative than males.

Knowing this, how should we design our educational systems? Research in education supports the cooperative/collaborative approach over the competitive approach. This research indicates that designing schooling along cooperative/collaborative approaches is more effective than designing them along competitive lines. See the three quotes given below:

> It takes Kohn an entire book to summarize the massive data indicating that competition in our society is harmful. Yet, our culture proclaims (without adequate supporting data) just the opposite, that competition is efficient, healthy, and fun. Actually, hard research data documents that people achieve more if they work cooperatively with others (than if they work competitively). We are so brainwashed, we find that hard to believe. (Think of it this way: trying to do your best is very different from trying to beat everyone else.) On the other hand, we can readily accept that a competitive job, school, or social situation, where someone wins by making others fail, causes dreadful stress, resentment of the winner, contempt for the losers, low self-esteem, and major barriers to warm, caring, supportive relationships. What is the solution? Kohn recommends replacing competition with cooperation, i.e. working together, assuming responsibility for helping each other do our best, and uncritically valuing each other's contributions. We need lots of research to help us to know when and how to reduce our competitiveness. To change our goals in life from competition to cooperation, we need new values and a new philosophy of life (see chapter 3). Competition implies a hierarchy; cooperation implies equality. (Tucker-Ladd, 2000)

> Gorriz and Medina (2000) also examined children using computer games, finding that girls prefer collaboration, non-closure and exploration, and games that require both thought and puzzle-solving skills while boys prefer competition. (C.O.P.E.,n.d.)

> Despite a recent surge of popular journalistic books (e.g., Fillion, 1997; Simmons, 2002; Tanenbaum, 2002), academic interest in competition among women was almost nonexistent until the 1980s. Initial research (Gilligan, 1982; Goodwin, 1980; Lever, 1976) found that girls tended to avoid competition in favour of tactics that diffuse conflict and preserve interpersonal harmony. When competition is made inevitable, girls used apologies and excuses to mitigate their behaviour (Hughes, 1988) or "double voicing" to promote their

> own cases while simultaneously taking into account the positions of their rivals, thereby preserving their relationships (Sheldon, 1992). This attenuation of competition in favour of sustaining positive relationships is thought to reflect socialisation into cultural norms against the overt expression of conflict among females (Miner & Longino, 1987; Tracy, 1991) and the greater centrality of intimate friendships to girls than to boys (Brown, 1998). (Campbell, 2004)

Here is a brief summary of this section:

1. With a little effort, a person can find games that meet his or her interests in or orientation toward competition, independence, and cooperation. There are lots of games in each category, and many games have overlapping characteristics.
2. If we think about our overall educational system as a game, we can see competitive, independence, and collaborative aspects of this game. In many cases, we can see a mismatch between the characteristics that an individual student desires and the characteristics that our educational system forces on the student.
3. The field of Games-in-Education can contribute to creating a school environment that better fits the individual competition-independence-collaboration needs of students.

Learning to Learn

While some people learn faster and better than others, we are all quite good at learning. We are all lifelong learners.

There has been quite a bit of research on how to help students learn faster and better. Somewhat surprising to me is that this is an area in which our educational system **has not** done a good job of translating theory into practice. You might test this out on yourself. Can you name any research that educators have done in the past two decades that specifically focuses on how to help students learn faster and better? Can you point to specific school wide and school district wide curriculum designed to help students learn to make use of these research results?

For example, metacognition and other reflective practices are very important in learning. Research indicates that even preschool age children can learn to do metacognition and can learn to reflect on their problem-solving and other activities. Are such metacognitive and reflective practices a routine part of the teaching/learning in schools that are familiar to you?

As another example, consider the fact that the Web is now the world's largest library, and that most students have access to the Web. Just because one has access to the Web does not mean that one has gained the knowledge and skills to make effective use of this global library as an aid to solving problems and accomplishing tasks. Moreover, this library is quite different than a static, print material based library. It is dynamic, with a significant portion of its content changing over the course of a day. This library is interactive, and a significant part of its content is in the form of "I, the computer, can do it for you." A search engine, for example, does a tremendous amount of work for the person making a search. The Web provides access to many computer programs that are designed to solve certain categories of problems. Relatively few students are learning to learn and solve problems in this environment.

As a third example, consider computer-assisted learning and distance learning via the Internet. While these modes of teaching and learning are growing in importance, few students are receiving explicit instruction on how best to make use of these aids to learning. Individual students are not learning whether or how well such teaching/learning environments fit their individual needs.

For a final example, consider the idea of self-assessment and of becoming an independent, self-sufficient learner who takes responsibility for his or her own learning. If anything, our current educational system seems to be moving away from this idea. Certainly, our schools could be doing a much better job of empowering students.

Situated Learning and Transfer of Learning

Situated learn and transfer of learning are two important components of the discipline called **learning theory** (OTEC, n.d.).

Situated Learning

Brown, Collins, and Duguid (1989) is a seminal article on situated learning. Quoting from the introduction to this paper:

> The breach between learning and use, which is captured by the folk categories "know what" and "know how," may well be a product of the structure and practices of our education system. Many methods of didactic education assume a separation between knowing and doing, treating knowledge as an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used. The primary concern of schools often seems to be the transfer of this substance, which comprises abstract, decontextualized formal concepts. The activity and context in which learning takes place are thus regarded as merely ancillary to learning pedagogically useful, of course, but fundamentally distinct and even neutral with respect to what is learned.
>
> **Recent investigations of learning, however, challenge this separating of what is learned from how it is learned and used. The activity in which knowledge is developed and deployed, it is now argued, is not separable from or ancillary to learning and cognition. Nor is it neutral. Rather, it is an integral part of what is learned. Situations might be said to co-produce knowledge through activity. Learning and cognition, it is now possible to argue, are fundamentally situated.** [Bold added for emphasis.]

Situated learning is a learning theory focusing on the situation or environment in which a particular learning activity occurs. For example, suppose that you are walking down a jungle path and you hear a particular sound that your brain/mind does not immediately recognize. You “freeze,” carefully look around, and see a large snake.

Your brain/mind recalls that a friend of yours was seriously injured several weeks ago by a snake, and the description the friend gave seems to fit this snake. You immediately learn that the sound you have heard in this jungle trail environment is associated with a dangerous snake. Likely, this learning will last a lifetime. Moreover, the learning occurs very quickly—this is apt to be an example of one-trial learning.

Contrast this with being a student sitting in a classroom that is in a large school located near your home. You live in a large city, and there are few or no dangerous snakes within miles of your home. You are viewing a video discussing dangerous snakes. You see and hear video of approximately the same scene as the jungle walker. However, the room you are in is hot and stuffy, you have just had lunch and you are sleepy, and the audio is turned up too high for your ears. What do you learn, and how long does this learning stay with you?

One of the reasons why a game can be a good learning environment is that the game player is immersed in the environment (the situation) of the game. The attention grabbing and attention holding characteristics tend to shut out distractions.

Low-Road/High-Road Transfer of Learning

The low-road/high-road theory of learning has proven quite useful in designing curriculum and instruction (Perkins and Solomon, 1992). In low-road transfer, one learns something to automaticity, somewhat in a stimulus/response manner. When a particular stimulus (a particular situation) is presented, the prior learning is evoked and used. The human brain is very good at this type of learning.

Low-road transfer is associated with a particular narrow situation, environment, or pattern. The human brain functions by recognizing patterns and then acting upon these patterns. Consider the situation of students learning the single digit multiplication facts. This might be done via work sheets, flash cards, computer drill and practice, a game or competition, and so on. For most students, one-trial learning does not occur. Rather, a lot of drill and practice over an extended period, along with subsequent frequent use of the memorized facts, is necessary.

Moreover, many students find that they have difficulty transferring their arithmetic fact knowledge and skills from the learning environment to the "using" environment. One of the difficulties is recognizing when to make use of the memorized number facts. In school, the computational tasks are clearly stated; outside of school, this is often not the case.

This helps to explain why rote memory is useful in problem solving, but critical thinking and understanding are essential in dealing with novel and challenging problems. It also supports the need for broad-based practice even in low-road transfer. We want students to recognize a wide range of situations in which some particular low-road transfer knowledge and skills is applicable.

Math education in schools tries to achieve an appropriate balance between rote memory and critical thinking by making extensive use of word problems or story problems. In word problems, the computations to be performed are hidden within a written description of a particular situation. The hope is that if a student gets better at reading and deciphering word problems—extracting the computations to be performed and the meaning of the results—that this will transfer to non school problem-solving situations.

It turns out that it is quite difficult to learn to read well within the discipline of mathematics. Many students have major difficulties with word problems and with learning math by reading math textbooks. Their depth of understand of math and their ability to read math for understanding stand in the way of their being able to deal with novel, challenging math problems that they encounter.

High-road transfer for improving problem solving is based on learning some general-purpose strategies and how to apply these strategies in a reflective manner. The *build on previous work strategy* is an excellent candidate to use to begin (or, expand) your repertoire of high-road transferable problem-solving strategies. To do this, think of a number of personal examples in which you have used this strategy as an aid to problem solving. Mentally practice what you did in each case. In the near future, each time you make use of this strategy, consciously think about its name and the fact that you are using it. Also, in the future when you encounter a challenging problem, consciously think through your repertoire of high-road transferable problem-solving strategies. Your goal is to increase your ability to draw upon this repertoire of aids to use when faced by a challenging problem.

The *break it into smaller pieces strategy* is another example of a high-road transferable strategy. This strategy is often called the divide and conquer strategy, and that is the name that will be used in the remainder of this book. It is helpful to have short, catchy names for strategies. A large and complex problem can often be broken into a number of smaller, more tractable problems. It is likely that many of your students do not have a name for the strategy and do not automatically contemplate its use when stumped by a challenging problem.

Here is a summary of some key ideas in problem solving. Suppose you are faced by a problem. Then your approach might be:

1. If the problem fits a memorized pattern in which you can apply stimulus/response, low-road transfer, your mind/body may react automatically and the problem may be quickly solved.
2. If (1) is not successful, think about the domain or general discipline of the problem and whether you have encountered the problem or a quite similar problem in the past. If you have specific knowledge and skills relevant to the problem or problem areas, draw upon this contextual, situational knowledge and skill in a conscious and considered manner to attempt to solve the problem.
3. If (2) is not successful, draw upon your general knowledge and skills in how to attach a new, challenging problem. Here, a large repertoire of high-road transferable problem-solving strategies is helpful.

Figure 1.3 illustrates these three approaches and provides an indication of how fast each may be in a particular situation.

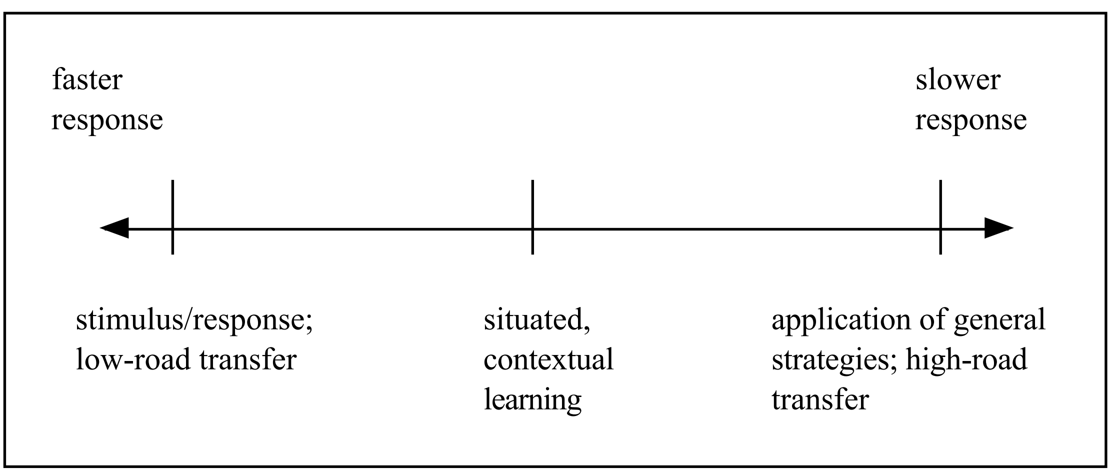


Figure 1.3. Often used approaches to problem solving.

In our exploration of strategies, we will emphasis teaching and learning for high-road transfer within the games domain and to other domains. Here is a strategy for such teaching and learning:

1. Identify the generalizable strategy that is being illustrated and used in a particular problem-solving situation.
2. Give the strategy a name that is both descriptive and easily remembered.
3. Working with your students, identify a number of different examples in other disciplines and situations in which this named strategy is applicable.
4. Have students practice using the strategy in a variety of areas in which it is useful, and where students have appropriate general and domain-specific knowledge.
5. In your everyday teaching, you will frequently encounter situations in which a particular problem-solving strategy is applicable, and you have previously helped your students gain some initial expertise in using the strategy. Take advantage of such situations by clearly naming the strategy (or, asking your students to name the strategy) and working with your students to refresh their memories on use of the strategy in a variety of situations.

Learning in a Game Environment

Think about your roles as a parent, teacher, or other adult figure facilitating a child learning to play a game and then playing the game. What might you do to increase the child's cognitive, social, emotional, and kinesthetic growth in a manner that will transfer to other games and to non-game environments? As you think about this, you will realize that Games-in-Education is a very challenging discipline!

You know that for a child, learning to play a game and them playing the game are closely interconnected. Indeed, much of the learning occurs during the playing. This is a good example of a learn-by-doing, hands on learning environment. The learning is in context (situated learning). The learning is immediately useful, contributing to being able to play the game and/or to play the game better.

This is sort of an immediate gratification situation. Contrast it with the delayed gratification that is common in most formal schooling. Many students are not impressed by statements such as: "You need to learn this so that you can use it in your course next year" or "Your need to learn this because it will be on the test next week."

Teachers understand the gratification issue. They recognize the value of having students immersed in a combination of learning and doing. This ties in closely with discovery-based learning. Thus, many teachers try to create learning environments in which students make immediate use of their new learning. However, this is a challenging educational problem, and often teachers do not succeed very well in meeting this challenge.

For example, suppose that students are learning how to solve a particular type of math problem. Their use of this new knowledge and skill consists of doing a whole bunch of this type of problem. Contrast this with a student learning a new type of chess opening (that is, sequence of opening moves) and then immediately using it in a chess game against an appropriate opponent. The new opening is used in the context of playing the overall game, and it adds to the fun of playing the game. It becomes part of the chess player's repertoire of openings. The chess literature contains detailed analyses of thousands of different chess openings. A good chess player is apt to have memorized a large number of opening sequences.

Think for a minute about the opening move in competitive game such as chess or checkers, and the opening sentence in a piece of writing. There are many different types of writing situations. While rote memorization of a range of first sentences might be helpful, a much better approach is to understand the various types of writing situations and what one is trying to accomplish in an opening sentence in these different situations. Thus, you can see that the writing challenge is much more complex than the opening move challenge.

Moreover, if you teach writing, you may see that we have raised an interesting topic you can discuss with your students. Rote memorization is quite useful in improving one's skill as a chess player. How useful is it in improving one's skill as a writer? When playing a game such as chess, one gets relatively quick feedback on how well one is doing. Contrast this with the feedback situation in writing. This line of thinking suggests to me that it is very important for writers to learn to provide immediate feedback to themselves. As a writer, I also know that delayed feedback from others is also essential to improving the quality of a document that I have written.

Precise Vocabulary and Notation

Figure 1.4 shows a chessboard. Notice that the columns (the files) of the 8 x 8 board are lettered a, b, … h, and the rows (the ranks) are numbered 1, 2, … 8. In chess, the person playing the White pieces always moves first. The lettering and numbering notation used to identify the spaces on the board is convenient and natural from the point of view of the person playing the White pieces.

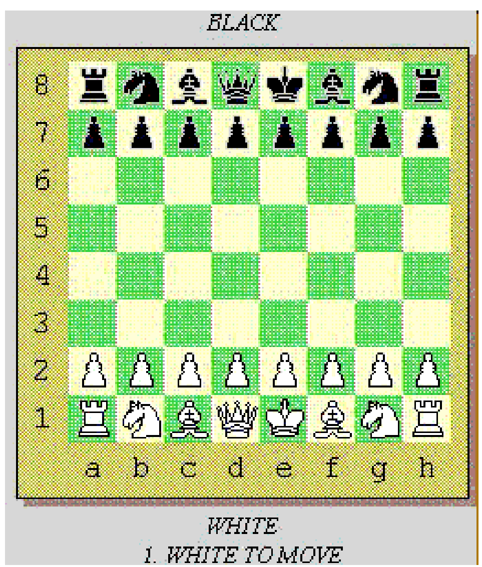


Figure 1.4. Lettering of columns and numbering of rows.

The names of the pieces are abbreviated as follow: K=King, Q=Queen, R=Rook, B=Bishop, N=Knight, and P=Pawn. This board coordinate system and the piece name abbreviations make it quite easy to record all of the moves in a game. For example, here are the first few moves of a game. The listing indicates that White's Bishop captures Black's Knight on White's fourth move.

1.	Pe4	Pe5
2.	Nf3	Nc6
3.	Bb5	Pa6
4.	BxN	

This, and other notational systems that are widely used in chess, allow players to precisely record the moves in a game (Calvin, n.d.). Such a written record can be used in writing about, talking about, and studying a game.

Keeping a detailed record of one's chess games and studying both one's own and other people's games is a strategy used to improve one's level of expertise in chess. Is this type of strategy applicable to other games? Is it applicable to non-game learning and problem-solving situations? Of course it is. So, let's give this strategy the name. Let's call it the *record one's moves strategy*. This is what a researcher does when conducting research in any field. Details of the research need to be precisely recorded so that the researcher and/or others can duplicate the experiment. Thus, it should be part of the repertoire of high-road transferable problem-solving strategies that you and your students routinely draw upon.

The *record one's moves strategy* helps to explain why each discipline tends to have some special notation and definitions of terms that are unique to the discipline. It is absolutely essential that people working in a discipline be able to accurately record the work they are doing so that it can be precisely communicated to others and to themselves. A novice in a discipline needs to learn the precise notation and vocabulary in order to take advantage of the accumulated knowledge in the discipline. That is, part of learning a discipline is to learn to read (for understanding) in the content area of the discipline.

Although our educational system places considerable emphasis on students learning to read in the content areas, this is such a challenge to readers that our schools do not experience a high level of success in the endeavor. Part of the process of learning to read in the content areas is to develop an understanding of what it means to read for understanding, and to be able to self-assess one's understanding. My analysis of research on reading in the content areas suggests that if a person gets good at reading in one content area, there can be substantial transfer of the "reading in a content area" skill to reading and learning to read in another content area.

A Few Important Research Findings

A Google search conducted 6/6/06 on

games OR gaming AND research AND education

produced about 167 million hits. Obviously, this search needs to be substantially narrowed! However, it suggests that many people are involved in conducting or writing about Games-in-Education.

Some parents and teachers feel that substantial and useful learning from games will occur merely through providing a child the opportunity to play games. However, Conati and Klawe (2000) indicate this is not sufficient:

> **These results indicate that, although educational computer games can highly engage students in activities involving the targeted educational skills, such engagement, by itself, is often not enough to fulfill the learning and instructional needs of students.** This could be due to several reasons.
>
> One reason could be that even the most carefully designed game fails to make students reflect on the underlying domain knowledge and constructively react to the learning stimuli provided by the game. Insightful learning requires meta-cognitive skills that foster conscious reflection upon one's problem solving and performance [2, 4, 24], but reflective cognition is hard work. [Bold added for emphasis.]

The Conati and Klawe research helps to make clear important roles of teachers when teaching in a computer game environment. See also Kirschner et al. (2006). With the aid of teachers, students can learn to be more reflective in such learning environments, and learning goals can be made more explicit. Students can be taught to do metacognition (thinking abut their thinking) and to use this reflective practice as an aid to their cognitive development.

Finally, to end this section, here is some quoted material about research on multiplayer, first person shooter (FPS) games. It is representative of some of the research on social aspects of multiplayer games.

> We argue that the playing of FPS multiplayer games by participants can both reproduce and challenge everyday rules of social interaction while also generating interesting and creative innovations in verbal dialogue and non-verbal expressions. When you play a multiplayer FPS video game, like *Counter-Strike*, you enter a complex social world, a subculture, bringing together all of the problems and possibilities of power relationships dominant in the non-virtual world. (Wright et al, 2002)

Final Remarks

Games have long been an important component of the lives of many children and adults. The advent of computer games means that on average, people spend much more time playing games now than in the past. In recent years, children in the United States have been spending more time playing electronic games than they have been spending watching television. It is generally believed that the combination of television and electronic games is having a negative impact on education because they compete for student attention and time. However, both television and games have educational values, so research in this area is not definitive.

The discipline of Games-in-Education is of growing importance in both informal and formal education. The research literature on the design and use of educational games—especially electronic games—is growing. We know that people learn from whatever situation or environment they experience. By combining ideas from situated learning theory and transfer of learning, we can learn how to make better educational use of games.

Activities for the Reader

This section contains some questions and activities for the person reading this book. Some are designed for people who are taking a workshop or course using materials from this book. The individual reader working alone may also find many of the questions and activities to be useful.

1. Think back to your own game playing experiences. Make a list of some of the things that you learned through this game playing.
2. Give some examples of games that you have played that you considered fun. Use these examples to explain what, for you, what makes a game fun.

3. Are there any games that you have played in both computer and non-computer mode? If so, select one and do a compare and contrast of the playing experience and learning experience.
4. Spend some time observing children playing some games. Write a brief report about what you observe going on. The report should include some conjectures about the learning that you think is occurring.
5. This chapter contains a discussion of opening moves in chess versus opening sentences in writing. This discussion illustrates a type of transfer of learning from game playing to writing. Find and discuss another example of transfer of learning from games to a core academic subject.

Activities for use with Students

This section contains some ideas for use with students. It is assumed that the teacher, parent, or other person making use of these suggestions will adjust the activities to fit the needs of the students.

1. What are some games that are fun to play? Engage an individual student or a group of students in a brainstorming activity designed to make a long list of games that they have played and enjoyed. As the list is being created, divide its items into three categories:
   a. Board games, card games, and other types of non-electronic games that are not organized sports.
   b. Electronic games.
   c. Organized sports.

   Use this activity to promote a discussion about whether a game can fit into more than one category, what is a game, is a puzzle a game, what makes a game fun, can a game be fun for one person and not for another, and so on.
2. Engage students in a discussion about what they have learned by playing a particular game that they have found useful in playing some other game or that they have found useful in a non-gaming situation. This might begin with an oral discussion and then lead to a written activity in which each student answers the question. During the oral discussion, introduce the terms *transfer of leaning* and *metacognition,* and help the students add these important concepts to their vocabulary. Transfer of learning is one of the most important ideas in education, and metacognition (including reflection) is a key aspect of learning.

Chapter 3

Sudoku: A Puzzle

In this book, we consider a puzzle to be a type of game. A puzzle is problem designed to challenge one's brain and to be entertaining. Many people spend part of almost every day working on crossword puzzles, Bridge or chess puzzles, number or word puzzles, and the other types of puzzles printed in daily newspapers and in a variety of magazines. They enjoy the challenge and the feelings of success as they solve the problem or accomplish the task presented by the puzzle. You can learn about a number of different puzzles at http://en.wikipedia.org/wiki/Puzzle.

> **Note to Teachers:** My belief is that every person is a teacher. Some do it as a profession, while others do it merely as an everyday part of their lives. I am a teacher who writes books. One of my teaching strategies is to try to get the reader to take an active part in their own learning. The previous paragraph provides an example of this. Why should I spend my writing time and effort trying to duplicate the good work that someone has already done and made available free in the Wikipedia? (Perhaps you are not familiar with the Wikipedia. It is a free encyclopedia where all of the entries have been contributed for free use, and readers can edit the entries.) Moreover, suppose you click on the link and begin to read about puzzles. There is a good chance you will find some information that seems particularly interesting to you, and you will follow up on it. Your learning will be driven by intrinsic motivation. You will be learning because you want to learn. Great!

A Game Without an Opponent

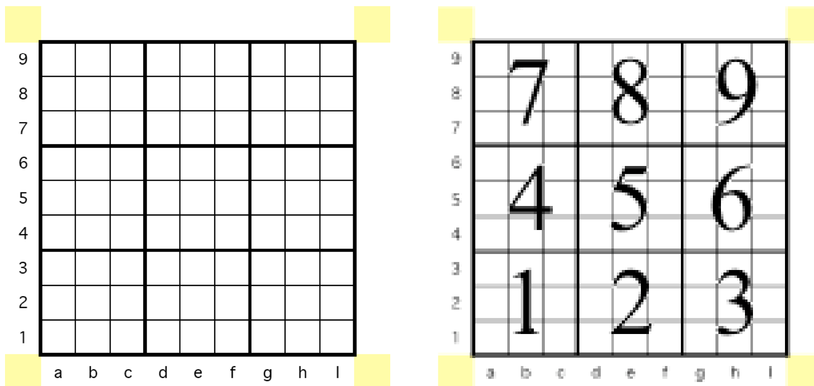
Chapter 1 contains a discussion of competition, independence, and cooperation. Most puzzles fall into the middle category; they are neither competitive not cooperative. Of course, if you like to take a competitive view of almost everything, you can think of a puzzle as a game in which you are competing against yourself. You are trying to solve a challenging problem or accomplish a challenging task. Typically, you are doing this for fun—because you want to. You ask yourself question such as:

- Do I have the knowledge, skills, and persistence to solve this specific puzzle? (For example, perhaps you are looking at a crossword puzzle. Some are much more difficult than others.)
- Am I enjoying spending time solving this puzzle? (Perhaps you are looking at a Rubric's Cube. From previous experience, you know that you get little or no enjoyment in trying to solve such spatial puzzles.)
- Am I getting better at solving this type of puzzle? (If you do jigsaw puzzles or crossword puzzlers frequently, you will get better at doing such puzzles.)
- How good am I (in solving this type of puzzle) relative to other people?
- Am I learning anything by solving this puzzle. (Perhaps you wonder if this brain exercise is good for your brain.)

- Why am I spending so much time "playing" with the puzzle, when I could be doing other, more productive, work. Puzzles, like other types of games, can be addictive. Am I addicted?

Introduction to Sudoku

In the remainder of this chapter, the Sudoku puzzle is used to illustrate various aspects of learning to solve a puzzle and increasing one's level of expertise in solving a puzzle. Figure 3.1 illustrates the playing board. The coordinate system is similar to that used in chess. It helps us to communicate precisely about the location of each of the 81 spaces on the board. Notice that the



board is divided into nine 3x3 regions, numbered 1 through 9.

Figure 3.1. Sudoku board grid and nine regions

Figure 3.2 illustrates an actual puzzle.

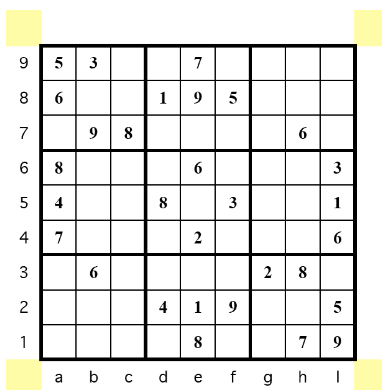


Figure 3.2 An example of a Sudoku puzzle.

A specific puzzle is specified by the set of *givens* entered onto the board, as illustrated in Figure 3.2. The goal (the problem) is to enter a numerical digit from 1 through 9 in each empty space of the 9x9 grid so that:

- Each of the nine regions region contains all of the digits 1 through 9.
- Each horizontal row and each vertical column contains all of the digits 1 through 9.

The rules or goal of this puzzle are very simple. Solving the puzzle does not depend on having knowledge of math or any other subject. Indeed, the puzzle might just as well make use of nine different letters from the alphabet or nine different geometric shapes. Sudoku is not a math or a word puzzle.

A 4x4 Example and a High-Road Transferable Strategy

In this chapter, we will explore the 9x9 Sudoku puzzle. However, there are 4x4, 16x16, and other variations on this puzzle.

Just for fun, try solving the two 4x4 Sudoku puzzles given in Figure 3.3. These two puzzles are the same, except that one uses digits and one uses letters. Notice that it is assumed that you can make up a correct goal (an appropriate set of rules) for these puzzles. That is, without any help from your author, you can transfer the rules of this game from a 9x9 board to a 4x4 board.

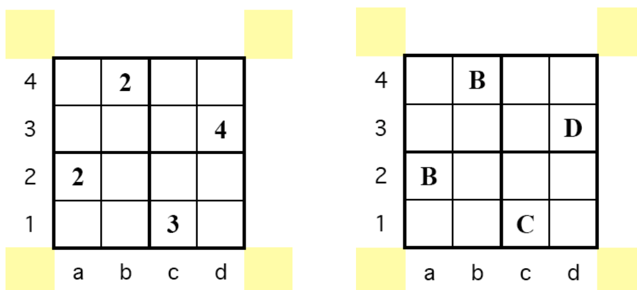


Figure 3.3. Two identical 4x4 Sudoku puzzles, one using digits, one using letters.

The chances are that you will decide that the 4x4 Sudoku puzzle is too simple to be much of a challenge for you. However, it might well be a challenge for young children.

In addition, it illustrates a very important aspect in problem solving. If a particular problem seems too difficult for you, try to create a simpler version of the problem or create a closely related problem that is not as difficult. The process of creating and solving a simpler version or a related problem may well give you insights that will help you to solve the more complex problem.

Throughout this chapter we will be looking for general strategies for problem solving that are applicable over a wide range of problems. The goal is to have you add each of these to your repertoire of high-road transferable problem-solving strategies. By the time you finish reading this chapter, you may well have significantly improved your general problem-solving skills. Moreover, you may well have developed some teaching strategies that will be very valuable to your students.

Let's name our newly discovered strategy the *create a simpler problem strategy*. The strategy has several purposes. It may help you to better understand the original problem. Solving the simpler problem may help you gain insights that will help you solve the more complex problem. If your simpler problem is carefully chosen, solving it will contribute to solving your original problem.

To add *create a simpler problem* to your repertoire of high-road transfer strategies, you must identify and consciously explore a number of examples that are meaningful to you. High-road transfer involves identifying a number of examples that are meaningful to you.

This requires reflective thinking. Here is a personal example. When I write a book—such as this one—I am not able to just sit down and write the whole book in a linear fashion. Indeed, I cannot even produce an outline that stands a decent chance of actually fitting the final product. To get started, I set myself a much simpler problem. I use a word processor to record my ideas as I brainstorm possible goals, audience, and content for the book.

I then set myself the problem of ordering my brainstormed set of ideas into a somewhat logical, coherent order. During this process, I throw out some ideas and add some new ideas.

I then set myself another simple problem—to develop a short summary and a set of references for some of the topics that seem particularly important. I can solve this problem off the top of my head and by use of the Web. In the process of solving it, I get some new ideas to add to my original brainstormed list. I may well rearrange the order of the brainstormed list, and I may well through out some of the items in the list.

Okay, now it's up to you. As you explore your own examples, think carefully about how you will help your students to learn this strategy. Make up some examples of the sorts that may be particularly relevant to them. Think about how you will help them to find personal examples. Think about how the sharing of such personal examples in class may help all members of the class find additional personal examples.

Metacognition

The next two sections are diversions, seemingly leading us away from solving the 9 x 9 Sudoku puzzle of Figure 3.2. However, we will return to this puzzle after the diversions.

A puzzle provides a situated learning environment. While some puzzles require considerable knowledge from outside the puzzle environment, others require very little outside knowledge. The Sudoku puzzle requires the player to be able to recognize and distinguish between each of nine different symbols. However, it does not depend on being able to read or to do math.

Even before we begin studying the Sudoku puzzle in some detail, you can do some introspection or metacognition (thinking about your thinking) as you are first faced by this problem-solving puzzle situation. Here are some questions that might help you learn more about yourself:

1. What are your personal feelings and thoughts as you first encounter a puzzle—especially, a puzzle of a type that you have not previously attempted to solve?
2. For you, personally, do you think digits, letters, or geometric shapes would be easiest for you in a Sudoku puzzle? Why?
3. Think about some non-Sudoku puzzle that you have solved or attempted to solve in the past. Was this an enjoyable experience? Did you develop a reasonable level of expertise with this puzzle? How much time and effort did it take you to develop your current level of expertise with this puzzle? Do you feel you are close to your upper limit in how good you can get in solving this type of puzzle?

The metacognitive questions given above are all stated in the context or situation of learning to solve a type of puzzle. However, they are applicable to learning how to solve problems in any discipline. That is, the questions represent a set of ideas that are applicable as one studies problem solving in any new discipline.

This is a very important idea. For many people, recreational puzzles represent a relatively non-threatening learning environment. Within this environment, you can learn about yourself as a learner. You can see yourself making learning gains, moving from an absolute novice to a person with an appreciable level of skill. In many puzzle-solving situations, you can see appreciable gains in expertise over a relatively short time.

Metacognition is an important aid to learning to solve problems in any discipline. It can be called the *metacognition strategy* for learning to solve problems. Think about the idea of high-road transfer of metacognition to the study of other types of problems. What is unique about puzzle problems that does not readily transfer to other types of problems? What is there about puzzle problems that transfers to other types of problems?

As you struggle with proving answers to these types of questions, think about your students being faced by the same issues and struggles. What can you do, as a teacher, to help your students learn to routinely use the metacognition strategy?

Is the Puzzle Problem Solvable?

Suppose you are now thinking about how to get started in solving the puzzle in Figure 3.2. Perhaps you spend some time looking at the puzzle, checking to see if the givens in any region, row, or column already violate the solution requirement that each row, column, and region must contain the digits 1 to 9. If the givens in a row, column, or region already contains two copies of a digit, then these givens cannot be part of a solution to the puzzle. That is, the puzzle that has these givens has no solution.

This is an important observation (a **Big Idea**!). For many people, the term problem means a math problem that has exactly one solution. However, a problem may have no solution, one solution, or more than one solution. Moreover, every academic discipline contains problems.

Solvability is an important issue in problem solving, and it is usually poorly taught in our precollege educational system. To help illustrate this, it may well be that you believe that every math problem has exactly one solution. Your goal, when faced by a math problem, is to "get **the** right answer."

Think about each of the following simple math problem examples:

1. Find a positive integer that, when multiplied by itself, gives the integer 16. This problem has exactly one solution.
2. Here is a slight modification of the problem. Find an integer that, when multiplied by itself, gives the integer 16. This problem has exactly two solutions
3. Next, consider the similar problem: Find an integer that, when multiplied by itself, gives the integer 15. This problem does not have a solution.
4. Here is a slight change in the unsolvable problem. Find a number that, when multiplied by itself, gives the integer 15. This problem has two solutions, and they are both irrational numbers.

5. Another slight change to the problem opens up the idea of imaginary numbers. Find a number that, when multiplied by itself, gives the integer minus 15 (that is, –15).
6. Now, here is still another math problem. Find two integers that, when added together, give the integer 12. With a little though, you should be able to convince yourself that this problem has an infinite number of solutions.
7. Here is a slight modification of this problem. Find two integers that, when added together, give the number 11 ½. Now the problem has no solution. Can you prove this?

I hope that by now you are convinced that even a quite simple problem may be unsolvable, may have exactly one solution, may have more than one but still a finite number of solutions, or may have an infinite number of solutions.

In summary, this section introduces a problem-solving strategy called the *explore solvability strategy*. When faced by a challenging problem, think about whether the problem is solvable. Spend some time exploring the idea that the problem might not be solvable, or that it might have one or many solutions. Think about the idea that if the problem has more than one solution, then perhaps one solution is better in some sense than another solution. What are criteria for a "good" solution? Work to understand the problem so that you can tell if you are making progress toward developing a solution.

You should spend some time adding this strategy to your repertoire of high-road transfer problem-solving strategies. Begin by finding some examples that are personally meaningful to you. Then spend some time developing ideas on how you will go about helping your students learn this strategy. One approach is to routinely expose your students to problems that look like the others they are studying, but that are unsolvable or have more than one solution.

Getting Started in Solving the Puzzle

Finally, we are now ready to begin start solving the Sudoku puzzle given in Figure 3.2. You should now be suspicious that perhaps the puzzle has no solution, or perhaps it has more than one solution. You might want to do a quick check of the givens to see if it is obvious that the puzzle has no solution. However, you should be aware that even if the set of givens do not make a row, column, or region with two copies of one of the digits 1-9, this still does not tell us whether the puzzle is solvable or whether it has more than one solution.

Let's pretend that I am an absolute novice in solving Sudoku puzzles. I stare at the puzzle for a while. My eyes tend to go to the upper left region, Region 7.

Within this region, for some reason my eye catches on the empty space b8. I think to myself: "This empty space needs to contain one of the digits 1-9. Right now, the digit 1 is not in Region 7. What happens if I place a 1 into the space b8? The result is shown in Figure 3.4.

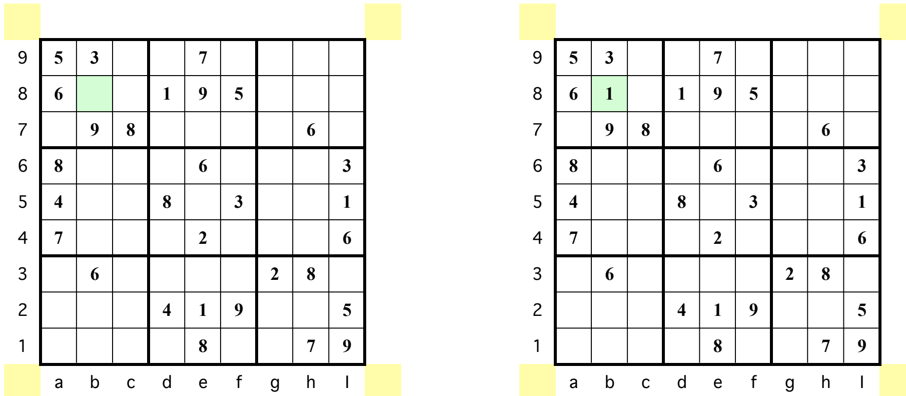


Figure 3.4. Trying a “1” in space b8.

Placing a 1 into space b8 is a step in the direction of having all nine digits in Region 7. However, you can now see that Row 8 in which I have inserted the digit 1 already contains a 1. Thus, the move is a mistake—a move that cannot lead to solving the puzzle. I have just used the *guess and check strategy.* I made a guess based on the information that currently the digit 1 does not appear in Region 7. I checked the result by looking at the row and column in which I placed the 1.

In many problem-solving situations, the guess and check strategy can be used mentally, without actually making a move. In Figure 3.4, it is easy to make the proposed move in my mind’s eye, and then to do the checking in my mind’s eye. That is, I don’t have to physically write a 1 into space b8 in order to “see” that this will make Row 8 have two 1s. Undoubtedly you have heard the expression: “Look before you leap.” That is an admonition to do a visual/mental check of possible results before taking an action.

In addition, it a problem-solving strategy. That should be part of your repertoire of high-road transfer problem-solving strategies. This strategy goes by other names, such as *engage brain before opening mouth* strategy Please spend some time thinking about how to help your students add this strategy to their repertoire of general problem-solving strategies.

Persistence and Self-confidence

We still haven’t made any progress in solving our Sudoku puzzle. Let’s try another approach. We are still examining the space b8. Figure 3.5 shows all possible moves that are not eliminated by a quick consideration the current entries in row 8, column b, and cell 7. That is, Figure 3.5 illustrates a start on an exhaustive search approach to filling in space b8 after making a quick mental elimination of obviously incorrect choices.

9	5	3			7				
8	6	2,4,7		1	9	5			
7		9	8					6	
6	8				6				3
5	4			8		3			1
4	7				2				6
3		6					2	8	
2				4	1	9			5
1					8			7	9
	a	b	c	d	e	f	g	h	I

Figure 3.5. Some possible moves in space b8.

Aha! I am beginning to see why a Sudoku puzzle can be a mental challenge. I stare at cell 7, and I mentally contemplate various possibilities. For example, I might mentally contemplate leaving the 7 in space b8, and putting placing the 2 and 4 as shown in Figure 3.6.

9	5	3	4		7				
8	6	7		1	9	5			
7	2	9	8					6	
6	8				6				3
5	4			8		3			1
4	7				2				6
3		6					2	8	
2				4	1	9			5
1					8			7	9
	a	b	c	d	e	f	g	h	I

Figure 3.6. Continuing a mental trial.

Now, if my mind's eye (mental image) is working well enough, I see that my contemplated sequence of moves is incorrect, since the situation that has emerged is that I will need to place a 1 into space c8, and that will mean that there are two 1s in row 8.

If my working memory (short-term memory) is good enough, I might well make my way through this maze of possibilities. In attempting to do so, I will be exercising my working memory and other parts of my brain. With practice, I will get better at this aspect of attempting to solve a Sudoku puzzle.

An alternative is to step back a little. Think of my first trial as being an exploration of cell 7. After putting quite a bit of effort into this exploration, I did not experience much (if any) success.

I could quit right now—just give up, and claim, "I am too dumb to learn to solve Sudoku puzzles. Probably this puzzle does not have a solution. Anyway, who cares?" Alternatively, I can persist, try a different cell to explore, and perhaps discover another strategy that might be helpful.

Think about this situation from a teaching/learning point of view. Many of our students have become convinced that they cannot learn to solve complex problems. They have learned that it is much easier to say, "I can't do it." than it is to persist, continue to learn, and continue to make incremental progress.

Persistence and self-confidence are two important characteristics of good problem solvers. Think about your own levels of persistence and self-confidence as a learner and as a problem solver. What might you do to improve your levels of these two characteristics? What might you do as a teacher to help your students increase their levels of persistence and self-confidence?

Games provide one possible piece of an answer to the question. As a teacher, parent, older sibling, and so on, you can use games to create challenging learning and problem-solving environments in which a learner gets an opportunity to gain in persistence and in self-confidence. With proper help from you, the learner can transfer these gains in persistence and self-confidence to other learning and problem-solving situations.

The Elimination Strategy

I will not give up! I am ready to select another region to explore in the Sudoku puzzle shown in Figure 3.2. As I explore the board, this time my eye catches on Region 5, and the empty space in the exact center of the board. The combination of Region 5, Row 5, and Column E has a lot of givens. Indeed, mentally or with the aid of pencil and paper I quickly discover that each of the digits 1-9 except the digit 5 is in the set of givens for the combination of Region 5, Row 5, and Column E. Thus, e5 has to be a 5. My first success! See Figure 3.7.

9	5	3			7				
8	6			1	9	5			
7		9	8					6	
6	8				6				3
5	4			8	5	3			1
4	7				2				6
3		6					2	8	
2				4	1	9			5
1					8			7	9
	a	b	c	d	e	f	g	h	I

Figure 3.7. Space e5 correctly filled in.

We have just discovered and used the *elimination strategy*. In exploring the space e5, we eliminated as many possible moves as we could. It turned out to be easy to eliminate all but one possible move. The elimination strategy is a good one to add to your repertoire of high-road transferable problem-solving strategies.

Continuing with my somewhat inane personal examples, in the morning when I get up I am faced by the problem of what to wear. I have a number of long sleeve shirts, and a number of short sleeve shirts. Thus, depending on the day's expected temperature, I can quickly eliminate about half of my shirts from consideration. I also have a number of dress shirts and a number of non-dress shirts. I can quickly eliminate one of these categories by thinking about whether this is a work or non-work day. These two eliminations greatly simplify my selection problem.

Here is a somewhat more complex example of using the elimination strategy. I am faced by the problem of obtaining some up to date information on a topic that will be in the book I am writing. A little thought eliminates from consideration my own personal knowledge and the books in my personal library that I have read. I also quickly eliminate all of the books and journals in the physical library on my campus, since I am at home and I want a quick solution to my problem.

This line of elimination and thinking leads me to doing a Google search on the Web. Unfortunately, my search produces about a million hits. That is, Google tells me that it may have found as many as a million sources of the information that I seek.

I definitely need to do some more elimination. I can narrow my search—for example, I can increase the number of terms in my search strategy. However, I thought carefully in developing my original search terms, and so it is not easy to narrow the search.

An alternative approach, one that I most often use, is to explore the brief descriptions of the first half dozen hits. This uses a guess and check strategy. If one catches my eye as possibly being relevant (a good guess), I go to the Website and browse it.

If this Website does not meet my needs, I will browse a couple more of the top numbered hits. In this guess and check process, I will be gaining information that will help me to narrow or reformulate my search. If none of the hits I browse meet my needs, I may decide to eliminate all million of the hits found by Google, and formulate a new search.

Finally, let's go back to our Sudoku puzzle. Notice that there are now only two blank spaces in Column E. Using the elimination strategy, you see that these must contain the digits 3 and 4. By a mental guess and check you easily arrive at Figure 3.8

9	5	3			7				
8	6			1	9	5			
7		9	8		4			6	
6	8				6				3
5	4			8	5	3			1
4	7				2				6
3		6			3		2	8	
2				4	1	9			5
1					8			7	9
	a	b	c	d	e	f	g	h	I

Figure 3.8. Two more successful moves in Column e.

Keep working on this puzzle. (Hint: Cell f3 looks like a fruitful cell to explore.) Pay careful attention to the strategies that you use. Each time you use one of the strategies named in this chapter, make note of this fact. This is a good way to solidify strategies in your repertoire of high-road transferable problem-solving strategies. If you use a strategy that has not been discussed earlier in this chapter, explore its for possible inclusion in your repertoire of high-road transfer problem-solving strategies.

Final Remarks

If you had not previously worked with a Sudoku puzzle, you have now learned the rules and practiced a little in solving a puzzle. You can now see that our goal is to use games and puzzles as a vehicle to help students get better at problem solving and to address other important goals in education.

Using a discover-based approach, we discovered some very important things that apply to problem solving in all disciplines. These include some high-road transferable general problem-solving strategies:

- Create a simpler problem
- Explore solvability
- Guess and check (also named look before you leap)
- Elimination

Researchers have found that the typical student has a quite small repertoire of general-purpose strategies that may be applicable when faced by a new, novel problem. In just a few minutes, we "discovered" four such strategies while exploring the Sudoku puzzle. Through appropriate teaching, students can add these to their repertoire of high-road transfer problem-solving strategies.

Strategies and strategic thinking are part of the more general topic, computational thinking. All of the strategies listed above can be carried out by a thinking human being. Two of them are well suited to implementation in computer programs. Thus, both the human and the computer aspects of computational thinking are represented. In subsequent chapters, we will explore computational thinking in more detail.

Many people enjoy learning new puzzles precisely because it provides them an opportunity to discover strategies that are particularly powerful in the puzzle. However, educational researchers tell us that relatively few people automatically transfer such strategies to use in other puzzles and to solving real world problems. Explicit teaching (by a teacher, or by the learner) is a major help in overcoming this difficulty.

Activities for the Reader

1. Many popular puzzles and games are available in handheld, battery powered, electronic format. Use the Web to see the features of competing models for generating and playing Sudoku puzzles, and how much they cost.
2. Go to the Web and find a puzzle that you have not previously "played" or tried to solve. Explore the puzzle using techniques somewhat like those illustrated in this chapter's exploration of Sudoku. Do metacognition and reflect on the learning experience. If this is a written assignment, keep detailed notes on the overall activity and then use them to support doing the written assignment.
3. Think about how you, personally, deal with novel, challenging problems that you encounter. Do you have any strategies that you tend to use frequently, and that are often effective? (Have you thought about the possibility of sharing this strategy with your students?) Do you have any strategies that you tend to use frequently, and that are seldom or almost never effective? (Have you thought about the possibility of helping your students to discover some of their personal ineffective strategies?
4. Suppose that you have a textbook that you have used before, and you want to look up something in it that you are fairly sure is in the book. What strategies

do you use? Are these strategies applicable to looking up information in other types of books? Are they applicable to looking up something on the Web?

Activities for use with Students

1. Talk to several children to learn whether they can tell you some general-purpose strategies that they use when faced by novel problems. In the process, include a focus on whether the children have vocabulary (such as the word *strategy*) useful in carrying on the conversation and in thinking about how they approach novel problems. Also, focus on problems from many different disciplines—not just math problems or math exercises.
2. Working with a group of students, such as a whole class, determine how many are familiar with Sudoku. If quite a few are familiar with this puzzle, then have the Sudoku-experienced class members teach the game to the others, working in one-on-one or in very small groups instruction mode. If few are familiar with the puzzle, teach it to the class. Make use of your Sudoku-knowledgeable students as aides to help the other students as they work on a puzzle. Then debrief this learning experience with the whole class. Direct the conversation so you gain increased insight into students helping students, students being helped by students, and the overall student experience in learning and playing with this puzzle.
3. Select one of the general high-road transferable problem-solving strategies discussed in this chapter. Use it to explain the meaning of high-road transfer of learning to your students. Engage them in gaining the knowledge and skills to do high-road transfer of this strategy. Do whole class brainstorming on type of problems in which this strategy might be applicable. For example, when trying to write a sentence that contains a word a student does not know how to spell, guess and check might be a useful approach. The "check" might come from looking at the spelled word ("It seems to look right."), from use of a dictionary, or from use of a spelling checker on a computer. Repeat this activity once a week for a number of weeks, teaching other strategies from this chapter or from your own repertoire of high-road transferable problem-solving strategies.

Chapter 4

More Puzzles

This chapter broadens our exploration of educational puzzles. It includes:

1. Discussion of some educational goals of puzzles.
2. Some good sources and examples of free puzzles.
3. Exploration of some additional high-road transferable, general-purpose aids to problem solving.

Goals for Using Puzzles in Education

Historical, culturalLearning abut oneself [Bold added for emphasis.]

There are many reasons why puzzles are used in informal and formal education. Here are eight somewhat general goals that one might have in mind while introducing a student to a particular puzzle. As you read through this list, pause from time to time to reflect on whether the ideas being presented are supportive of the general educational goals of your school and school district.

1. Historical, cultural. The puzzle may have historical and cultural significance. For example, parents and grandparents may want their children and grandchildren to learn some of the puzzles that they played during their own childhoods. Teachers may want to share some the puzzles from their childhood with their students. Particular puzzles may be common in a town or larger region; for this reason, they might commonly be included in a school's curriculum. In a school setting, students might study the history of a puzzle or set of puzzles; this can include the history and cultural environment in which a puzzle was invented.

   It is easy to see how "Historical, cultural" goal fits in with general goals of education. Indeed, puzzles and games can provide a historical thread that has meaning to children and adults of all ages.
2. Logical thinking and problem solving. Most puzzle solving requires use of logical thinking and one's problem-solving skills. Solving puzzles often requires strategic and creative thinking. Especially with some mentoring help, students can transfer their increasing puzzle-based logic and problem solving to other situations.
3. Discipline or domain specificity. Many puzzles are discipline specific, and may well require knowledge and skills in a specific domain within a discipline. A word puzzle may be particularly good at "exercising" a

student's spelling and vocabulary skills, while a math puzzle may be good for practicing mental arithmetic, and a spatial puzzle may be useful for improving one's ability to visualize the spatial placement and movement of objects.

4. Persistence and self-sufficiency. Many puzzles require a concentrated and persistent effort. The puzzle solver is driven by intrinsic motivation and develops confidence in his or her abilities to face and solve challenging problems. Improving persistence and self-sufficiency are important educational goals.
5. Learning about oneself as a learner. A puzzle environment allows one to explore one's learning characteristics. Many games and puzzles allow the learner to get started and experience some success after just a little learning, and then to continue to experience much more success through additional learning. Students learn how concentrated effort and practice over a period of time leads to increased expertise.
6. Peer instruction. Children learn many puzzles and games from other children. Learning to learn from one's peers and learning to help one's peers to learn are both quite important educational goals.
7. Individualization of instruction. Puzzles and games can be used to help create differentiated instruction, where the focus might be independent, cooperative, or competitive activity.
8. Busy work or pure entertainment. Puzzles are often used at school and home to keep students occupied or entertained. The teacher or parent has no particular educational goal such as those listed above, but merely wants to keep the student occupied and out of mischief. Teachers and parents make such uses of puzzles and games as aids to classroom and home child management. Use of ideas from this book can help improve the educational value of such activities.

Teachers thinking of making increased use of puzzles in their classrooms should think carefully about the list of possible goals given above. They might well want to add to the list. For example, none of the goals mention the idea of individualization of the curriculum. Many puzzles come in a range of difficulties. Thus, the same general type of puzzle (such as Sudoku) comes in very easy versions and in versions that will challenge the brightest students.

Teachers should also think about the importance of novelty versus allowing students to use the same puzzle repeatedly. A puzzle may well provide a good environment for a student to learn some of his or her capabilities and limitations as a learner. This is a good goal. However, typically it is not appropriate to allow a student to use school time to play/solve the same puzzle or type of puzzle repeatedly, moving toward a very high level of expertise in the puzzle. Typically, it is better to involve students in the use of many different puzzles and to target learning goals such as the above list, rather than to have a goal of students achieving a very high level of expertise in a particular puzzle.

Free Puzzles

Many people generate and/or accumulate puzzles that they make available free on the Web. Some of the Web-based puzzles can be played on a computer, while others can be printed out and used in a paper and pencil mode. A recent Google search of "*free puzzle*" produced nearly a million hits. Many of these sites also offer free access to some games.

Here are four examples that attracted my attention:

1. Puzzle Choice: http://www.puzzlechoice.com/pc/Puzzle_Choicex.html. Provides free access to crossword, word search, number, logic puzzles, and Soduko.
2. AIMS Puzzle Corner: http://www.aimsedu.org/Puzzle/. Quoting from this site:

   The AIMS Puzzle Corner provides over 100 interesting puzzles that can help students learn to enjoy puzzles and the mathematics behind them. The puzzles are categorized by type, and within each category are listed in order of increasing difficulty. The puzzles have not been assigned a grade level appropriateness because we have discovered that the ability to do a puzzle varies by individual not grade level.
3. Free Puzzles: http://www.freepuzzles.com/. Provides access to a large and growing collection of puzzles. Categories include: puzzle games, puzzle links, geometry, logic, math, miscellaneous, weight, and moves.
4. http://perplexus.info/tree.php. This Website uses the following categorization terms for puzzles: logic, probability, shapes, general (includes tricks, word problems, cryptography), numbers, games, paradoxes, riddles, just math, science, and algorithms.

A Puzzle a Day …

If you are a teacher who believes in use of puzzles in your classroom, then you might think about accumulating enough puzzles so you can provide your students with a different one each day. A good starting point is the collection of puzzles at http://perplexus.info/tree.php listed above. During and/or right after you use a puzzle with your students, spend a couple of minutes writing notes to yourself about how well the puzzle was received by the students, what the students learned, and how to make use of the puzzle a better learning experience. Do this for a year and you will have written a book that you can share with your colleagues and that will be useful to you for years to come.

This suggestion is a good illustration of the divide and conquer strategy. For most people, writing a book seems like an insurmountable task. However, finding and using one puzzle, and then writing a few thoughts about the results, is an easy task. Do this 180 times and you are well along to writing a lengthy book. The http://perplexus.info/tree.php Website provides one way to categorize puzzles—that is, a way to organize the puzzles in your collection into coherent chapters in a book.

Free Does Not Necessarily Mean Free

Typically, Web sites that provide free puzzles and games make income to sustain themselves by:

1. Selling ads.
2. Selling games and puzzles.
3. Selling game and/or puzzle subscriptions or memberships.

Thus, as you browse Websites offering free puzzles or free games, use some care to avoid purchasing services or subscriptions that you really don't want to buy. In addition, many sites providing free games and puzzles want to add your email address to their email list and to sent you ads. You might decide to avoid all such sites—or perhaps paying in this manner does not bother you.

As you browse, looking for sources of free puzzles and other types of games, from time to time you will encounter excellent Websites that offer "no strings attached" free materials. Please share these with your friends. A steadily growing number of people are producing excellent Web-based materials that are made available free. This is a significant trend, and eventually it will have a major impact on our educational system. Imagine the impact on the educational systems of the world if high quality computer-assisted instruction materials were available free in many different languages and at all grade levels, to all people of the world!

The Websites that offer free puzzles vary tremendously in quality and quantity. I have spent quite a bit of time browsing some of these Websites, and the ones I specifically mention in this chapter are ones that caught my eye for some particular reason. Most of the sites I examined did not pass my informal "catch my eye" requirement. There are various reasons for this. Some are too commercial. In some, it is hard to find the free puzzles. In some, the free puzzles do not work correctly. In some, the amount of free materials is very limited. Some of the sites are limited in that the puzzles run only on a PC or only on a Mac.

Jigsaw Puzzles

Jigsaw puzzles come in many different levels of difficulty. A typical jigsaw puzzle has only one solution, but one can arrive at the solution in many different ways.

Incremental Improvement

The incremental improvement strategy is very useful in certain situation, such as in putting a jigsaw puzzle together. However, it often is a poor approach to problem solving, as will be illustrated later in this section.

Each piece that you correctly add to the completed part of the puzzle represents an incremental gain, an incremental improvement. If a jigsaw has only one solution, then the incremental improvement strategy will always succeed in solving the puzzle. Correctly joining any two pieces together is also an incremental step toward completing the puzzle.

If it is easy to tell an edge piece from a non-edge piece, then the divide and conquer strategy may be a good approach. Separate off all of the edge pieces. Than the original puzzle now consists of an "edge" puzzle and an "interior" puzzle. The edge puzzle contains less pieces than the whole puzzle and is likely a simpler challenge than the whole puzzle. After the edge has been completed, one then begins to assemble the interior, often by directly attaching interior pieces to the completed edge.

However, some jigsaw puzzles have some pieces that are exactly the same size and shape. The coloring and patterns in a puzzle may make it difficult or nearly impossible to decide if two pieces that seem to fit together actually belong together. This may lead to putting together a number of pieces that don't actually belong together. Backtracking (undoing pieces) may well prove to be an essential strategy in solving this puzzle. As with other strategies that we have "discovered" in this book, consider the *backtracking* strategy as a possible addition to your repertoire of high-road transfer problem-solving strategies.

Backtracking is a great topic to explore with your students. In writing, for example, "revise, revise, revise" is one of the key ideas to producing a good product. Revision is a form of backtracking. Similar statements hold for any project-based learning activity that leads to a product, performance, or presentation.

As another example, consider the situation in which you have said something that you did not really mean to say, or have taken an action that you did not really mean to take. In both cases, you want to backtrack—you want to make a revision of what you have done. While an apology or other attempts to undo your actions sometimes works, this is clearly not as easy or effective as making revisions to a paper you are writing.

There are many problem-solving situations in which incremental improvement is not a successful strategy. Take a look at the two dimensional hills in Figure 4.1. Starting at A, the goal is to climb to the peak at C. Incremental improvement, by moving in small steps steadily uphill starting at A, will not lead you to C. Instead, you will reach B, the top of a peak that is not as high as C.

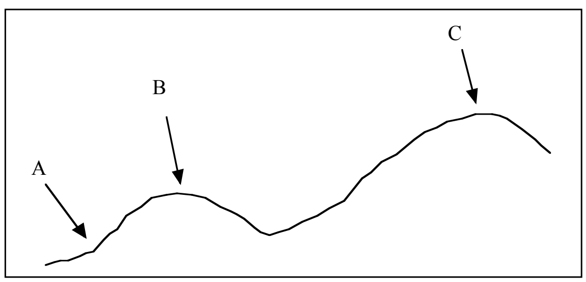


Figure 4.1. Incremental improvement (hill climbing) starting from point A.

If you are a golf sports fan, you know about Tiger Woods. Golfers are always trying to make incremental improvements in some part of their game. Tiger Woods decided that he needed to make a major change in his swing—he needed to backtrack, to unlearn the swing that had carried him to a high level of success. This backtracking and relearning eventually led to improving his game.

More generally, you should have little trouble identifying problem situations in you life or problem situations in the world where incremental improvement does little to solve a problem, and is often a waste of time and other resources. Probably you can quote several adages that are relevant, such as:

> Sometimes you have got to break it before you can fix it.
>
> Things may get worse before they get better.

In summary, there are some problems that can be solved by incremental improvement. Many real-world problems do not have this characteristic. One of the characteristics of an expert problem solver in a particular domain is the person's knowledge of which problem-solving strategies are apt to be successful. Another characteristic is having good insight into when to quit trying a particular strategy and switch to another strategy. These types of expertise tend to require many years of learning and experience.

Figure 4.2 given below is the same as Figure 3.8 from the Sudoku chapter. The three moves a7: 2; b8: 7; and c9: 4 can each be considered as an incremental improvement. Each increases the total number of spaces that have been filled in, and none produces a region, row, or column with a duplicate digit entry. Unfortunately, this sequence of moves is a dead end. The only remaining possible move into region 7 is c8: 1. This means that Row 8 would then have two 1s. We must backtrack in order to move forward.

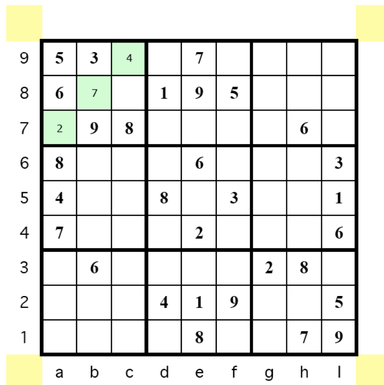


Figure 4.2. Incremental improvement in Region 7 leads to a dead end.

Online Jigsaw Puzzles

My Google search of *free online jigsaw puzzles* produced about 1.5 million hits. I was curious as to what I might find through this search, so I browsed a few dozen of these hits. See, for example, http://www.jigzone.com/.

Some free online puzzles are designed to allow and require rotation of pieces. My Google search of *free online jigsaw puzzles with rotation* produced about 274,000 hit. However, many of the online jigsaw puzzles do not have interlocking pieces.

Many of the online puzzles are designed to be solved just by sliding puzzle pieces right/left or up/down to their correct location, without any rotations. All of the pieces are displayed in their correct rotation for insertion by sliding without rotating. This greatly simplifies the complexity of a puzzle.

A slider puzzle can be thought of as a type of jigsaw puzzle in which there is a limited amount of open space for sliding pieces into. My Google search for *free slider puzzles* produced well over 1.6 million hits. See, for example, http://gotofreegames.com/slider_puzzle/free_slider_puzzle.htm. Solving this type of puzzle requires use of two dimensional special visualization skills. Spatial intelligence is one of the eight categories of Multiple Intelligences identified by Howard Gardner.

A major advantage of online jigsaw puzzles is that the pieces do not get lost—for example, they do not get chewed up by a pet or sucked up by a vacuum cleaner. Another advantage is that the same puzzle picture is often available at a number of different difficulty levels. A very young child may enjoy working with a six-piece version of the puzzle, while an older child may enjoy the challenge of a puzzle containing hundreds of pieces.

A disadvantage of online jigsaw puzzles is that many people like to work together with others when doing a jigsaw puzzle. One of my life's pleasures is working together with my wife as we do a jigsaw puzzle and listen to an audio book

Complexity of a Puzzle or Other Problem

Complexity is an interesting topic. What makes one puzzle more complex or more challenging than another? More generally, what makes one problem more complex or challenging than another? This is a good topic for discussion in any discipline that you teach. What makes one poem harder to understand than another? What makes one idea in science harder to understand than another? What makes one math problem harder than another? Unfortunately, this topic is usually not covered very well in most courses. Have you discussed it with the students you teach?

Before considering problem complexity in general, let's look at the simpler issue of jigsaw puzzle complexity. In doing this, we are using the strategy *create a simpler problem*.

What can we learn by studying the problem of what makes one jigsaw puzzle more complex than another? In discussing this problem, we will surely come up with ideas such as having more pieces tends to make a puzzle more difficult. If a puzzle has a very small number of pieces, the guess and check strategy can be quite effective.

We might well come up with the idea that if the pieces are easy to orient correctly (so that, after orientation, then can be placed into position without rotation) the puzzle is much easier than one where the proper rotation of each piece is a challenge. That is, we can think of orienting each individual piece as solving a number of smaller problems (the problem of orienting a piece); this contributes to solving the larger problem.

After further discussion, we might decide that the coloring or pattern of a puzzle makes a lot of difference. In some puzzles, the colors or patterns make it quite easy to sort pieces into groups that must fit near each other. This makes the puzzle much easier (because now one can solve smaller, simpler problems) than if such sorting is difficult or impossible.

If we are mathematically oriented, we might gather data on how long it takes a typical person to solve jigsaw puzzles of various sizes. For example, does it take four time as long to do a typical 200 piece puzzle as a typical 100 piece puzzle, and four times as long to do a typical 400 piece puzzle as a typical 200 piece puzzle? Or, perhaps the difficulty level triples for each doubling in size? The point is, one can do empirical research on this question.

Okay, we have now made good progress on studying the complexity of jigsaw puzzles. Next, the mental challenge is to take information about solving jigsaw puzzles, and apply it to studying the complexity of other types of problems. One problem is harder than another if it cannot readily be broken into smaller sub-problems. One problem is harder than another if it has many more choices—many more possibilities to try if one is using a guess and check approach. One problem is simpler than another if it can be solved by incremental improvement, while the other cannot.

Here is a quote that I thoroughly enjoy. In essence, it says that it is easier to write a long document than to write a short document.

> "I have made this letter longer than usual, only because I have not had the time to make it shorter." (Blaise Pascal, almost 400 years ago.)

Abraham Lincoln's Gettysburg Address provides an excellent example of where short was much better than long.

Water-Measuring Puzzles

Here is an example of a water-measuring puzzle:

> Given a 5-liter jug, a 3-liter jug, and an unlimited supply of water, how do you measure out exactly 4 liters?

Notice that the same problem can be stated using a different unit of measure.

> Given a 5-gallon jug, a 3-gallon jug, and an unlimited supply of water, how do you measure out exactly 4 gallons?

My Google search of *puzzle problem water measuring* produced nearly a million hits. There are many different water-measuring problems. According to Ivars Peterson, such problems date back to the 13th century (Peterson, 2003). Peterson's article gives additional examples and discusses some of the underlying mathematics of how to solve this type of problem.

Many problems can be solved by starting at a solution and working backward. Let's try this idea with the water-measuring problem given at the beginning of this section, where the goal is to measure out four liters. What are some ways to make the integer 4 that might be relevant to this problem?

a. $4 = 2 + 2$

b. $4 = 1 + 3$

c. $4 = 5 – 1$

From a working backward point of view, $4 = 2 + 2$ tells me that if I manage to get two liters into each jug, the problem is solved. The representation $4 = 1 + 3$ tells me that if I can get one liter into one of the jugs and three liters into the other, the problem is solved.

Suddenly, and **aha** strikes me. One of the jugs holds exactly three liters. So, if I can just figure out how to get one liter into the other jug, the problem is solved.

However, before thinking about how to do that, let's think about $4 = 5 – 1$. I know how to get five liters, but how do I get minus one liter? (Maybe I need to think outside the box? My mind gets confused as I try to think of a jug containing -1 liter of water. However, I can understand pouring one liter out of a jug, thus decreasing its contents by a liter. Pouring is like subtraction. Aha! If the 3-liter jug has two liters in it, then I could fill the 5-liter jug and pour from it until the 3-liter jug (that contains two liters) is full, thus leaving four liters in the 5-liter jug.

My two aha moments give me two approaches to solving the puzzle. In the first, I strive for getting one liter into the 5-liter jug. In the other, I strive for getting two liters in the 3-liter jug. Thus, by working backward using some simple arithmetic and keeping my brain in gear, I have formulated two new problems. If I can solve either one of them, I can then solve the original problem.

How do I measure out exactly one liter or exactly two liters? Using simple arithmetic skills, I see that $5 – 3 = 2$. With a flash of insight, I see that if I fill the 5-liter jug and pour into the empty

3-liter jug, I will end up with two liters in the 5-liter jug. I have now found a pathway to solving the problem.

The *working backwards* strategy is a powerful aid to solving many different kinds of problems. You will want to add it to your repertoire and your students' repertoires of high-road transferable problem-solving strategies. You and your students may at first find it challenging to find problems that are often solved by working backwards. Here is a hint of one source of such problems. You need to be at work at 7:30 in the morning. What time should you set your alarm for?

Spatial Intelligence

Almost all teachers are aware of Howard Gardner's work on Multiple Intelligences. His first book on this topic was published in 1983. Nowadays, many teachers pay attention to Gardner's work as they design and present instruction. The eight types of intelligences that Gardner has identified are (Gardner, 2003):

- Linguistic intelligence ("word smart"):
- Logical-mathematical intelligence ("number/reasoning smart")
- Spatial intelligence ("picture smart")
- Bodily-Kinesthetic intelligence ("body smart")
- Musical intelligence ("music smart")
- Interpersonal intelligence ("people smart")
- Intrapersonal intelligence ("self smart")
- Naturalist intelligence ("nature smart")

When I was graduating from high school, I took a variety of vocational aptitude tests. My spatial intelligence tested well below 100 on an IQ-type scale with a mean of 100. I want to share two parts of this story. First, I was advised that I should not attempt to major in math, as many people believe that math requires having good spatial sense. It turns out, however, that I had little trouble in undergraduate and graduate work in mathematics, making a straight A average in math courses as a earned a doctorate in this area. In my math studies, my strong logical/mathematical intelligence more than overcame my weak spatial intelligence

Second, I am terrible at finding my way when walking or driving around a city. Indeed, I can easily get lost in a large building! Even though I pay careful attention to this situation, I haven't improved. I partially overcome this difficulty by making careful maps and/or by carefully planning and using maps. I have a younger sister with a doctorate in physical chemistry, and she suffers the same spatial intelligence challenge.

Third, a few years ago, my wife and I began doing jigsaw puzzles together as we listen to audio books. At first, I was very poor at putting jigsaw puzzles together, and I was embarrassed by my ineptitude. Eventually, however, I got a lot better. I developed some jigsaw puzzle-solving strategies that fit well with some of my strengths, and my spatial abilities in the jigsaw domain improved with practice.

The third piece of the story is particularly relevant. One's expertise in an area can be increased by study and practice. If you have a researcher-oriented mind, perhaps your first question would now be: "Did my improvement in jigsaw puzzle spatial expertise transfer to other spatially oriented problem-solving domains?"

I don't know, as I did not gather data before beginning the jigsaw puzzle "experiment." My guess, however, is that I am as bad as ever at finding my way around in a city or large building.

What I do know, however, is that there has been considerable research on this general topic. Indeed, one of my doctoral students worked on this topic about 20 years ago. She was interested in whether playing spatially oriented computer games would help improve girl's general spatial abilities more than it improved boy's general spatial abilities. In her particular study, both girls and boys improved, but the girls did not improve more than the boys. A general discussion about spatial intelligence is available at http://www.brainconnection.com/topics/?main=fa/navspace-hippocampus.

Many video games require use of spatial memory. The following is quoted from Ranpura (n.d.):

> A tiny, pixilated soldier dodges past burning embers and ruined walls. His guide, a young boy watching through a computer monitor, knows that just ahead, beyond a darkened doorway and a hairpin left turn, the soldier will find a floating white medical kit to nourish and soothe his battered body. He will recharge, then navigate his way through an extensive labyrinth of corridors to the next level of the maze.
>
> The boy playing the video game nudges his joystick, guiding the soldier efficiently through countless rooms. He knows this virtual world well, and has an intimate understanding of its topography. In his mind's eye the bitmapped patterns and flashing lights become three-dimensional hallways, staircases, and doors.

Figure 4.3 illustrates a spatial puzzle named Assemble the Square that is suitable for use by students of all ages. The puzzle provides you with a number of pieces that can be dragged without rotation onto a 4x4 square, to exactly cover the square. The puzzle is available at http://www.vemix.com/GlFlashGm.php. The Website can generate a large number of different sets of pieces that can be assembled into a square.

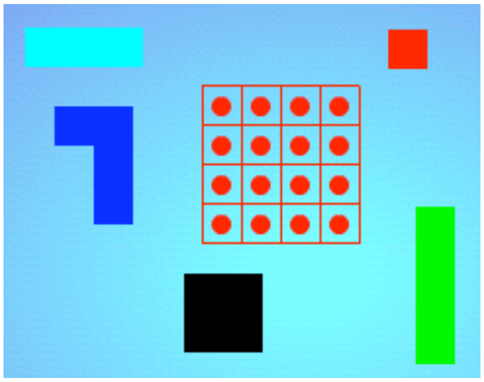


Figure 4.3. Five pieces to be dragged without rotation to form a 4x4 square.

Tower of Hanoi

The Tower of Hanoi puzzle consists of three pegs and a number of disks of different sizes that slide onto the pegs. The puzzle starts with the discs neatly stacked in order of size on one peg, smallest at the top, thus making a conical shape. See Figure 4.4.

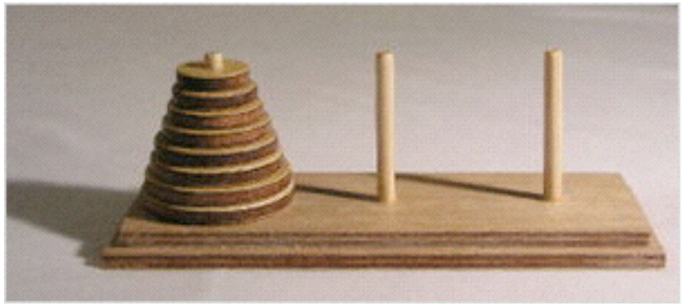


Figure 4.4. Tower of Hanoi puzzle,
http://en.wikipedia.org/wiki/Tower_of_Hanoi

The object of the game is to move the entire stack of disks to another peg, obeying the following rules:

- only one disc may be moved at a time
- no disc may be placed on top of a smaller disc

Mathematicians consider this as a mathematical game. They state and prove theorems about the solvability of this and similar puzzles. Children with no knowledge of the underlying mathematics enjoy the game.

Most people find the Tower of Hanoi puzzle somewhat overwhelming the first time they face it. Indeed, only those who are quite persistent do not give up after exploring (trial and error) for a few minutes.

However, this puzzle provides an excellent opportunity to try out one of most important general problem-solving strategies. It is called the *explore a simpler case* strategy. The idea is to create a simpler version of a problem that is close enough to the original so that solving the simpler problem gives one some useful insights into the original problem.

For an example, consider a Tower of Hanoi puzzle that has exactly three disks, and set yourself the goal of ending up with the three disks moved to the middle peg. Figure 4.5 is from the Website http://math.bu.edu/DYSYS/applets/hanoi.html, where one can set different sizes for the game and play it free on the computer.

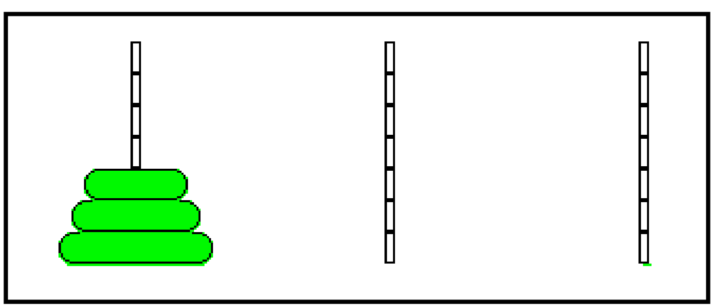


Figure 4.5. Three disk Tower of Hanoi puzzle.

The 3-disk puzzle is still somewhat of a challenge. Figure 4.6 shows an intermediate position in a sequence of moves leading to solving the puzzle.

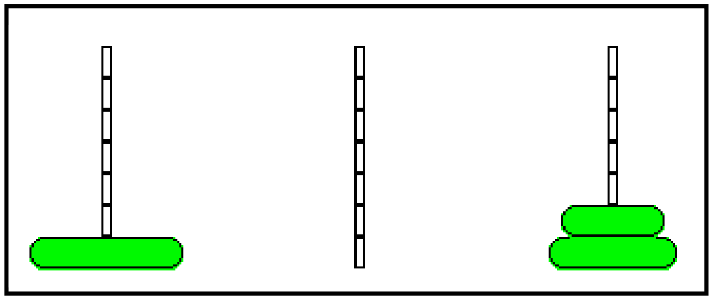


Figure 4.6. Position achieved after three moves.

Notice that I did not give you all of the details for solving the 3-disk puzzle. Instead, I pointed you in a right direction and left you to fill in the details. This is the way that many math books are written. The author discusses a particular theorem, aims you in a right direction, and leaves you to fill in the details. This approach is used because one of the goals is to help the reader get better at making proofs. One way to get better at making proofs is to fill in the steps that an author leaves out in presenting an outline of a proof. This is an example of the teaching and learning strategy *learn to fill in the details*.

I am hoping for an **aha** from you, my reader. One way to teach is to provide students with all of the details of how to solve a particular type of problem or accomplish a particular type of task. Students are expected to memorize the details, and then to practice over and over again, to develop speed and accuracy. A different approach is to present the general ideas and an outline of an approach. Students are expected to figure out the details for themselves. Notice the advantage of the second approach at some time in the future when a student makes a tiny error in remembering a procedure. Rote memory is useful, but it is a poor approach in many educational situations.

After completing the 3-disk puzzle, you might want to try 4-disk puzzle. Figure 4.7 illustrates a possible intermediate goal that you might work toward in attempting to solve this puzzle.

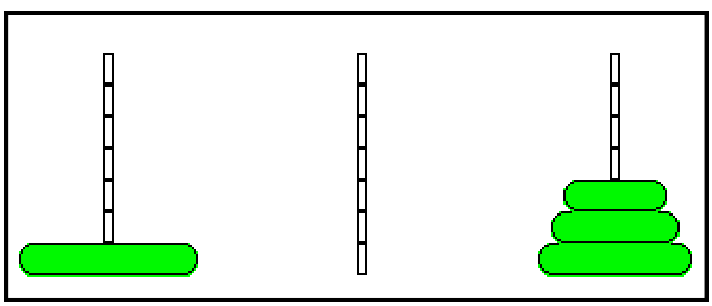


Figure 4.7. An intermediate goal in solving the 4-disk puzzle.

This sequence of examples illustrates another very powerful general problem-solving strategy. It is called the *look for patterns strategy*. Perhaps Figures 4.6, 4.7, and 4.8 suggest to you the possibility of setting an intermediate goal of moving all but the bottom disk onto the third peg. In essence, this pattern shows how a problem with a certain number of disks can be solved by solving the problem with one less disk.

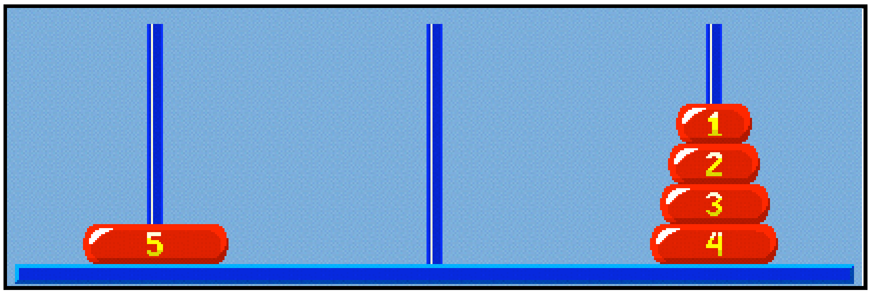


Figure 4.8. A possible intermediate goal in solving the 5-disk Tower of Hanoi puzzle.
http://chemeng.p.lodz.pl/zylla/games/hanoi5e.html

Bridge Crossing Puzzle Problems

My Google search of *bridge crossing puzzle problems* produced about 733,000 hits. Here is a typical bridge crossing puzzle:

> Four people have to cross a bridge at night. The bridge is old and dilapidated and can hold at most two people at a time. There are no railings, and the men have only one flashlight. In any party of one or two people cross, one must carry the flashlight. The flashlight must be walked back and forth; it cannot be thrown, etc. Each person walks at a different speed. One takes 1 minute to cross, another 2 minutes, another 5, and the last 10 minutes. If two people cross together, they must walk at the slower person's pace. There are no tricks—the people all start on the same side, the flashlight cannot shine a long distance, no one can be carried, etc. What is the fastest they can all get across the bridge?

The story (perhaps apocryphal) is often told that many years ago such a puzzle was given during interviews of programmers applying to work at Microsoft. Many people like to play with this type of puzzle and make up variations. For example:

a. Suppose that in the 4-person puzzle, the 5-minute person is changed into an 8-minute person. Does that change the total time needed to get all four across the bridge?

b. Suppose that there are only three people needing to cross the bridge: the 1-minute person, the 5-minute person, and the 10-minute person. What is the fasted the three can get across?

c. Suppose that in the three-person puzzle (b), the 5-minute person is changed into an 8-minute person. What is the fasted the three can get across? How is it possible that the answer to (a) is smaller than the answer to (c)?

This type of puzzle can be approached by using the *bottleneck strategy*. The bottleneck strategy is applicable in analyzing lots of different kinds of problems in which a number of different activities need to be accomplished in a timely fashion. A team of people may be able to accomplish such a task faster than one person, provided one can identify situations in which more than one person can be working at a time in a productive manner.

The bottleneck in the bridge example is the two slower walkers. In the original version of the puzzle, if each walks accompanied by a faster walkers, then it takes 18 minutes just to get these two across. If they walk together, it takes only 10 minutes for the two to cross. These two constitute the bottleneck. Figure out how to have them walk together, and you (may) have made a good step toward solving the puzzle.

You will want to add the bottleneck strategy to your repertoire and your students' repertoires of high-road transferable problem-solving strategies. You might be interested in reading about multitasking. In multitasking, a person does two or more tasks simultaneously. A Google search of multitasking produces more than 6 million hits. Many of these hits provide evidence of inefficiencies of multitasking.

Brain Teasers

Many people like brain teasers. My Google search on *free online brain teaser* produced more than two million hits. The Website http://www.puzz.com/iqteasers.html contains a number of what it calls IQ Brain Teasers. IQ Brain Teaser # 102 is:

> At Parkview High School, the science club has 11 members, the computer club has 14 members, and the puzzle club has 25 members. If a total of 15 students belong to only one of the three clubs, and 10 belong to only two of them, how many students belong to all three clubs?

Notice that this is a type of logic puzzle that requires significant reading skill. Many brain teaser puzzles require good reading skills and good use of logic. In addition, math skills are often helpful. Math people can solve this particular math puzzle mentally, using only elementary school arithmetic. If you are not able to figure out a direct way to solve the puzzle, think about using trial and error.

Symmetrical Word Box Puzzles

The Website http://www.rinkworks.com/brainfood/ contains a large number of different types of brain teasers. For example, there are a number of different Symmetrical Word Box puzzles. Quoting from the Website:

> Word Boxes are like miniature crossword puzzles, except that each word is filled in across *and* down the grid. That is, the answer to 1 across is the same word as the answer to 1 down; 2 across is the same as 2 down; etc. Can you solve these Word Boxes?

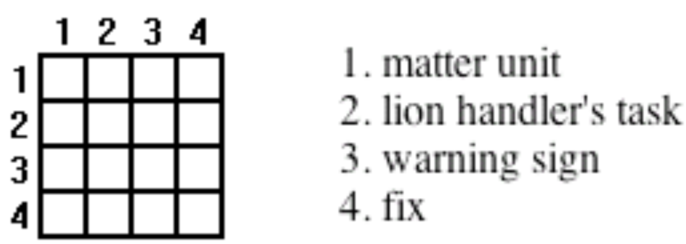


Figure 4.9. An example of a 4x4 Symmetrical Word Box puzzle.

On 6/7/06, the Website contained 84 of these 4x4 puzzles, each with a hint and with a solution. It also contained a number of 3x3, 5x5, and 6x6 puzzles. If you want to give your students a different word puzzle each day, this Website will get you off to a good start.

Logi-Number Puzzles

The Website also contains a large number of Logi-Number puzzles. Quoting from the Website:

> Logi-Number Puzzles are a cross between logic problems and mathematical puzzles. In each, you must determine what values the variables are equal to, using the rules of the game and the given clues. The rules are: (1) all the variables are equal to integer values between one and the number of variables in the puzzle,

and (2) none of the variables are equal to each other. For example, if there are six variables, each will equal a number from 1 to 6. Since no variable equals another, all six values will be used.

1. $A + B = D$
2. $B + F = E$
3. $C + D = E$
4. $B \neq 1$

	1	2	3	4	5	6
A						
B						
C						
D						
E						
F						

Figure 4.10. An example of a 6 x 6 Logi-Number puzzle.

Personally, I find the “box” representation of this puzzle problem to be confusing. There are six variables, each having a different positive integer value, and the possible values are 1, 2, 3, 4, 5, and 6. How might one go about solving such a puzzle? The following represents my thinking as I worked to solve this puzzle. I have never previously encountered this type of math puzzle.

To begin, I thought about solvability. Unless the person posing this puzzle tells me explicitly that this puzzle has a solution, than I don’t know if it does or doesn’t. Also, unless the person tells me that it has exactly one solution, I don’t know if it has more than one possible solution. However, I assumed that the puzzle has exactly one solution. As I work to solve the puzzle, however, I will keep an open mind on the possibility that the puzzle does not have a solution.

My next thought was that perhaps I could use my knowledge of algebra to solve the puzzle. The puzzle uses algebraic notation and some algebraic equations, so perhaps I can easily solve it using eighth grade or 9^{th} grade algebra. However, there are 6 unknowns, with 3 equations and 1 inequality. From my study of algebra, I remember how to solve 2 linear equations in 2 unknowns, or 3 linear equations in 3 unknowns, and so on. However, I do not know an algorithm for solving 3 linear equations and one linear inequality in 6 unknowns. This situation is unlike any that I have previously encountered.

Hmmm. Since E is the sum of two different integers in the range 1 to 6, the very smallest it could be is 3. Under the constraints of this puzzle, the only way to get 3 by adding two of the unknowns, is 1 + 2. However, E must be larger than 3 since if B + F = 3, than C + D will certainly be larger than 3. Similarly, if C + D = 3, than B + F will be larger than 3.

Aha. A small insight. Perhaps I can make some progress by eliminating some possible solutions. That is consistent with the given elimination information that B ≠ 1.

Can E = 4? No. In this puzzle, the only way to get a 4 by adding together two of the unknowns is by adding 1 and 3. However, we need two different ways to get E.

Can E = 5? I see that 5 = 1 + 4 and that 5 = 2 + 3. Thus, I cannot immediately rule out the possibility that E = 5.

Can E = 6? I see that 6 = 1 + 5 and that 6 = 2 + 4. Thus, I cannot immediately rule out the possibility that E =6.

This elimination approach does not seem to be going very well. By elimination, I conclude that E = 5 or E = 6, but I can't tell which is correct. I have made some progress with this approach, but it may be that it is not a good way to go. For a moment, I feel stuck.

Then I see that I can make use of a combination of the first and third equations and conclude that A + B + C = E. Aha. I have used some algebra. Why didn't I try that earlier? It must be that E = 6, since that is the smallest possible sum of three different integers in the range of 1 to 6.

My initial elimination efforts to determine a value for E were not too fruitful. I did gain some information through this guess and check approach. Now, however, I feel a small sense of satisfaction because I am making some progress. It has taken quite a bit of "messing around," exploring, making trials, and getting a feel for the problem.

During my elimination approach, I found that there are exactly two possible (legal, following the rules of this puzzle) ways that E could be 6: 1 + 5 = 6; 2 + 4 = 6. From this, using elimination, I conclude that A = 3. This is because the values for B, C, D, and F must come from (and use up all of) the four integers 1, 2, 4, and 5, and I know F = 6.

From the first equation, it is now evident that B = 2. Why? Because I know that B cannot be either 1 or 3, and the first equation tells me the B cannot be larger than 3. From this point, it is quite easy to complete the puzzle.

Here are five educational values that I see in this type of puzzle:

1. The puzzle makes use of algebraic notation and some simple algebra ideas that are taught before students take an algebra course.
2. The puzzle requires use of numbers and simple arithmetic that can be done mentally.
3. The puzzle illustrates use of the elimination strategy and requires persistence.
4. The logical arguments used in doing the puzzle are much like one uses in solving other math problems and in doing math proofs. It looks to me like there is the possibility of quite a bit of transfer of learning to these aspects of doing math.
5. Writing, and explaining one's math/logic thinking and processes, can be built into use of this activity in a school setting. Such writing and explaining are important components of learning math. From a math book authoring point of view, my discussion of how I solved the puzzle problem allowed me to leave some gaps to be filled in by the reader. That is a standard technique used in writing math books.

Cryptograms

The Website also contains Cryptogram puzzles and a Cryptogram puzzle maker. As an example of using the puzzle maker, I provided the sentence:

DAVID MOURSUND HAS WRITTEN MANY DIFFERENT BOOKS

I received the following encryption:

BETCB VZMAPMXB FEP SACYYGX VEXO BCJJGAGXY LZZIP

I then used the same sentence as input a second time, and got:

GVFEG SYRTMRJG XVM NTEWWCJ SVJK GEUUCTCJW QYYLM

These Cryptogram puzzles are based on simple letter substitutions. Here is a challenge for you and your students. If I use an encrypted sentence as input, thus encrypting the encryption, will the result be a harder puzzle than the original?

My 6/8/06 Web search on *cryptogram* using Google produces over 300,000 hits. My search on cryptography produced over 52 million hits. Cryptography is an important discipline with a long and interesting history. Nowadays, computers play a major role in this discipline. Quoting from http://en.wikipedia.org/wiki/Cryptography:

> Cryptography (or cryptology) is a discipline of mathematics and computer science concerned with information security and related issues, particularly encryption and authentication and such applications as access control.
>
> Cryptography, as an interdisciplinary subject, draws on several fields. Prior to the early 20th century, cryptography was chiefly concerned with linguistic patterns. More recently, the emphasis has shifted, and cryptography now makes extensive use of mathematics, including topics from number theory, information theory, computational complexity, statistics and combinatorics. Cryptography is also a branch of engineering, but an unusual one as it deals with active, intelligent and malevolent opposition (see cryptographic engineering and security engineering) unlike other sorts of engineering in which only nature is an 'opponent'. There is active research examining the relationship between cryptographic problems and quantum physics (see quantum cryptography and quantum computing). And, in the everyday world, cryptography is a tool used in computer and network security for such things as access control and information confidentiality.

Miscellaneous Additional Examples of Puzzles

There are many different types of puzzles. This section lists a few that can be accessed from and used on the Web.

Peg Puzzles

Peg Puzzles are mental, spatial puzzles that involve jumping pegs over each other, with a jumped peg being removed, to achieve a particular goal. My 6/8/08 Google search of *free online peg puzzles* produced over a million hits. The Quiz Hub Website http://quizhub.com/quiz/quizhub.cfm offers a variety of free online puzzles and games, including eight Peg Puzzles. Quoting from the Website:

> The goal is to remove pegs from the board by jumping over each peg with another peg; this removes the "jumped" peg (similar to Checkers jumps). Click and drag with the mouse to move a peg. Only horizontal and vertical jumps are allowed. The game is over when no more jumps are possible. You win the game by removing all the pegs except one from the board. A perfect game would leave one peg in the center position.

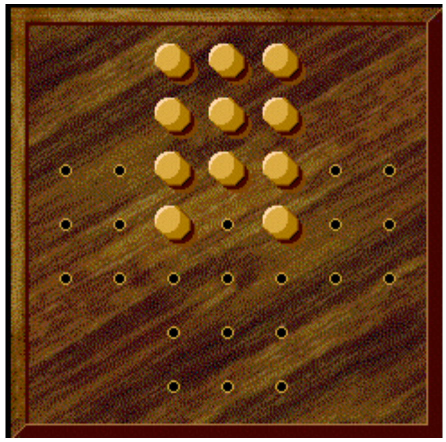


Figure 4.11. A Peg puzzle.

Peg puzzles are now available both in physical format (a playing board with holes, and pegs) and on the computer. When I was a child, people often made their own peg puzzles, and this is still a fun activity for children of all ages. It is easy to drill holes in a board and use golf tees for pegs.

Traditional Crossword Puzzles

Of course, you can access free crossword puzzles in many newspapers and magazines. Many Websites offer free online crossword puzzles. A 6/8/06 Google search of produced well over 8 million hits. For example, see http://www.quizland.com/cotd.htm. Online resources frequently give you choices of difficulty level and other features, such as general topic area. In addition, when working online you can correct errors more easily than when working with a pencil or pen.

Some online crossword puzzle programs, such as http://www.quizland.com/cotd.htm, provide feedback on each letter that you enter. This may be useful to a person who is just beginning to learn how to do crossword puzzles. However, this type of feedback removes one of the key challenges of a crossword puzzle. It is the challenge of using the crossing of words to help determine the possible accuracy of words that have been have entered.

Many Websites provide free access to a computer program that can generate a crossword puzzle that is based on words and clues you provide. My Google search on the term *free crossword puzzle maker* produced more than 1.2 million hits. For example, see Instant Online Crossword Puzzle Maker at http://www.puzzle-maker.com/CW/.

Compared to traditional crossword puzzles, these are of very modest quality. However, many teachers make use of computer software to develop such puzzles for their students. An alternative approach—perhaps educationally more sound—is to have students develop such puzzles for use by their fellow students, siblings, parents, and so on. While this might be done through the use of a computer, a more challenging task is to develop such puzzles by hand, working to achieve rather compact puzzles with a large number of crossings.

Math Computation Puzzles

A 1/28/07 Google search of *free math computation puzzles* produced about 795,000 hits. Figure 4.12 is an example of a math square puzzle from http://puzzlemaker.school.discovery.com/MathSquareForm.html.

Directions:

Try to fill in the missing numbers. Use the numbers 1 through 9 to complete the equations.

Each number is only used once. Each row is a math equation. Each column is a math equation. Remember that multiplication and division are performed before addition and subtraction.

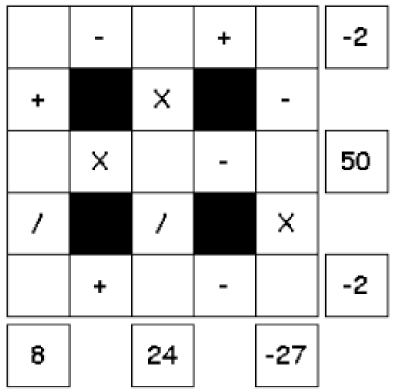


Figure 4.12. A Math Computation puzzle.

At first glance, you might decide that a Math Computation puzzle is the math equivalent of a (word) Crossword puzzle. However, in my opinion, the math puzzle is decidedly inferior. In the word puzzle, one draws upon their full knowledge of words, definitions, and obscure clues. Doing a crossword puzzle increases one's repertoire of such knowledge.

As you work on the math puzzle, think about whether the activity is fun for you. Think about what you are learning as you attempt to solve such a puzzle. What are some alternative ways in which you might learn the same things?

Final Remarks

There are a huge number of puzzles that are available for free use from the Web and other sources, and/or that people can easily construct for themselves. For the teacher or parent who cares to make a little effort, students can be provided with one or more new puzzles each day throughout the school year. Alternatively, students can learn just a few puzzles, and these can be used multiple times through the school year. For example, students can learn to do crossword puzzles, and there are plenty of such puzzles available to meet the needs of students throughout a school year.

Many puzzles come in a range of difficulty levels. This means that a teacher can make use of a particular type of puzzle (such as a crossword puzzle) and select versions that fit the various capabilities of students in the class. Students can find a level of the puzzle that they find appropriately challenging, and then move up to more difficult versions as they increase their knowledge and skill in solving the type of puzzle.

Puzzles are inherently educational. However, some puzzles have much more educational value than others. In addition, the educational value of puzzles can be substantially increased by appropriate teaching and mentoring. Thus, a teacher who is interested in puzzles should have no difficulty justifying the routine integration of puzzles into the curriculum.

Activities for the Reader

1. Many Websites provide free access to a computer program that can generate a crossword puzzle that is based on words and clues you provide. My 6/8/06 Google search on the term *crossword puzzle maker* produced more than 2 million hits. For example, see Instant Online Crossword Puzzle Maker at http://www.puzzle-maker.com/CW/. Many teachers develop such puzzles for their students. An alternative approach—perhaps educationally more sound—is to have students develop such puzzles for use by their fellow students, siblings, parents, and so on. Discuss educational values of such puzzles and the teacher-made versus student-making approaches.
2. Select a goal of education that you feel is quite important and that you help your students to achieve. Find a puzzle that is suitable for use by your students and that helps to support the educational goal. Discuss how the game supports the goal. Note that in this activity, you start with an educational goal and look for a puzzle that helps to accomplish the goal.
3. Select a puzzle. Analyze it from the point of view of how it supports various general goals in education. Note that in this activity, you start with a "solution," (a puzzle) and you look for a problem (an educational goal) that this puzzle helps solve.
4. What makes one Sudoku puzzle easier or harder than another? The Website http://www.monterosa.co.uk/sudoku/ publishes three computer-generated, guaranteed to be solvable, different levels of difficulty, Sudoku puzzles each day.

Activities for use with Students

1. Ask your students who are "into" puzzles to bring some interesting examples to class. Then ask for volunteers to do two things:

   a. Demonstrate and talk to the whole class for a couple of minutes about a puzzle.

   b. Teach a person (another volunteer from the class) more details about the problem or task represented by the puzzle, and how to solve or accomplish it.

   Meanwhile, the rest of the class serves as observers. They keep notes on the teaching and learning process. They are looking for what works, what doesn't work, and how the teaching/learning might be improved. This information is shared in a whole class discussion and debriefing. The activity can be used repeatedly, with different puzzles and different participants.

2. Spend some time talking to your students about what they can learn from puzzles. Then:

   a. Involve the whole class in working together to analyze a puzzle that most or all are familiar with.

b. Then have each student select a puzzle that he or she is familiar with, and analyze it from an educational point of view. The results are to be written into a report to hand in to the teacher.

3. Have individual students or teams of students explore mechanical puzzles. A good starting point is the Wikipedia Website http://en.wikipedia.org/wiki/Mechanical_puzzle. The following examples are from that Website.

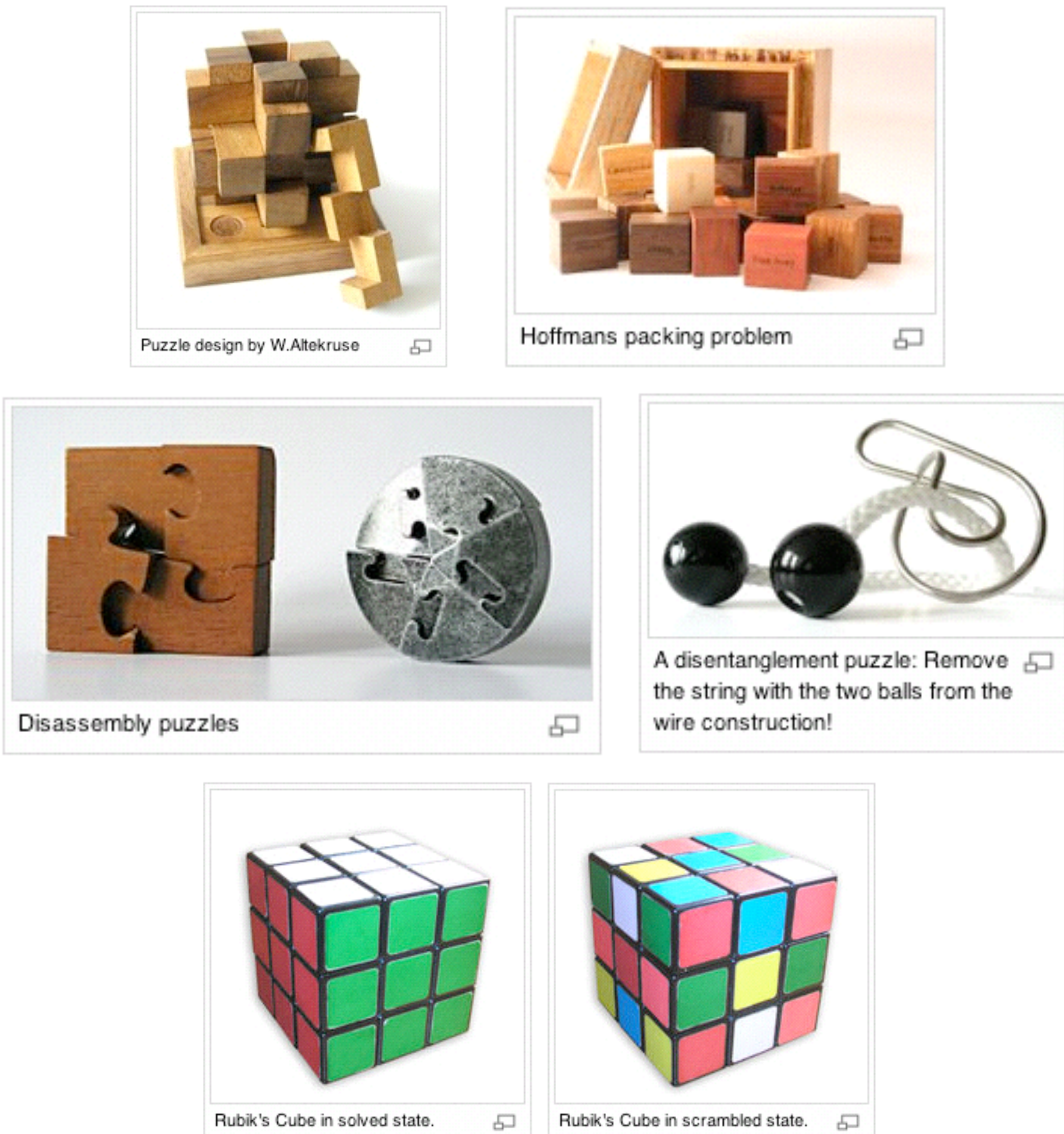


Figure 4.13. Examples of mechanical puzzles.

Chapter 5

One-Player Games

Probably you are familiar with one or more versions of the type of card game called solitaire. Most often solitaire games are played by a person playing alone, using one or more standards decks of playing cards, or playing electronically. However, some solitaire games have been adapted to involve more than a single player.

This chapter discusses some one-person solitaire games that can be played with physical cards or electronically. It also contains a brief discussion of Tetris, a one-player computer game that does not make use of a deck of cards.

There are many Websites that allow a person to play a variety of solitaire games for free. Some sites provide free software downloads, and many sites sell collections of solitaire programs that can be purchased (McLeod, n.d.). In addition, there are many books that describe a variety of solitaire games and contain the rules for playing these games.

Learning to Play a Game

The process of learning any game consists of:

1. Learning some vocabulary so that you can communicate about the game. It is useful to think of a particular game as a self-contained sub discipline of the overall discipline of games. Thus, each game has its own vocabulary, notation, history, culture, and so on. Precise vocabulary is important in order to understand the rules and to facilitate communication among people playing the game.

   Note how this same idea applies to solving real world problems. Suppose your computer is not working right. Do you know precise vocabulary to describe the problem? If not, you will have difficulty using information retrieval to find help, or talking to a person to get help. Getting help from stored information and from people is a very important strategy in problem solving. It requires effective communication between you and the information source.

   More generally, consider reading across the content areas. To read with understanding within a discipline content area, you need to know how to read, you need to have an understanding of the special vocabulary and notation used in the discipline, and you need to have some understanding of the discipline

2. Learning the legal moves (plays). Each game has a set of legal moves. Notice that this is consistent with the formal definition of the term "problem." One

can create a variation of a game (in essence, a new game) merely by changing the rules.

3. Gaining knowledge and skill that help one to make "good" moves. Often this knowledge is in the form of strategies that help to govern one's overall play as well as one's decisions on individual moves or small sequences of moves.

4. Gaining speed and accuracy at making good moves.

Solitaire (Patience)

Quoting from the Wikipedia http://en.wikipedia.org/wiki/Solitaire:

> **Solitaire** or **patience** is any of a family of single-player card games of a generally similar character, but varying greatly in detail. The games are more commonly known as "Patience" in British English whilst "solitaire" is the American English term.
>
> These games typically involve dealing cards from a shuffled deck into a prescribed arrangement on a tabletop, from which the player attempts to reorder the deck by suit and rank through a series of moves transferring cards from one place to another under prescribed restrictions.

There are many different solitaire games. The most commonly played one is called Klondike. For many years, Microsoft has provided a free electronic version of Klondike in its Windows operating system. Thus, it is probably the most widely played electronic game in the world.

It is assumed that you are at least somewhat familiar with Klondike. It uses a standard 52-card deck of playing cards. The card deck is shuffled and then dealt out, as illustrated Figure 5.1. If you are not familiar with the game, you might want to read a little about its rules at http://en.wikipedia.org/wiki/Klondike_solitaire.

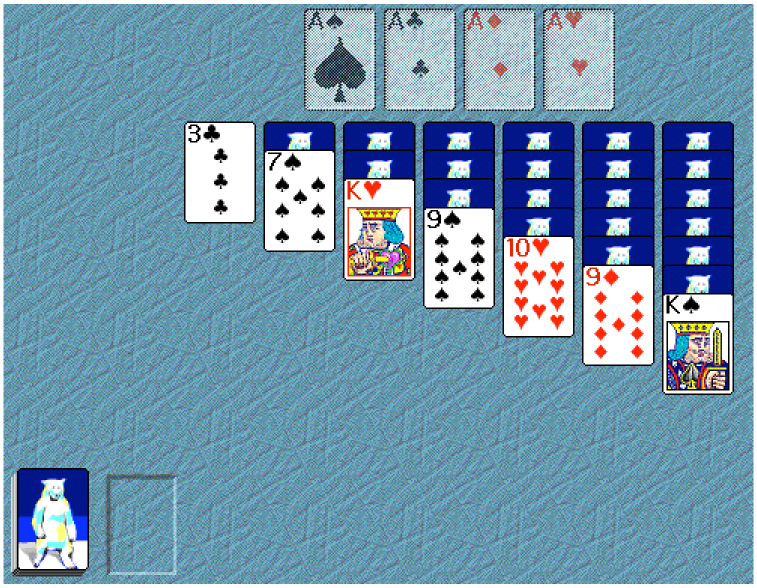


Figure 5.1. The start of a game of Klondike solitaire.

(The Klondike solitaire screen shots used in this section were made from Eric's Ultimate Solitaire; see http://www.deltatao.com/ultimate/.)

The top row of the layout in Figure 5.1 is the computer representation of the four **foundation** stacks where cards will be built up in sequence, starting with the ace. Collectively, these four stacks are called the foundation. There are no actual cards in the foundation at the beginning. The game is won by getting all 52 cards onto the foundation.

Below the foundation are seven piles of cards, containing 1, 2, … 7 cards, respectively. The top card of each pile is exposed, while the remaining cards are face down. Finally, the remaining cards in the deck (shown in the lower left corner) are face down and are called the **reserve** or the **stock**. To their right of the reserve is an empty space for the **waste** pile.

Figures 5.2 shows the results after the game player has taken the top three cards from the reserve, turned this set of three cards over in a manner that does not display the first and second cards, and placed the three cards on top of the waste pile. The player has also moved the 9 of spades onto the 10 of hearts, and then turned up the card that was beneath the 9 of spades.

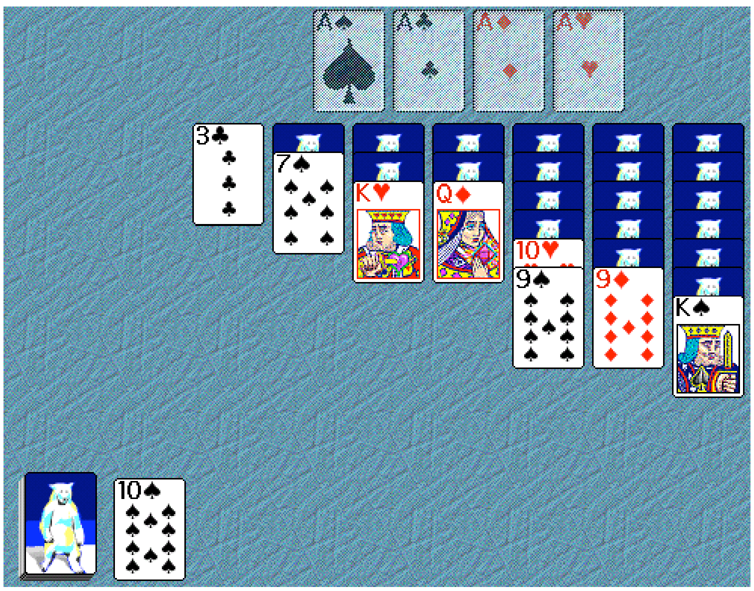


Figure 5.2. The display after early in playing the game.

Figure 5.3 shows the game after a number of different moves have been made by the player. Three of the foundation stacks now have cards in them.

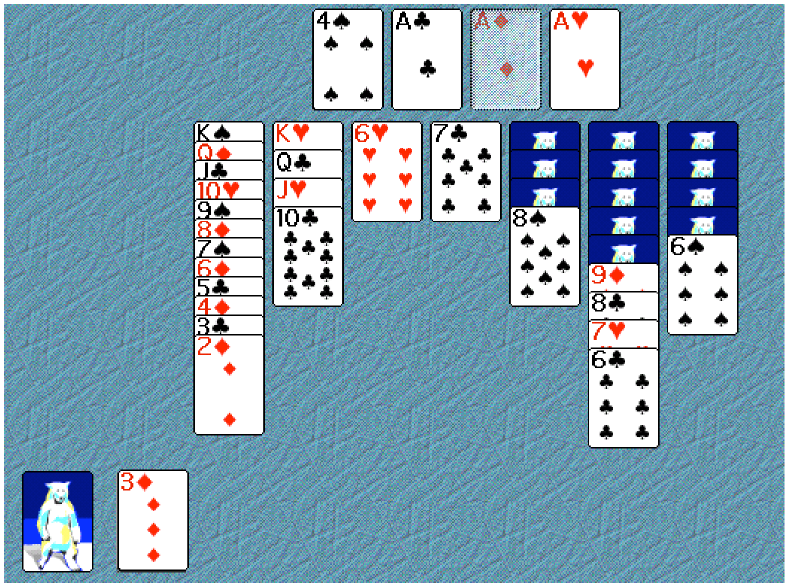


Figure 5.3. Later in the game …

Winning and/or Playing Well

Klondike is fairly easy to learn to play. You win the game if you get all 52 cards into the foundations. However, that does not occur very often. If you have played Klondike a large number of times, you probably have a sense of how often you win.

If you are mathematically inclined, you might wonder what percentage of deals are winnable, or what percentage of the time a good player wins. It turns out that the first question is a math problem that has not yet been solved.

However, (using the strategy of pose a simpler but related problem) some people have explored a variation of this problem. Suppose that the player can see all of the cards (that is, all cards are face up). Than a computer program has been developed that wins about 70% of the time, and good human players win about 35% of the time. See http://en.wikipedia.org/wiki/Klondike_(solitaire).

To answer the second question, one merely has to keep statistics for a number of good players, as they play a large number of games. In addition, Klondike is sometimes used as a gambling game in casinos, so that data should be available on the odds of wining. After I spent a good deal of time searching the Web, I found Aldous and Diaconis (1999):

> Rabb [41] simulated a common form of Klondike in which cards are turned over three at a time (with only the top card exposed) and where one can cycle through the deck indefinitely. She found that the computer won about 8% of games whereas she won about 15%. In work in progress, Diaconis – Holmes – Koller study modern game-playing heuristics applied to Klondike. Preliminary results suggest a win probability around 15%.

Personally, I sometimes cheat when playing Klondike, and yet my win percentage is probably less than 10%.

Many players also use a measure of how well they did when they did not win—namely, the number of cards added to the foundation stacks. Note, however, this may not be a very good measure of how well you have played in a particular game. You have no idea of how many cards a good player will have added to the foundations when playing the exact same deal.

I find it interesting to think about the intrinsic motivation that drives so many people to play Klondike repeatedly. The possibility of winning is somewhat motivational. However, winning perhaps 10% of the time or less is not very encouraging—rather, I finds this to be discouraging. Still, I feel somewhat good when I an able to play a large number of cards onto the foundation stacks.

What holds my attention and keeps me motivated, however, seems to be the overall process. My mind/brain seems to interpret the process as one in which I am accomplishing something that it deems worthwhile.

As I play the game, I am continually involved in doing something. I am turning up cards from the reserve and remembering the location of some of these cards. I am thinking about possible moves, trying to figure out good moves. I am following the rules as I make moves. New cards are displayed because of my moves. In summary, my mind and body are engaged, small rewards are occurring all of the time, and occasionally I win. Perhaps I am in a mild “flow” state.

The previous paragraph reminds me of the P. T. Barnum statement, “You can fool most of the people most of the time.” A mind/brain is a complex thing. However, in a mind/brain, pleasure can come from quite simple things. Playing Klondike stimulates my mind/brain in a manner that brings me pleasure. The same holds true for many other games. Over the years, I have come to understand this. I have also come to understand that from time to time I fall into an addictive-like behavior of playing games rather than doing other things that have greater “redeeming” values.

I have talked to a number of people about this type of game-playing experience. They tell me about how they have learned to carefully restrict (ration) their game playing. Their level of addiction is not so strong that it overwhelms their determination to use their time for other more productive activities.

Applications to Other Games and General Problem Solving

In Klondike, as well as in many other games and problem-solving situation, there are possible moves, plays, or actions. While you would like to make a good move, you often fail to do so. As you play, you can learn more about problem solving by reflecting on your play. For example:

- You do not “see” (discover, recognize) a possible move, so that it receives no consideration. This can be through carelessness and oversight, or it can be caused by just not spending enough time in careful thinking and searching for possible moves. While some real world problem-solving situations require very quick decision making, the majority allow time for reflection and for consideration of consequences of moves.
- You find a possible play or move, give it consideration, but make a relatively obvious mistake in this consideration. Immediately upon making the move you recognize the mistake and want to take the move back. The message is clear—look before you leap, think before you act.

- You find two or more possible legal moves and do a compare/contrast consideration of the moves. If one is clearly better than the others, you make it. However, quite likely you will not know for sure which is clearly the best move. It may turn out that the one you think is best isn't, because you lack information on what will happen because of your move. (In Klondike, for example, you may not know what card will turn up. In negotiating a business deal, you do not know for sure how a person will react to your proposal.) This type of uncertainty literally petrifies some people. They just seem unable to make decisions in the face of uncertainty. Practicing in a game-playing environment, where it is easy to take back moves, may help such a person get better at making decisions under uncertainty.

The Solitaire Game Eight Off

Eight Off is my favorite one deck solitaire game. It is mentally challenging, but I can win most of the time if I think and play carefully enough. I find this game to be far more mentally challenging than Klondike. Moreover, it better illustrates the value of thinking many moves ahead when making a decision of what move to make.

Eight Off is available in many commercially available bundles of computer solitaire games. It can be played free at a number of Websites. All but one of the screen shots used in this section are from the Eight Off game # 31853 from Acescardgames.com (available free) at http://www.acecardgames.com/en/. As you cycle through the choices to bring up an Eight Off game, you will eventually come to a dealt out game and some small symbols in the upper right cornet. Click on the # symbol and you can key in the number 31853 to be playing the exact deal discussed in this section.

Figure 5.4 shows the layout for the specific example of Eight Off that will be used to illustrate the rules and playing the game.

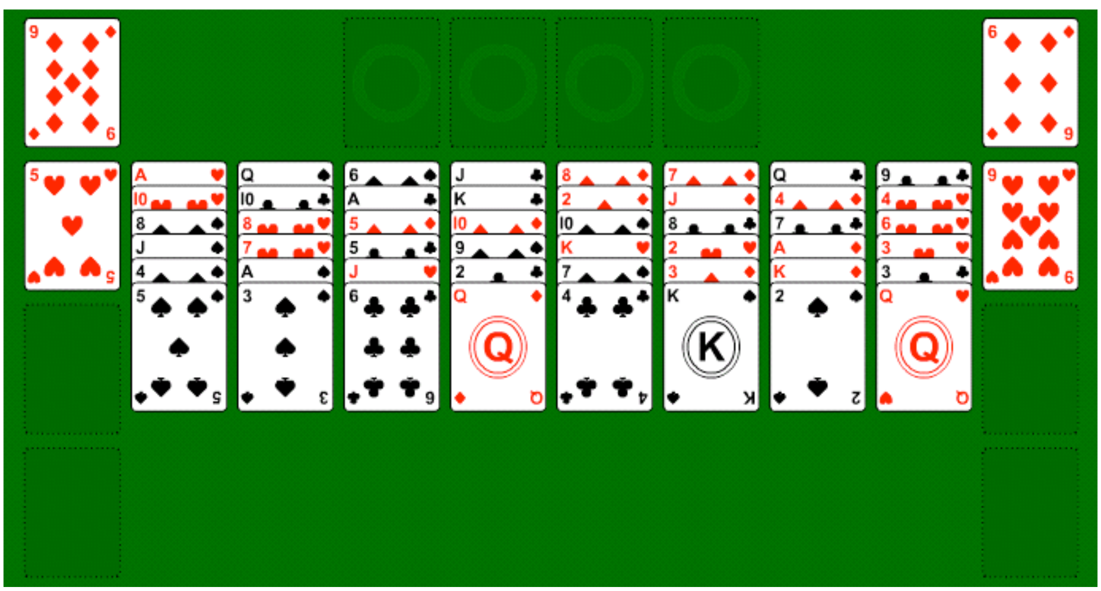


Figure 5.4. The start of a game of Eight Off.

A regular deck of 52 playing cards is shuffled. The first 48 cards are then dealt face up in eight columns (called Main Stacks) of six cards each. The remaining four cards are dealt face up into four of the eight Free Cells. Some players like to have half of these Free Cells on each side of the Main Stacks, while others like to place all of them below the Main Stacks. The choice does not affect the playing of the game.

Figure 5.4A shows an alternative layout from a version of Eric's Ultimate Solitaire computer software.

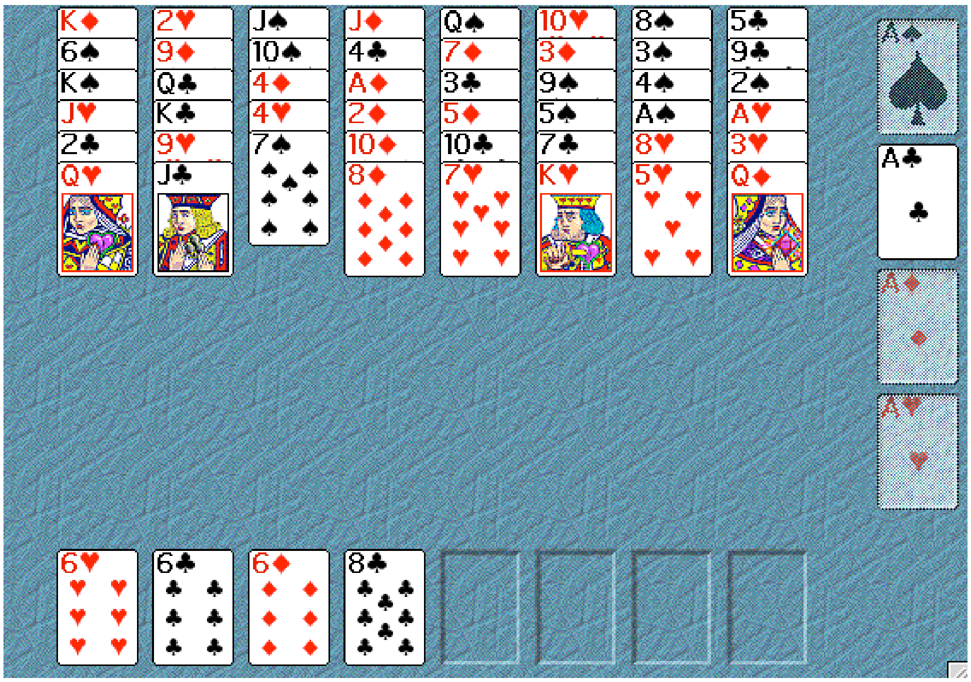


Figure 5.4A. A nice computer display of an Eight Off layout. One card has been played to the Club Object Stack.

Above the Main Stacks is space to build four Object Stacks. An Object Stack is built up in a suit, starting with the Ace and continuing with 2, 3, 4… Jack, Queen, and King of the suit. The object of the game is to build all four Object Stacks until they contain the entire 52-card deck.

The rules for playing are as follows:

1. Cards are played one card at a time.
2. The last card in each Main Stack (in the example of Figure 4.4, these include the 5 of spades, the 3 of spades, the 6 of clubs, and so on) and each card in the Free Cells is available to play.
3. Cards that are available to play may be played as follows:
    - If the card is an Ace, it is played in an empty Object Stack.
    - The card may be added to an Object Stack, provided that it is the next card in rank of that suit and Object Stack.
    - The card may be played to any empty Free Cell or to any empty Main Stack.
    - The card may be played by adding it to any Main Stack whose top card is of the same suit and is the card immediately above it in rank. In Figure 5.4, for example, the 2 of spades can be played on the 3 of spades. However, the 5 of spades cannot be played on the 6 of clubs.

The set of rules is relatively simple. Some people can read and memorize such a set of rules quite quickly, while others will find they need to refer back to the rules from time to time until all become familiar. This situation gives us some important insights into schooling. Often, schools expect students to memorize information in advance of when they will need to use it. The students are tested over the memorized information outside of the context in which they might eventually use the memorized information.

However, most people learn best when they are immediately find use of what they are memorizing. The memorization is interspersed with the using. The learner eventually memorizes what needs to be memorized through frequently looking it up and using it.

This can be summarized in a problem-solving strategy *memorize through use*. A different name for the strategy in the *only memorize if quite useful strategy*.

For convenience is discussing the game, I have lettered the eight Main Stacks a through h. See Figure 5.5.

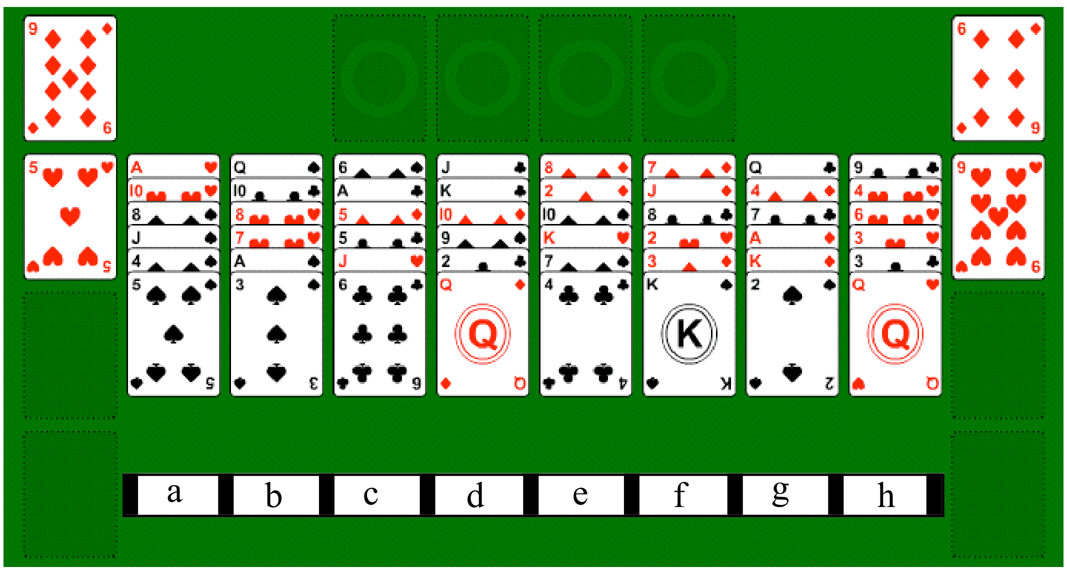


Figure 5.5. The 8 Main Stacks are lettered a through h.

Eight Off is a solitaire game that requires thinking in sequences of moves. Notice the Ace of spaced is the second card in Main Stack b. If I move the 3 of spades to an empty Free Cell (currently we have 4 empty Free Cells), this will expose the Ace of spaces, so that it can be played in one of the Object Stacks. The result is shown in Figure 5.6.

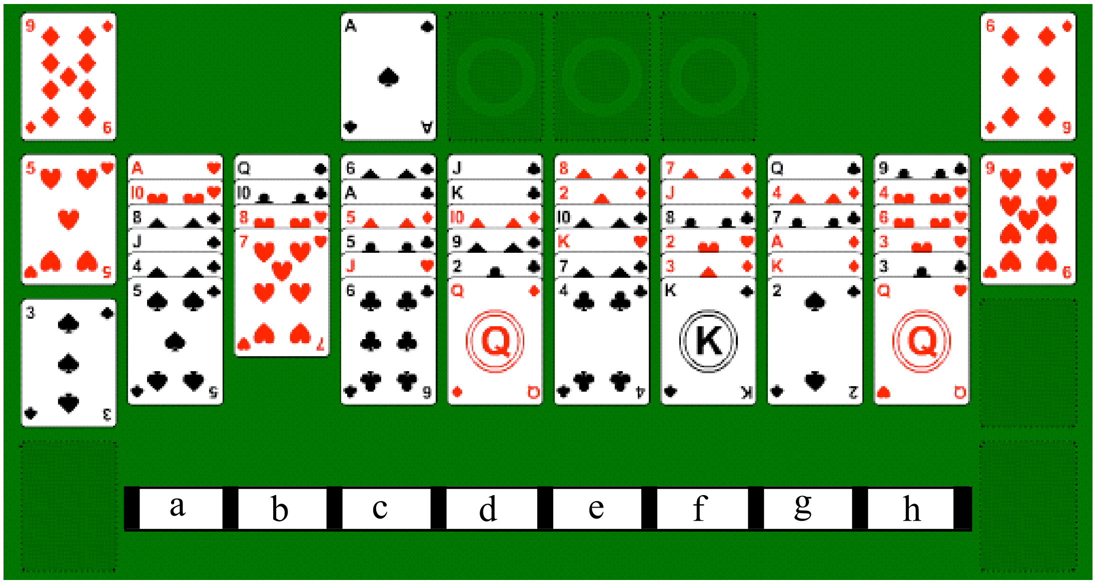


Figure 5.6. A sequence of 2 moves is completed.

You can see that the 2 of spades in Main Stack g and the 3 of spades in the Free Cells can now be played on the Ace of spades in the Object Stack. The result is shown in Figure 5.7.

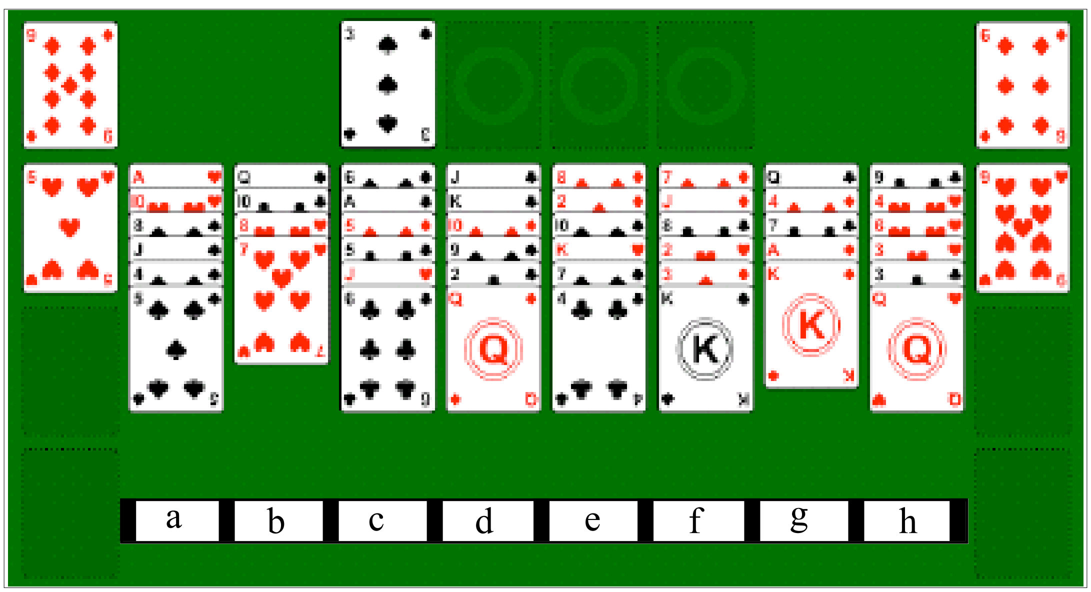


Figure 5.7. Two more cards have been added to the spade Object Stack.

Strategies Used So Far in Our Eight Off Game

Okay, that was a good start. We started out by designing a sequence of moves. This is an important strategy that we will call the *sequence of moves strategy*. The idea is to think in terms of multi-step sequences of moves or actions when attacking a complex problem. These steps may be done sequentially, they may be done in parallel (all at the same time), or they may be done in a combination of sequential and parallel steps. Large problems that are being worked on by a team of people are attacked using the sequence of moves strategy. Thus, this strategy should be part of your repertoire and your students' repertoires of high-road transferable problem-solving strategies.

The first sequence of moves that was used was designed to get an Ace into the Object Stacks. Just for the fun of it, lets call this the *getting an Ace into the Object Stacks strategy.* This strategy is useful in playing Eight Off. Indeed, it is a strategy useful in many different solitaire card games.

However, it is not a general-purpose problem-solving strategy that we will want to add to our repertoire of high-road transferable problem-solving strategies. Most real world problems do not involve getting a card called an Ace onto a space called an Object Stack.

Score, and Then Work to Improve Your Score

But wait! Perhaps there is something akin to this. Consider events such as the long jump, discuss, and the shot put in a track meet. A contestant gets three tries, with only the best one counting. A foul in a try counts as a distance of zero. Many contests will focus heavily on not fouling on their first trial, not trying to get as great a distance as they are capable of. That is, the athletic has two goals: get a relatively good distance, and get as long a distance as possible. The athlete decides to focus on the first goal in the first try. If the athlete does not foul in this try, than the second and third tries are all out efforts to achieve the greatest distance possible.

So, we have another general-purpose strategy that is suitable for adding to one's repertoire of high-road transfer problem-solving strategies. Let's call it the *score, then improve your score strategy*.

For example, suppose that the problem a person faces is a short answer or objective test. The score and improve strategy might lead the student to browsing through the test, answering the questions that he or she is confident about an answer. Then go back and spend time on the other questions.

For another example, consider being faced by a complex problem, but one that can readily be broken into a number of smaller or somewhat easier subproblems. After using the strategy of breaking the original problem into subproblems, one might use the strategy of first solving some of the easier subproblems. This assumes, of course, that the subproblems are independent of each other, so can be done in any order. Progress on the easier subproblems is somewhat like first answering the easier questions on a test. However, it also has the advantage that solving the easier subproblems may provide one with insights that will help in solving the more difficult subproblems.

For another example, consider writing an essay. One can write a few paragraphs and edit them over and over again, polishing them so they are perfect. This may take all of the available time. A different approach would be to do a quick rough draft of the whole document, and then begin polishing it.

Returning to the Eight Off Solitaire Game

The moves that we have made so far can all be viewed as contributing to an incremental improvement toward the goal of having all 52 cards in the Objects Stacks. However, it may well be that this particular Eight Off solitaire game cannot be solved by just "any old" collection of incremental improvement sequences. For example, look back at the start of the game given in

Figure 5.4. Consider the sequence of moving the 2 of spades onto the 3 of spades, moving the King of diamonds into an empty Free cell, and moving the Ace of diamonds into an empty Object Stack.

This sequence of three moves results in an incremental improvement, just as did the sequence of moves that we actually made. Which of these two sequences of moves is better? Might one be a good start on winning the game, while the other be a start on losing the game? Remember the incremental improvement picture in Figure 4.1, where the choice of starting point determines whether incremental improvement moves you to the highest peak.

Mobility: An Important New Strategy

Probably you have heard the adage, “Don’t paint yourself into a corner.” It is applicable in many game-playing and non-game situations.

I have played Eight Off many times, winning more often than I lose. I tend to lose when I fill up my Free Cells, thereby cutting down in my freedom to make sequences of moves that involve use of empty Free Cells. Having quite a few empty Free Cells gives me lots of options that can be carried out in a sequence of moves.

In games such as chess and checkers, the word mobility is used to describe having options. A high level of mobility of one’s collection of pieces means that one has many possible moves; a low level of mobility means that one’s possible moves are severely restricted.

Let’s use the same term in discussing Eight Off. Having lots of empty Free Cells and empty Main Stacks gives one a high level of mobility in developing a sequence of moves. In many games and in many real world problem-solving situations, it is desirable to keep one’s options open—to maintain or increase one’s mobility. Let’s call this the *mobility strategy*. Another name for this strategy is *don’t box yourself into a corner*. This is an important strategy to add to your repertoire and your students’ repertoires of high-road transferable problem-solving strategies.

The mobility strategy helps me to decide between the opening sequence of moves that I actually made, and the sequence that would have led to getting the Ace of diamonds into the Object Stacks. This latter choice would have decreased my mobility.

Returning to the Eight Off Game

Now, finally, back to our Eight Off game. I examine the current situation given in Figure 4.7. I think in terms of incremental improvement, but I hold in mind the mobility strategy. An obvious incremental improvement would be to use the sequence of 2 moves that ends with the Ace of diamonds being played in the Object Stacks. However, this sequence of moves decreases my mobility. Therefore, I spend some more time analyzing the current situation. Soon I see that a three-move sequence will add the 4 and 5 of spades to the spade Object Stack. This sequence does not decrease my mobility, so I make it, producing the position shown in Figure 5.8.

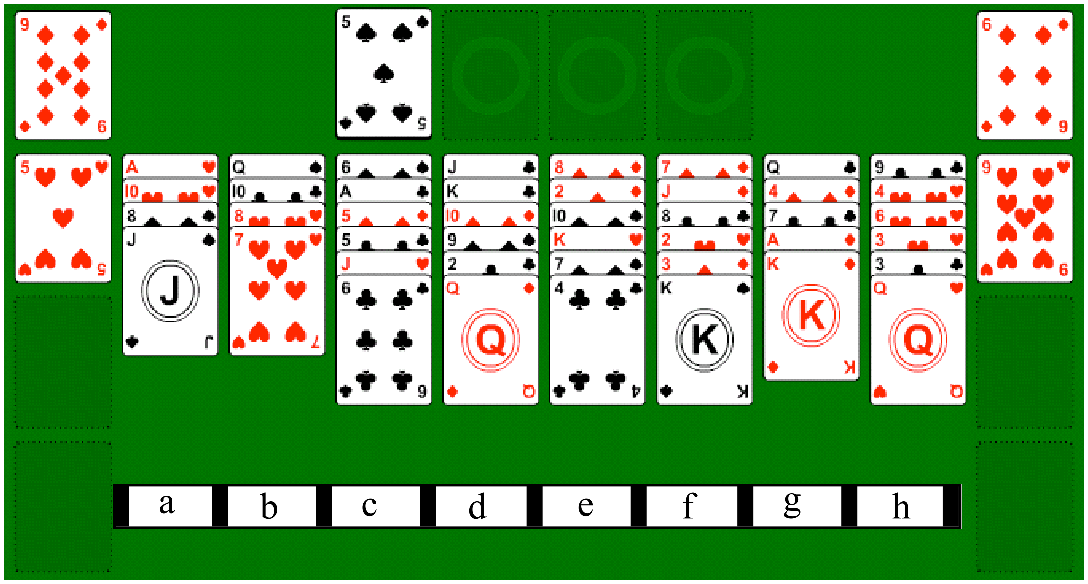


Figure 5.8. Two more cards added to the spade Object Stack.

After long and careful thought about the situation shown in Figure 5.8, I see how I can get the Ace of hearts into the Object Stacks in a complex (8-move) sequence that results in only one card being added to the Free Cells, and the 10, 9, 8, and 7 of hearts being in Main Stack a. (See if you can figure out how to do this.)

However, I decide on the 2-move sequence focusing on the Ace of diamonds, as this is a more likely choice for a beginner. The result is shown if Figure 5.9.

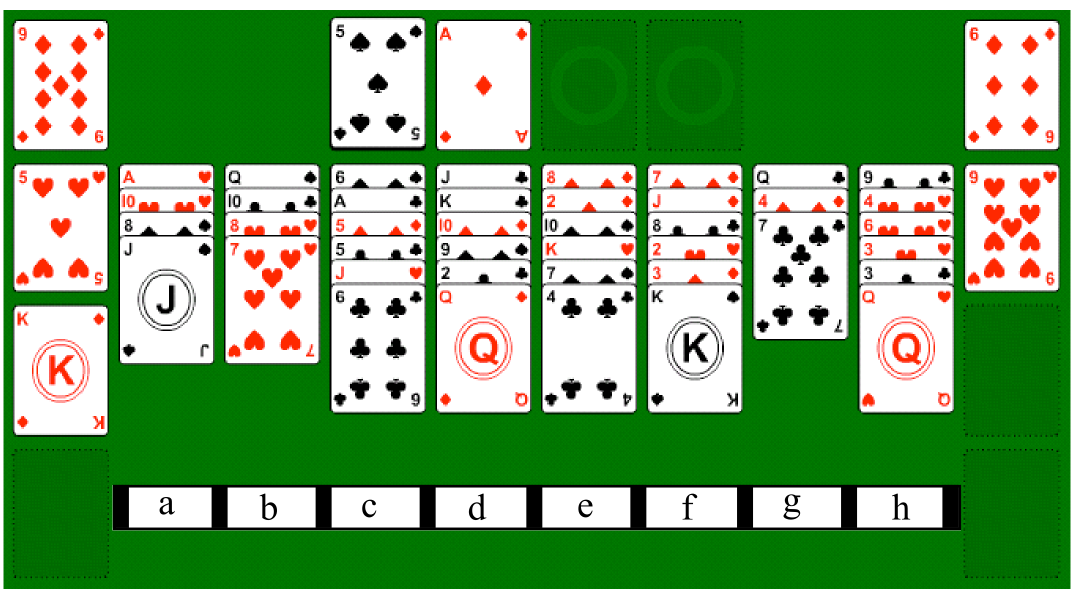


Figure 5.9. An Ace added to Object stacks, but decreases mobility.

Again, we have made some incremental progress by this sequence of two moves. However, we now have only 3 empty Free Cells. As I stare at the game situation shown in Figure 5.9, I remember the 8-move sequence that I decided to not use. This time I see how to do an even longer sequence. I will begin by playing the 6 of clubs on the 7 of clubs, they by making the Jack of hearts a playable card. I will then move the top three cards in Main Stack a to the three empty Free Cells. I will continue by playing the Ace of hearts to an Object Stack, and the Jack, 10, 9, 8, and 7 of hearts to Main Stack a. (Note that moving the 8 and 7 of hearts to Main Stake a requires first moving the 7 of hearts to an empty Free Cell). The result is shown in Figure 5.10.

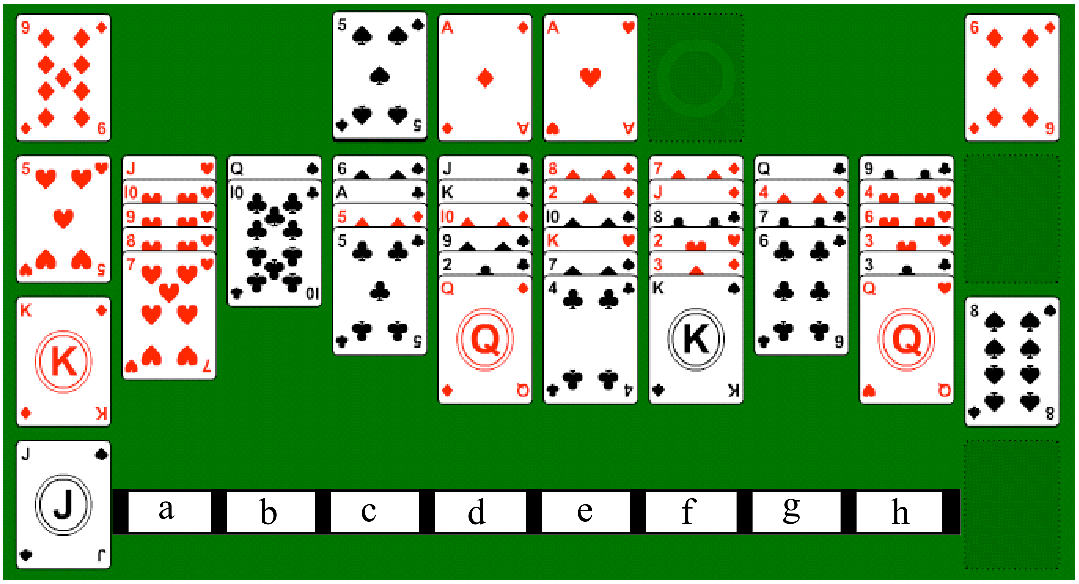


Figure 5.10. The game situation after a very long sequence of moves.

I am now down to having just two empty Free Cells. However, I have created a Main Stack with a long ordered sequence of hearts. Experience in playing the game has taught me that this is desirable to create Main Stacks that contain long sequences of a suit. In this particular example, suppose that I eventually manage to get the 2, 3, 4, 5, and 6 of hearts to the Object Stack. Then I will be able to add my long sequence of hearts in Main Stack to the heart Object Stack.

Undaunted, I plunge ahead, planning another sequence of moves. I notice that by moving the 5 of clubs onto the 6 of clubs, and then the 5 of diamonds to an empty Free Cell, I can move the Ace of clubs to the Object Stacks. If I then move the 4 of clubs onto the 5 of clubs, I will be able to add the s, 7, and 8 of spades to the space Object Stack. The result of this 7-move sequence is shown in Figure 5.11.

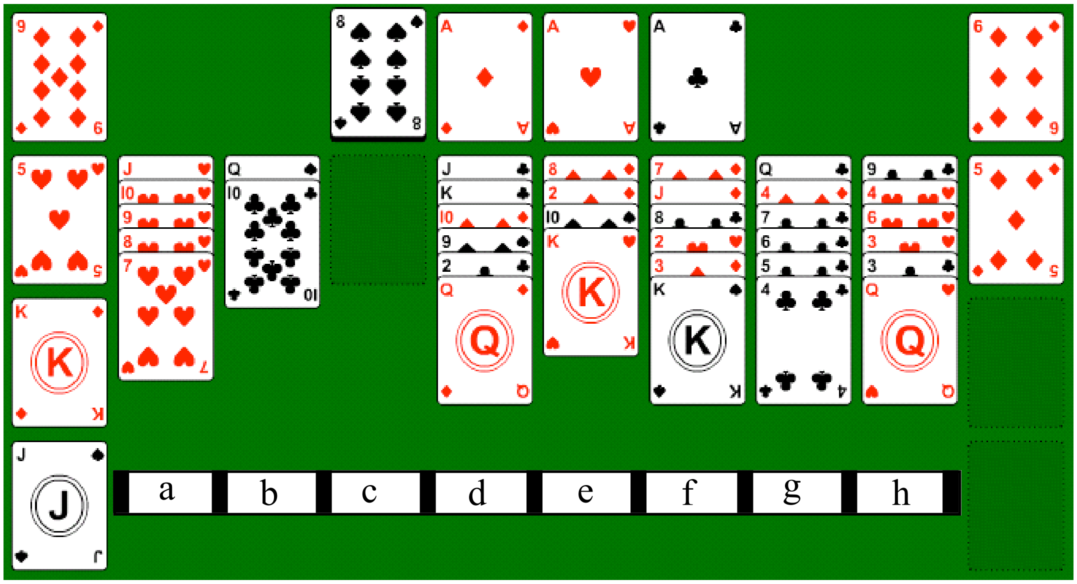


Figure 5.11. A 7-move sequence creates an empty Main Stack.

This was an excellent 7-move sequence. It increased the number of cards in the Object Stacks, and it increased my mobility.

The next sequence of moves that seems to me worth exploring is to move the King of diamonds to the empty Main Stack, the Queen of diamonds onto the King of diamonds, and the 2 of clubs onto the Ace of clubs in the Object Stack. This sequence of three moves does not change my mobility, and it adds a card to the Object Stacks. However, I see that the sequence can be continue by playing the 9 of spades to the spade Object Stack, and the 9 of diamonds onto the 10 of diamonds. This will increase my mobility. Figure 5.12 shows the results of this 5-move sequence. Note that I have added cards to the Object Stacks and I have increased my mobility.

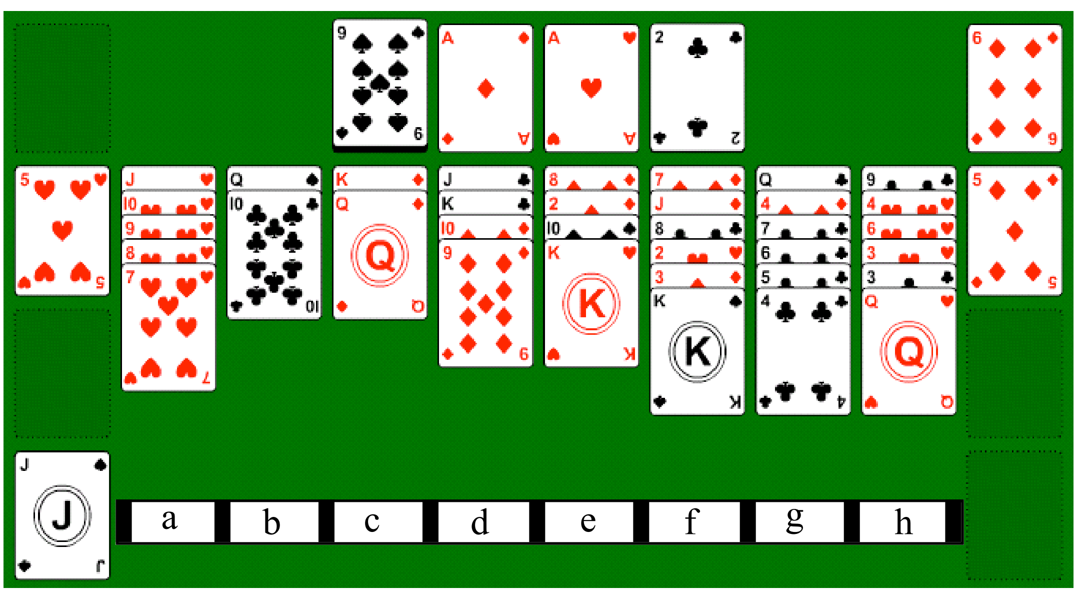


Figure 5.12. A 5-move sequence increases mobility and adds to the Object Stacks.

It now becomes evident that if I move the Queen of hearts onto the King of hearts, I can play a sequence of clubs onto the club Object Stack. The result is shown if Figure 5.13.

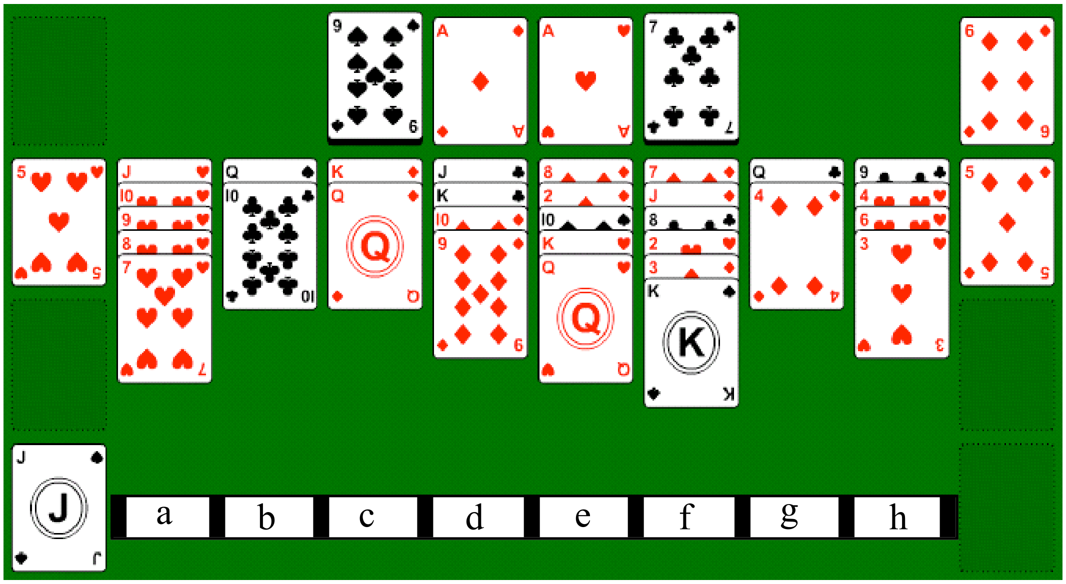


Figure 5.13. A sequence of clubs is added to the club Object Stack.

Based on my long years of experience in playing this game (one of my "mild" game addictions), it is now clear that I will win the game. I can see, for example, that I can create another empty Free Cell by adding the 6, 5, 4, and 3 of hearts to Main Stack a. I will follow that by moving the 9 of clubs onto the 10 of clubs and using Main Stack h as I create a sequence of diamonds. The result is shown in Figure 5.14.

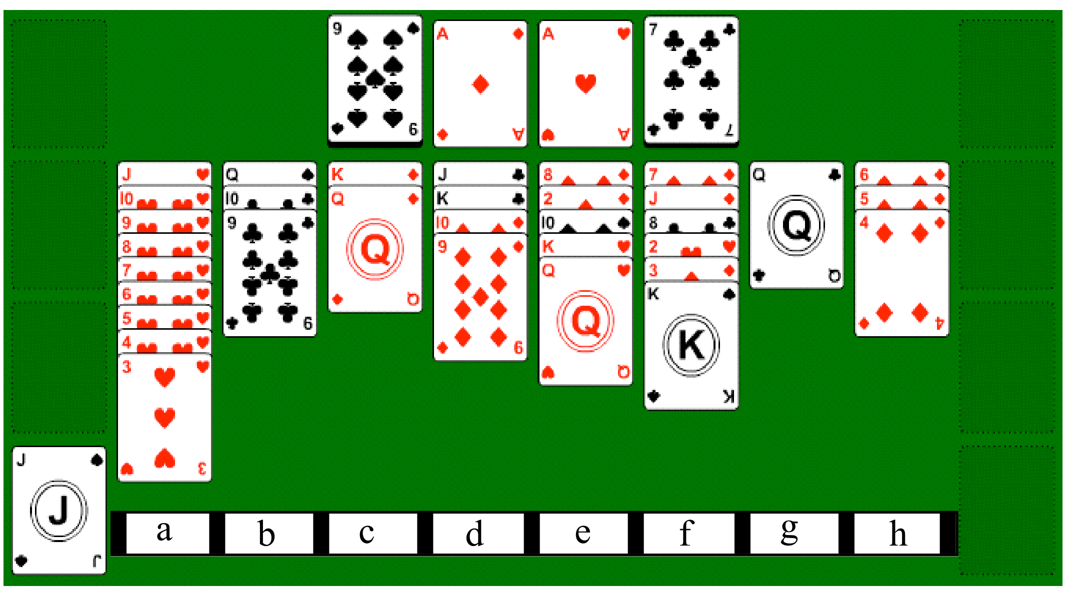


Figure 5.14. Notice the large number of Free Cells.

Even if you have never played Eight Off before, you should have no trouble continuing from the situation in Figure 5.14 and winning the game.

A Warning About the Building Sequences Strategy

In playing this game, I have made use of a strategy of building sequences in the Main Stacks. However, I did not provide an appropriate warning to go along with this game-specific strategy. Imagine that the game situation looked exactly as in Figure 5.14 except that the two of hearts was the first card in Main Stack a. Would I still be able to win the game?

It is not immediately obvious that I can win. To uncover the 2 of hearts, I need to move the 9 cards sitting on top of it. I only have 7 empty Free Cells. If I am cleaver enough, I still might win.

After a little thought, I see that if I begin by creating an empty Main Stack, I can eventually free up the 2 of hearts.

This illustrates an important concept in game playing and more general problem solving. As you employ various strategies to decide on actions that seem to help move toward winning a game or solving a problem, you may well be working yourself into a hole from which there is no recovery except back tracking. In some games and in some real-world problems it is easy to back track. In others, it isn't easy, and it may be impossible. An increasing level of expertise in a game or in a real-world problem solving allows one to avoid some of the dead end, losing sequences of actions that various strategies suggest might be helpful. Having a large repertoire of problem-solving strategies is helpful, but it does not guarantee success.

The one-deck solitaire game fortress (available for free play at http://www.acecardgames.com/en/) has some characteristics somewhat similar to Eight Off. If you have learned to play Eight Off and not learned to play Fortress—or, vice versa—this provides a good opportunity to analyze transfer of learning between the two games.

Tetris

There are relatively few computer games that women enjoy more than men. Tetris is one of these. It is a solitaire (one-player) game, but it is not played using a deck of cards. Tetris (sometimes called Penta) is a available on a huge range of handheld, game machine, and computer platforms. Quoting from http://en.wikipedia.org/wiki/Tetris:

> ***Tetris*** is a puzzle game invented by Alexey Pazhitnov (last name sometimes transliterated Pajitnov) in 1985, while he was working for the Academy of Sciences in Moscow, Russia during the days of the Soviet Union. Pajitnov has cited pentominoes as a source of inspiration for the game. Its name is derived from the Greek word "tetra" meaning *four*, as all of the blocks are made up of four segments.
>
> The game (or one of its many variants) is available for nearly every video game console and computer operating system, as well as on devices such as graphing calculators, mobile phones, and PDAs. *Tetris* has even appeared as part of an art exhibition on the side of Brown University's 14-story Sciences Library [1]. The game first gained mainstream exposure and popularity in the late 1980s beginning in 1988 [*citation needed*]. *Tetris* consistently appears on lists of the greatest video games of all time; it is believed to be the best selling game ever, due to its wide availability on almost every modern computer and game system made.
>
> **Gameplay**
>
> Seven randomly rendered tetrominoes or tetrads—shapes composed of four blocks each—fall down the playing field. The object of the game is to manipulate these tetrominoes with the aim of creating a horizontal line of blocks without gaps. When such a line is created, it disappears, and the blocks above (if any) fall. As the game progresses, the tetrominoes fall faster, and the game ends when the stack of tetrominoes reaches the top of the playing field.

Playing this game requires hand-eye coordination, as well as quick recognition of figures in two dimensional space and quick decision-making. I am relatively poor in all of the abilities that it takes to become good at this game. Thus, it is not surprising that I do not enjoy playing Tetris.

However, I find it interesting to introspect as I play the game, and I find it interesting to see how practice makes me better at the game. At a beginner's level, the game can be set so that the pieces fall very slowly and one can experience success. One's mind/brain/body adjusts to the demands of the game (learns).

I find it interesting to see/sense this learning occurring, and that with practice I get better. Through playing this game, I have gained increased appreciation for the learning capabilities of my mind/brain/body.

Final Remarks

I suppose that meditation and one-player games have certain things in common. For me, when I am playing a game such as Klondike, I shut out the outside world. The cares of the outside world go way.

I also feel that this shutting out of the outside world and being deeply involved in an activity provides an example of what Mihaly Csikszentmihalyi call flow.

Activities for the Reader

1. If you have had experience with meditation, think about some of the similarities and differences between meditation and playing one-player games.
2. Select a solitaire game that you have not previously played. Introspect, and then write notes to yourself about these introspections, as you learn to play the game. For example, you might think about the challenge of learning the rules, and how this challenge compares with learning the rules of appropriate social behavior in a particular situation, or learning the "rules" for carrying out some job or task. You might think about how you get better at playing the game as the rules become internalized—sort of automatic, governing your behavior with little conscious thought. You might think about how the game is similar to and different from other solitaire games you have played.
3. Suppose that you are playing a game of solitaire, and you "take back" a move or "peek" at a hidden card, in violation of the rules of the game. Is "cheating" an appropriate word to describe this situation? Compare and contrast this activity with that of cheating on a test or cheating on one's income tax return. Can you think of a more appropriate term to use in a one-player game-playing situation?

Activities for use with Students

1. Playing cards and card games have a very long history. Select some aspect of this history that interests you, study it, and write a report on your findings. To the extent possible, tie your findings in with other historical events and people. For example, it is speculated that Napoleon Bonaparte developed the solitaire games *Napoleon at St. Helena* and *Napoleon's Square*.

2. Find a game of solitaire that you have not played before. Learn to play it. Then do a personal compare and contrast with a solitaire game that you already know how to play. Which game is more fun, more challenging, more attention-holding, and so on. Which game would you recommend to a friend, and why?
3. In your own words, explain the difference between a puzzle and a one-player game. Which do you like better, and why?

Chapter 6

Two-Player Games

There are many different kinds of two-person games. You may have played a variety of these games such as such as chess, checkers, backgammon, and cribbage. While all of these games are competitive, many people play them mainly for social purposes. A two-person game environment is a situation that facilitates communication and companionship.

Two major ideas illustrated in this chapter:

1. Look ahead: learning to consider what your opponent will do as a response to a move that you are planning.
2. Computer as opponent. In essence, this makes a two-player game into a one-player game.

In addition, we will continue to explore general-purpose, high-road transferable, problem-solving strategies.

Tic-Tac-Toe

To begin, we will look at the game of tic-tac-toe (TTT). TTT is a two-player game, with players taking turns. One player is designated as X and the other as O. A turn consists of marking an unused square of a 3x3 grid with one’s mark (an X or an O). The goal is to get three of one’s mark in a file (vertical, horizontal, or diagonal). Traditionally, X is the first player. A sample game is given below.

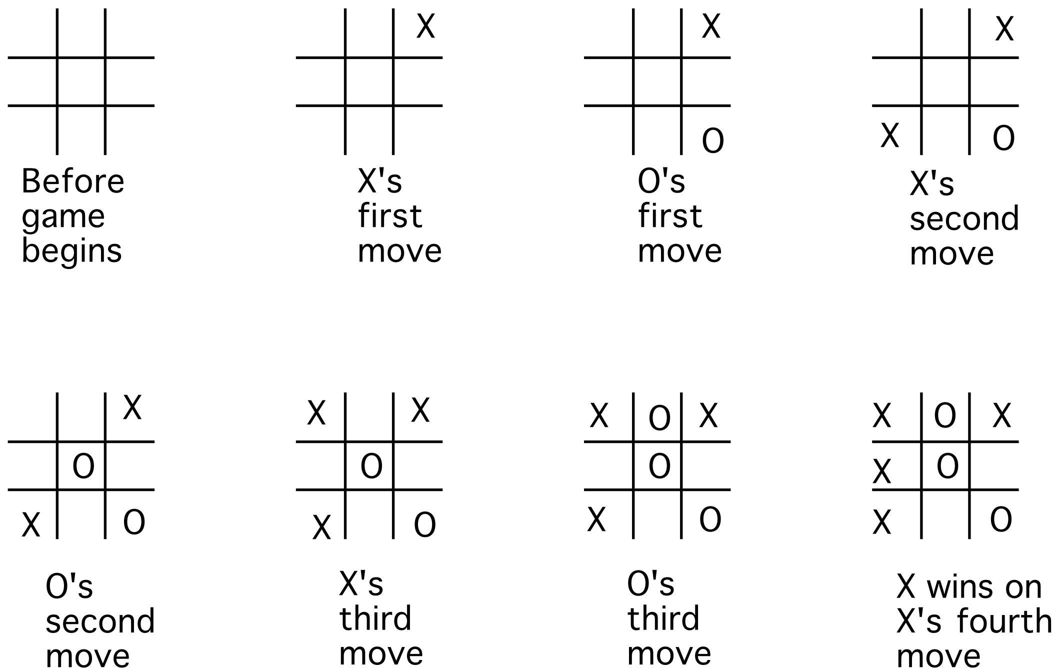


Figure 6.1. Example of a Tic-Tac-Toe game.

TTT provides a good environment in which to explore how a computer can play a game. You are familiar with the idea of random numbers. For example, if you designate one side of a "true" coin as a 0, and the other side as a 1, then repeating flipping this coin generates a random sequence of 0's and 1's. If you repeatedly toss a "true" six-sided die, you will generate a random sequence of integers in the range [1, 6]. In many games, a spinner is used to generate random moves. The process of shuffling a deck of cards is a process of randomizing the locations of the cards in a deck.

Randomness is a complex area of study. For example, suppose you throw a pair of "true" dice, and add up the total. You will get an integer in the range [2,12]. However, a sequence of such throws will not produce a random sequence of integers in this range. Some numbers, such as 2 and 12, will occur much less frequency than others. The number 7 will occur far more frequently than 2 or 12. The study of this and related types of situations is part of the field of probability.

It turns out that random numbers are quite important in many non-game settings. For example, an educational researcher is conducting an experiment in which one set of students receives a certain treatment, and a different set receives a different treatment. To decide which student gets a particular treatment, all of the student names are written on identical small pieces of cardboard and placed in a box. The box is then thoroughly shaken and the contents thoroughly stirred. Then names are drawn out one at a time, alternately placing the name into the group to receive the first treatment or the group to receive the second treatment.

Computer programs have been developed that generate pseudorandom numbers. (See http://en.wikipedia.org/wiki/Pseudorandomness.) Quoting from the Wikipedia:

> A pseudo-random variable is a variable which is created by a deterministic procedure (often a computer program or subroutine) which (generally) takes random bits as input. …

Pseudo-random number generators are widely used in such applications as computer modeling (e.g., Markov chains), statistics, experimental design, etc. Some of them are sufficiently random to be useful in these applications. Many are not, and considerable sophistication is required to correctly determine the difference for any particular purpose.

You know that computers can play some games quite well. Perhaps you believe that is a computer has been programmed to play a game, the computer will never lose. However, that is not the case. Let's use TTT for an example. Suppose that a computer has been programmed to make random moves when playing against a human opponent. When it is the computer's turn to make a move, it selects one of the legal available moves at random, and makes that move. As you might expect, a human player can often beat such a computer program.

Your students may enjoy creating a "by hand" simulation of this situation. Prepare nine small pieces of paper that are numbered 1, 2, … 9, respectively, and place them in a small box. Number the spaces of a TTT board with the nine digits as follows:

1	2	3
4	5	6
7	8	9

Figure 6.2. A TTT board with its squares numbered 1 to 9.

Let us suppose, as an example, that X is going to play first and that X's moves will be randomly generated. You play O against the random mover. Start at step 1.

1. To generate X's move, stir up the pieces of paper in the box and draw one out. Its number will be the space in which X moves. Then one of the following 3 situations occurs:

   1a. If this move completes a file with three X's, X wins and the game ends.

   1b. Otherwise, if this is the ninth move in the game, the game ends and is a draw.

   1c. Otherwise, go to step 2.

2. You (O) make a move. If this produces a file with three O's, you win and the game ends. Otherwise, look into the box and remove the slip of paper that contains the number corresponding to the move you just made. Then go to step 1.

The set of steps can easily be written as a computer program. The set of steps is an algorithm that generates moves for X and determines who wins or if the game is a draw. It should be evident to you that just because a computer has been programmed to play a game it does not follow that the computer wins all the time or will always play well. Indeed, the random number player will play poorly. However, it will occasionally best a child who is just learning to play the game.

The idea of using random numbers in a computer program adds an unpredictability dimension to what a computer can or cannot do. People often argue about limitations of computers by stating that a computer can only do what it is told to do in a computer program. However, when this "telling the computer" includes making use of random numbers, the programmer or the program user may not be able to accurately predict the results.

A TTT Algorithm that Never Loses

Next, we will explore a TTT algorithm that can be followed by a person or programmed into a computer, and that plays quite well. This algorithm is specifically designed to produce moves for X, who moves first.

Begin by numbering the nine squares on the grid as follows:

2	6	3
7	1	8
4	9	5

Figure 6.3. TTT board numbered to help specify a game-playing algorithm.

The first player (X) uses the following 4-part algorithmic procedure to determine what move to make at each turn:

1. Examine the grid and carry out the following sub-steps:
   - 1a. If there are one or more files that contain 2 X's and no O's, play in the one that contains the lowest numbered blank space. Thus, you win the game, and the game ends.
   - 1b. Otherwise, if there is only one blank square remaining, play in it. The game then ends as a draw.
   - 1c. Otherwise, go to step 2.
2. If there is a file containing 2 O's and no X, play in that file. Otherwise:
3. Consider each possible remaining legal move, from the lowest numbered one to the highest numbered one. For each, see if making that move would result in the creation of two or more distinct files each containing two X's and no O's. If (and as soon as) such a possible move is discovered, make it. Otherwise:
4. Move in the lowest numbered unused square.

Through some careful thought, you should be able to convince yourself that X (playing first) never loses. This algorithm that never loses is dependent on X going first, on the board being numbered as shown, and on the "look ahead" feature in step 3.

Use of the *look-ahead strategy* is a key feature in writing a program that plays a good game of chess, checkers, or other somewhat similar games. On a more general note, look ahead is a process of considering the consequences of possible actions—before taking an action. In essence, in look ahead allows one to study possible outcomes of an action. This is important in computer game playing, but it is also an important and routine aspect of functioning as a responsible human being. A game-playing environment (various types of games and computer simulations) can be used as an aid to helping students learn to look ahead and gain increased responsibility for their own actions.

The 3 x3 TTT game is not much of an intellectual challenge. There are a variety of games that can be considered as modifications of TTT (Boulter, 1995). At Boulter's Website, you can play on boards of size 3 x 3 up to 7 x 7, and the boards need not be square. You can set your own rules for how many squares in a row are needed for winning. Games that are somewhat similar to TTT in that one wins by getting n-in-a-row include connect four, gobblet, nine men's morris, pente, three men's morris, gomoku, and quarto. There are also 3-dimensional variations of TTT.

Gomoku

Quoting from http://www.springfrog.com/games/gomoku/:

> Considered by many to be one of the world's greatest strategy games, Gomoku was introduced to Japan by the Chinese in 270BC. The full name of Gomoku is actually Gomoku Narabe, which is Japanese for "five points in a row." Japanese chronicles show that at the time of the late 17th and early 18th Century Gomoku Narabe was at its height of popularity, being played by young and old alike. By 1880 the game had reached Europe where it is also known as Gobang.

Gomoku can be thought of as a much more challenging version of Tic-Tac-Toe. The goal is to get exactly five markers in a horizontal, vertical, or diagonal file. Many people enjoy playing this game. It is also a game that can be used as a programming challenge in an Artificial Intelligence course. See, for example, http://web.cs.wpi.edu/~ruiz/Courses/cs4341_A97/project.html. This illustrates a somewhat common and very valuable use of games in education.

I downloaded a free version of Gomoku for my Macintosh computer from http://www.macgamesandmore.com/best_freeware.html. Notice that a number of free games for the Macintosh are available at this site. The free version had six levels of difficulty, and the board could be set for various sizes. (See the Preferences available under the Gomoku pull down menu.) Figure 6.4 illustrates the end of a game in which I played black, and won.

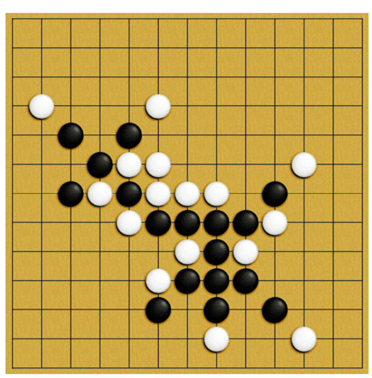


Figure 6.4. Black won this Gomoku game.

Gomoku is a strategy game that most people find quite challenging. Many computer implementations of this game allow the human play to select the level of his or her (computer) opponent. When first learning to play the game, you can select a very weak computer opponent. In that environment, you can experiment with strategies and perhaps develop a winning strategy against the weak opponent.

Notice the two dimensionality of the game play. To play well, you must consider threats and opportunities throughout the 2-dimensional board. You must do careful look-ahead to thwart threats and develop possible winning positions.

Connection Games

There are many variations of 2-player games in which a player attempts to form a connection between two borders. Figure 6.5 shows an empty 11x11 cell Hex game board and a completed game in which blue has won by completing a connection between the two blue borders. The screen shots are from http://www.cs.ualberta.ca/~javhar/hex/.

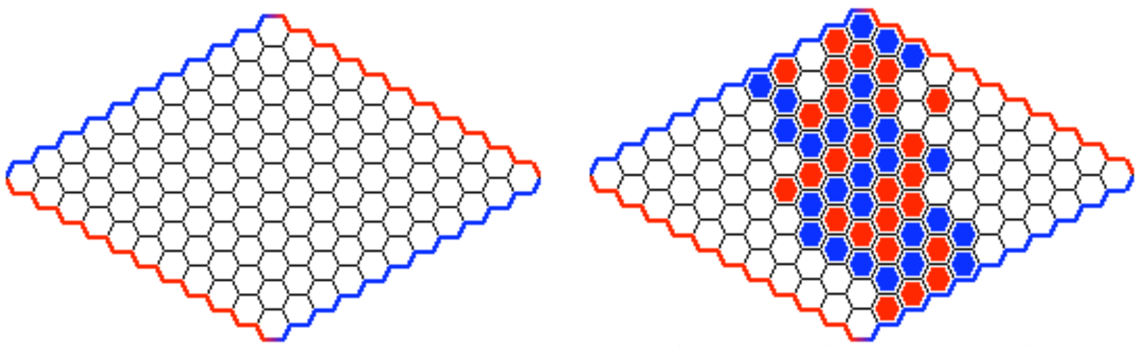


Figure 6.5. Hex board and a completed game won by blue.

In Hex, players take turns coloring in one of the empty cells with their color, or placing a token of their color on the board. Mathematicians have proven that the player moving first can always win—if the player avoids making a mistake that then puts the second player into the position of having a winning strategy. Explicit winning strategies are known for board sizes up to 9x9, but not for larger boards.

For more information about connection games, see Pegg (2005). His interest in games in education is broader than just connection games. Quoting from Pegg's short article:

> At a family gathering a few years back, I taught the game of Go to a young nephew. In the space of a few hours, he learned the rules, various tools of strategy, and applications of that strategy. He recognized the traps I set for him in a series of quick demonstration games. Then we played a 13-stone handicap game on a 9x9 board, and he beat me.
>
> In math instruction, one learns the rules, various tools of strategy, and applications of that strategy. Students learn to recognize common traps within a series of demonstrated problems. Notice the parallels here. **Could abstract games work as part of a school curriculum?** Historically, outside of Go and Chess, there haven't been many books on abstract games. That started changing in 1959 with Martin Gardner's column "The Game of Hex". [Boldface added for emphasis.]

Chess

In some two-person games, there are ranking systems that rank the best players in a country or worldwide. For example, look at the chess site of the World Chess Federation, http://www.fide.com/ratings/topfed.phtml. As of 1/29/07, I see that Russia is the top ranked country in the world, followed by Ukraine and then the United States. I see that the top ranked woman is number 13 in the combined list of top men and women chess players.

Interestingly, chess remains a widely popular two-person game even though an inexpensive chess program playing on an ordinary microcomputer can readily defeat the great majority of human chess players.

I have found the history of computer chess to be quite interesting. As electronic digital computers were first being developed and then became commercially available, a number of people decided that computer chess was an interesting and challenging problem. Eventually, computer versus computer chess tournaments were held, and then computer versus highly ranked human players became of interest. In 1997, a computer developed by IBM especially for chess playing beat Garry Kasparov, the reigning world chess champion. See http://www.research.ibm.com/deepblue/.

In recent years, Garry Kasparov has taken a leadership role in developing *Super Chess*, in which a team consisting of a computer and a human play against another team consisting of a human and a computer. This effort is part of ongoing research on how to take advantage of human and machine knowledge and capabilities in working to solve complex problems.

There are several important ideas involved in writing a compute program that will play good chess. The first is having the computer memorize a large number of good opening sequences of moves and the moves needed to win or avoid losing when there are only a small number of pieces remaining on the board. Many such situations have been analyzed by excellent (human) chess players, with the results recorded in books and in other chess publications. Can you imagine the human memorization challenge of memorizing 15,000 to 30,000 or more different sequences of moves, with some of the sequences being 10 or more moves by you and by your opponent? This is a trivial task for a computer, but is an overwhelming challenge to most humans.

The second important idea is evaluating a board position. At any particular time in a game, how can one tell how well each player is doing? It is easy to count pieces remaining on the board. It turns out that mobility of one's pieces is an important consideration, and this can be measured. However, there are many other important considerations, such as the quality of one's defensive structure or offensive thrust, progress toward getting a pawn to the eighth rank (and thus turning it into a Queen), and so on. Much chess research has gone into developing computable schemes for relatively accurately evaluating and rapidly evaluating a board position. A good human chess player may be able to evaluate about two or three board positions per second. This high speed is accomplished mainly by the quick recall of memorized patterns from one's brain/mind. It is not done by quick analysis of all possible moves of individual pieces. The computer program that defeated Kasparov could evaluate 200 million board positions per second.

The third requirement is to have an efficient, fast implementation of the look-ahead strategy. This requires generating huge numbers of sequences of possible moves and evaluating the resulting board positions.

A huge amount of people's time and effort has gone into developing good computer-playing chess programs. A number of early researchers in Artificial Intelligence selected this game and other games as vehicles in which to explore how to develop intelligent-like computer programs. Games were a popular choice of such researchers both because they were an appropriately difficult challenge and because the results could easily be communicated to non-computer people. I am impressed to learn that computer programs have beaten the world's best players of checkers, backgammon, chess, and so on.

There are significant educational implications to such accomplishments. There are many jobs (professions) in which people work with relatively clearly defined sets of rules to solve relatively difficult problems. Over the years, more and more of these jobs are being handled directly by computers or by a combination of people and computers working together. Our educational system needs to understand this situation and to educate accordingly.

The computerization of games and the uses made of artificial intelligence will help you to understanding computational thinking. When you think about solving problems and accomplishing tasks outside the world of games, consider the following two facts:

1. Computer programs have been developed to *facilitate* the play of each of the games considered in this book. The programs "know and understand" the rules sufficiently well to check that a player's moves (be they a human player or a computer) are legal. The computer system "knows and understands" the rules for scoring and winning.
2. For many of the games considered in this book, computer programs have been written that can play the game. These programs can serve as an opponent in two-person games, and as a player in games involving larger numbers of players. In some cases, computer programs have been developed so that they can defeat the best human players in the world.

I have used quote marks around "knows and understands" because the compute does not know and understand in the way a human does. However, a computer can follow and enforce the rules. Similarly, most computer programs that play games do not do this by imitation of how a human knows, understands, and plays a game. However, computers can be programmed to make effective use of their high speed and large storage capacity to play quite well. As you think about facilitating the education of today's children, consider how these computer capabilities and limitations—not knowing and understanding the way that a brain/mind knows and understands—can compete with and can augment humans as they solve problems and accomplish tasks. If a problem situation requires human understanding and working with the complexities of human-to-human interaction, humans far exceed the capabilities of computers. If a problem situation requires knowing and precisely following a fixed set of rules, making use of large amounts of memorized information, and functioning very rapidly, then computers are apt to be able to far exceed the capabilities of humans.

Moreover, keep in mind that computer capabilities are going to continue to rapidly increase. Not only will the computers of the future be faster and have large storage capacity, they will also be "smarter." It may take a large team of human computer programmers several years to develop a computer program that has some useful, new, "intelligent-like" capabilities. Nevertheless, once this programming task is completed, the program can be installed on millions of computers. This rapid and accurate dissemination is not at all like our educational system trying to integrate a new idea into teaching. Part of computational thinking is understanding the computer-based accumulation and rapid dissemination of capabilities.

Checkers

Checkers is a board game played on the same board as chess, but it is a much simpler game. Some of the early research with computerization of checkers involved studying rote learning. In a very simple game such as TTT, it is easy to have a computer memorize every possible sequence of moves that can occur in a game. The computer can then be programmed to use this information in a manner to never lose a game and in a manner to plan sequences of good moves.

Suppose you are a researcher interested in learning the value of memorizing a hundred different opening sequences of moves in checkers. Develop a game playing program and gather baseline data by having the computer play against itself by using the program. Then make a copy of the program and add 100 memorized openings to it of these programs, and then have the two programs play against each other a number of times. You will perhaps learn that this makes little difference in which computer wins, or you may see that the computer with the memorized openings has a distinct advantage.

You can then continue your research, adding to the number of memorized openings, adding memorized sequences to use near the end of the game, and so on. You can experiment with what happens when one computer has only a modest number of memorized openings and end games, while the other has many more. You can test out various board evaluation procedures.

In checkers, as in chess, the number of possible opening sequences is immense. It turns out that brute force memorization of all possible games is impossible with current computers. Indeed, checkers and chess games move relatively quickly into the middle game in which memorization of sequences of moves is no longer of value. As the play proceeds and many pieces are lost, then in chess and checkers one moves into the end game. There, the number of pieces on the board becomes small enough so that memorized sequences of moves are again valuable.

Many real world problems can be thought of in terms of opening, middle game, and end game. Rote memory (perhaps aided by looking up information in a book, referring to one's notes, or use of a computer) can be very valuable in the opening and end game. Thus, a good education focuses on preparing students to handle the "middle game" of the types of problems they will encounter when using their education. Over emphasis on rote memory is a very poor approach to education.

Machine Learning

Suppose that you have two identical computer programs that can play checkers. Call these programs P1 and P2. Each uses the same combination of measures to determining how good a particular board position is. You then add to P1 a set of directions that makes some changes to the board evaluation procedure. These might be random changes or some specific pattern of changes you want to explore in the formula one of the programs is using, perhaps counting mobility more strongly, and advancement of pieces less strongly.

You then have the two programs play against each other a number of times. If P1 is now significantly better than P2, then make a new P2 that has the same board evaluation function as P1 and repeat the whole process. If the two programs remain approximately equal in playing strength, then P1 makes another set of changes to its board evaluation process and a new round of game play occurs.

Voila! You have written a computer program that learns, all by itself, how to play a better game. There are many types of computer-based problem-solving situations in which variations of this technique can be used. Examples include developing a better program to handle voice input to a computer, developing a better program to make money buying and selling stocks, and developing better medical diagnostic programs.

This type of machine learning, and the underlying research and programming, all fits into the general field of Artificial Intelligence. It involves and is an example of computational thinking. Often people and computers work together on this type of machine learning. The best of the improvement ideas developed by humans are combined with the "ideas" that the computer comes up with. The results may well be better than either the humans of the computer can do alone.

Hangman

Many children learn to play the 2-person game named Hangman. One player—the Game Master—thinks of a word, indicates the length of the word, and perhaps provides a clue, such as whether the word is a noun or a verb. The other player—the Word Guesser—attempts to guess the letters in the word. As illustrated in Figure 6.6, correct guesses are entered into their correct location in Target Word. Incorrect letters are added to the Bad Guess list, and each incorrect letter leads to adding one piece to the gallows and the person being hung.

Figure 6.6. Completed example of a game. The initial clues were "eight letter verb."
http://www.freepuzzles.com/PuzzleGames/Hangman/Hangman.asp

Nowadays, some people consider the name of this game and its gallows to be inappropriate for children. It is a simple matter to rename the game (for example, to *Guess my word*) and to establish a rule such as *10 incorrect guesses and the Word Guesser loses*.

In the traditional version of the game, the hangman diagram grows with each incorrect guess. A large number of incorrect guesses leads to the gallows and hung person being completely drawn; the Game Master wins, and the Word Guesser loses.

In a teacher-led setting, the teacher may want to write a large number of suitable words and their clues on pieces of paper, and places them in a box. The Game Master draws one of these pieces of paper from the box, reads the clues to the Word Guesser, and draws the boxes for recording correct and incorrect guesses.

Note that a certain type of intelligence is needed by each player. It is relatively easy to understand how the Game Master can be a computer. The role of the Word Guesser can also be played by a computer. The computer makes use of a large dictionary, information about the frequency of letter usage in words, placement of vowels in words, and so on. Thus, the game of Hangman can help us to learn a little bit about artificial intelligence.

Relative Frequencies of Letters Use

If you want to improve your level of expertise in Hangman and many other games that involve forming or guessing words, then a good strategy is to memorize information such as the relative frequency of letter use in written English. Let's call this the *letter frequency strategy*. There are other lists that can be memorized and are useful in similar games. The Wikipedia site http://en.wikipedia.org/wiki/Letter_frequencies contains letter use frequencies, top ten beginnings of words, top 10 end of words, most common bigrams, and most common trigrams.

An earlier part of this book introduced the strategy: only memorize if quite useful. Word games constitute a large situation in which memorization is very useful. In addition to the ideas mentioned in the previous paragraph, it can be helpful to have memorized the spelling, definitions, and crossword puzzle definitions/clues for tens of thousands of words. With a good memory and quick recall, this memorized information may help you to do very well in certain television quiz or game programs, and in many games that people play.

Even a small amount of this memorization will increase your expertise in Hangman and similar word guessing games. For example, it is not too hard to memorize the two nonsense words ETAOIN SHRDLU. As the frequency table given below indicates, this gives you the 12 most frequently used letter, in their order of use.

Letter	Frequency
E	0.12702
T	0.09056
A	0.08167
O	0.07507
I	0.06966
N	0.06749
S	0.06327
H	0.06094
R	0.05987
D	0.04253
L	0.04025
U	0.02758

Figure 6.7. Frequency estimate for the 12 most used letters in written English.

Such memorization and quick recall is useful in most (if not all) problem-solving domains. In essence, one memorizes solutions to frequently occurring problems or subproblems, and to frequently used aids to solving problems or subproblems.

Othello (Reversi)

The title "Othello" is a registered trademark of Anjar Corporation. The game Reversi was developed well over a hundred years ago, and is essentially the same as Othello. See http://home.nc.rr.com/othello/history/.

This is a two-person game. I have played it many times, but I don't recall ever playing against a human opponent. It is a game that lends itself to playing against a computer or against another person, with both playing on a computer. Some of the advantages of playing it on a computer include:

- There is no need to have the special playing board and pieces.
- Computer catches all illegal moves.
- Computer keeps track of score.
- Computer does all of the "physical" movement of the playing pieces.
- If playing against a computer, one can set the skill level of the computer.

A free version of the game can be played on the Web at http://www.freegames.ws/games/boardgames/othello/othello.htm. The figures shown in this section are from that Website. Figure 6.8 shows the setup at the beginning of the game. The 8x8 board is shown with two black pieces and two white places placed on the board. The flip side of a black piece is white, and the flip side of a white piece is black. Computer versions of the game allow one to set the level at which the compute is to play.

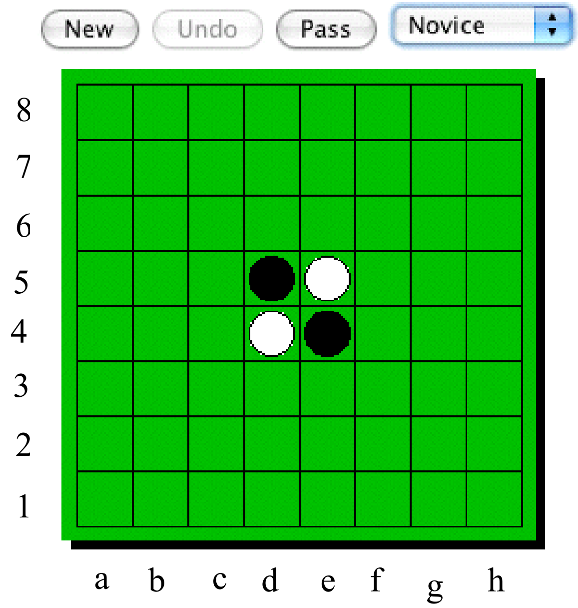


Figure 6.8. Setup at the beginning of an Othello game. Graphics from http://www.freegames.ws/games/boardgames/othello/othello.htm

Brief summary of rules.

- A legal move by black is one that causes one or more of the white pieces that are connected together in a row, column, or diagonal segment to be surrounded by having a black at each end. The result of such a move is that all white pieces that are in the connected segment are flipped from white to black. Note that a move may surround more than one segment, and that all of the white pieces in all of the surrounded segments are flipped to from white to black.
- If black has one or more legal moves, black must make one of them. Otherwise, black passes.
- A similar set of rules apply to white.
- The game ends when both players pass, one right after the other, or when the board is completely full. Each player's score is the number of pieces of the player's color that are on the board when the game ends. A game may end in a win for either player, or in a tie.

The X's in Figure 6.9 shows the four legal moves that black can make from the starting board position of Figure 6.8.

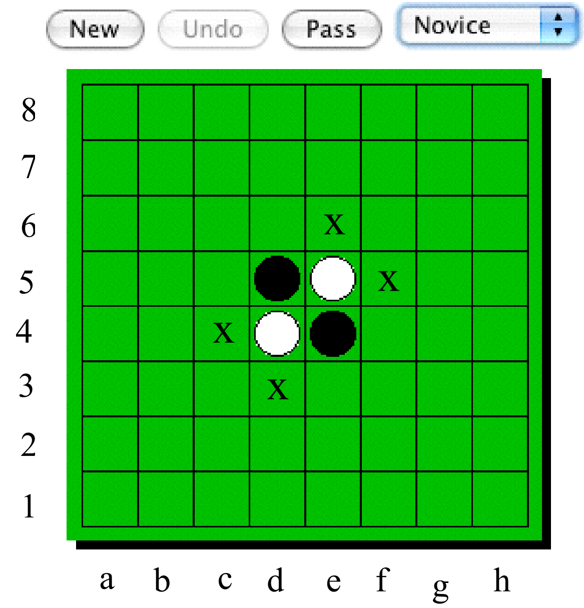


Figure 6.9. The four possible legal first moves of black.

Figure 6.10 shows the results of black playing in d3 and then white playing in c5.

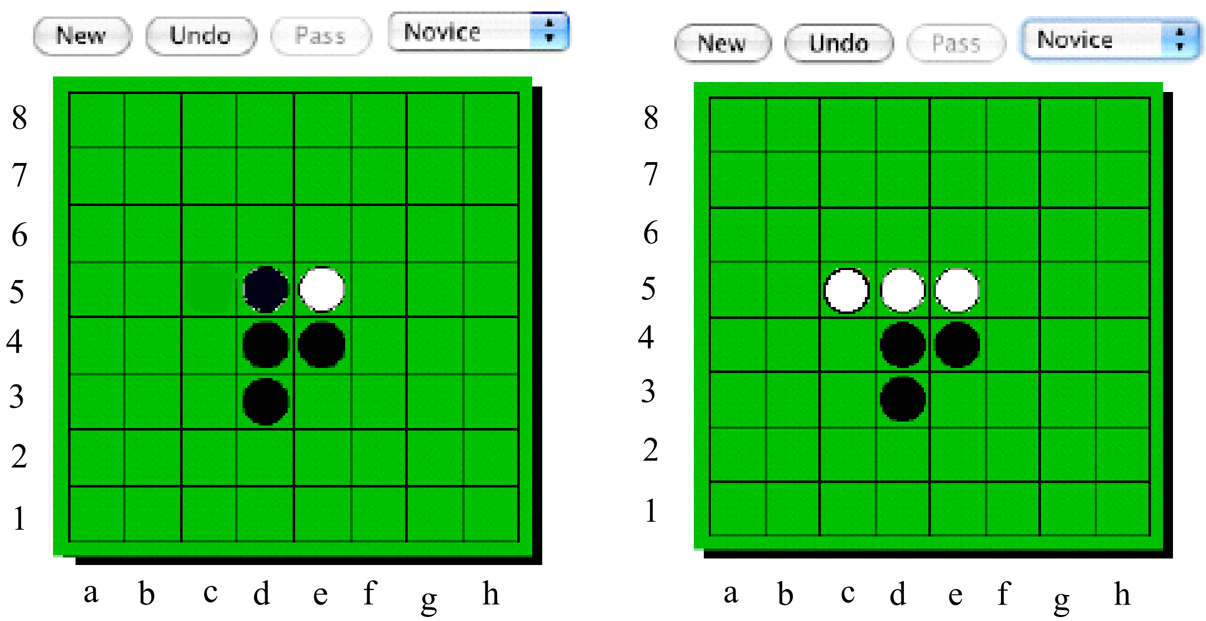


Figure 6.10. Black plays in d3 and then white plays in c5.

At the end of the moves illustrated in Figure 6.10, both black and white have three points. Figure 6.11 shows black's next legal moves.

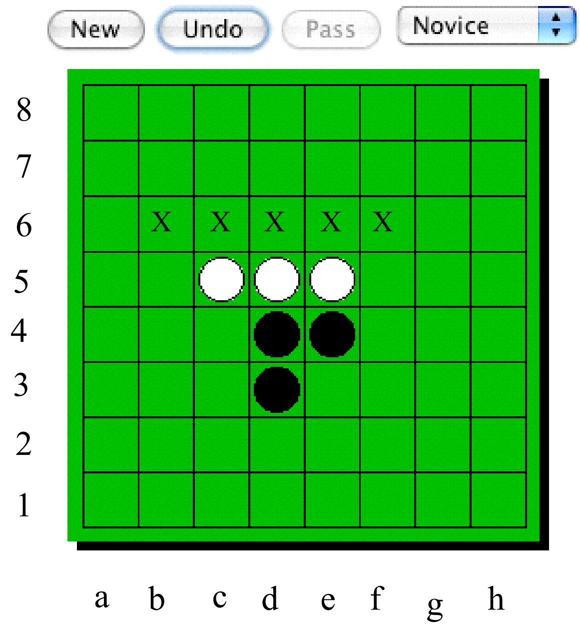


Figure 6.11. Blacks possible moves.

Figure 6.12 shows the results of black making the move f6 and white responding with the move e3.

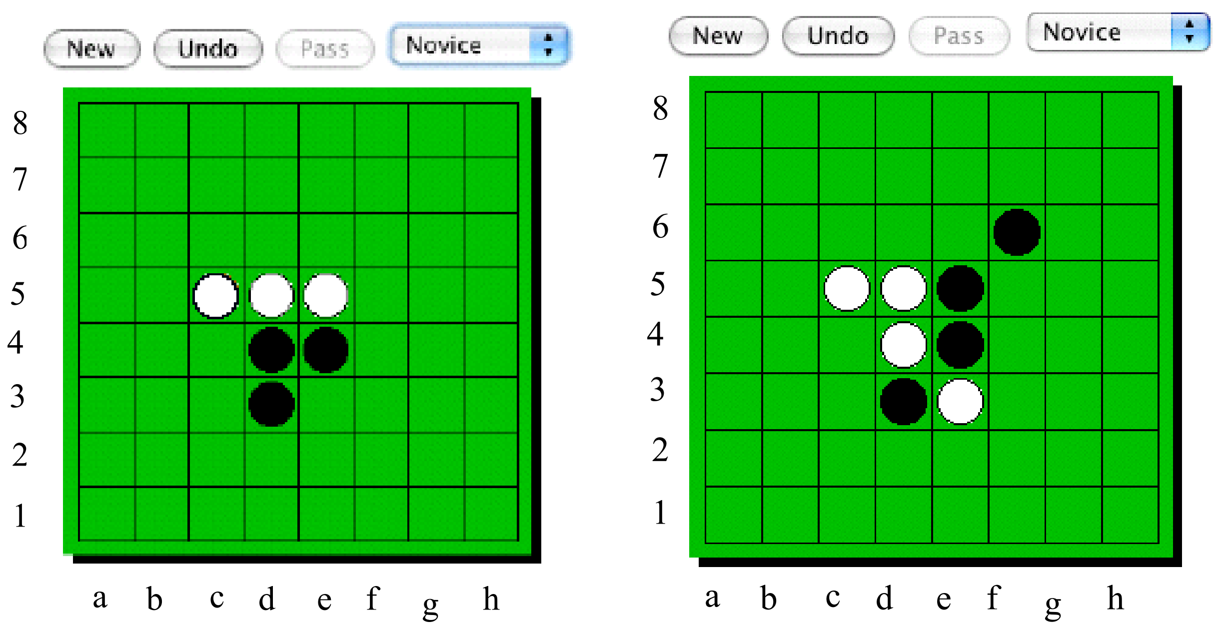


Figure 6.12. Black moves into f6 and white responds with e3.

Othello is a two-person game with simple rules, but with a high level of complexity. If you don't believe this, try playing against the computer when it is set at a relatively high level of expertise.

The Website http://home.nc.rr.com/othello/rules/ contains an analysis of some strategies and a history of the game. In earlier parts of this book, I have tended to focus on strategies that might be useful in many different game and non-game problem-solving situations. Research in problem solving suggests that general-purpose problem-solving strategies tend to be somewhat weak as compared to strategies that are quite specific to a particular game or type of problem. A good example of this is the mobility strategy discussed earlier in this book. In many different games and in many non-game problem-solving situations, maintaining or increasing one's options (one's level of mobility) may be helpful. This is a "wait until something better comes along" type of strategy. One first looks for a good move that may contribute significantly toward achieving a winning position. If no such move can be found, than a fall back approach may well be to make a move that maintains or increases mobility.

The Website http://home.nc.rr.com/othello/strategy/ discusses some strategies that are specific to Othello. For example, it offers the suggestions:

1. Memorize some common (good) opening sequences.
2. In the early part of the game, don't grab too many of your opponents discs.
3. Try to avoid placing discs in the three squares adjacent (horizontal, vertical, diagonal) to the corner squares.
4. Try to play in the corner squares.

If you have not developed any strategies specific to Othello, then learning just a very few strategies can greatly improve your level of play. This same concept holds in most problem-solving situations. There is usually considerable advantage to learning some strategies that are specific to the type of problem one is attempting to solve.

Learning *domain-specific problem-solving strategies* is an important aspect of increasing one's level of expertise in a specific domain.

Dots and Boxes

Dots and boxes is quite easy for a child to learn to play. Two children can play against each other, or one can play against a computer. Figure 6.12 illustrates a game played on a 2 x 2 grid. The game is more complex and challenging when played on larger grids.

Starting with an empty grid of dots, players takes turns adding a single horizontal or vertical line between two unjoined adjacent dots. A player who completes the fourth side of a box earns one point and takes another turn. The game ends when no more lines can be placed. The winner of the game is the player with the most points. For details and strategies, see http://en.wikipedia.org/wiki/Dots_and_boxes.

Very young plays have trouble learning to plan ahead—to think about what how their opponent may respond to a certain move. Dots and boxes is a good game in which to practice that strategy.

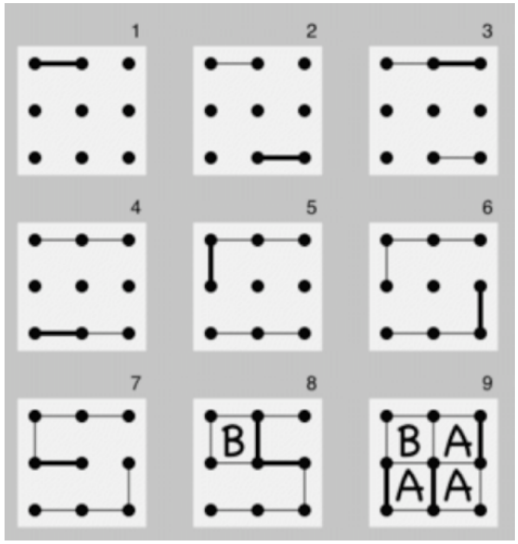


Figure 6.13. Example of 2 x 2 dots and boxes.
http://en.wikipedia.org/wiki/Image:Dots-and-boxes.png

Cribbage

Cribbage is a popular 2-person game. The game is played using a standard 52-card deck of playing cards and a cribbage board, which is used to show the score accumulated by each player. Nowadays, one can also play cribbage against a computer, or people can play against each other online.

Quoting from http://en.wikipedia.org/wiki/Cribbage,

> According to John Aubrey, cribbage was invented by Sir John Suckling, a British poet, in the early 17th century. It was derived from an older card game called Noddy. It has survived, with no major changes, as one of the most popular games in the English-speaking world.

The rules and play in this game are moderately complex. Details are available at http://www.cribbage.org/rules/default.asp and at the Wikipedia site mentioned above. Here is the gist of the game. The two players are each dealt six cards. Each player keeps four cards and discards two cards face down into a crib. The four cards in the crib belong to the dealer and are scored after the playing of the cards in each player's hand.

A starter card is turned up from the remaining deck of cards, and players take turns playing a card. Detailed rules govern this playing of the cards, and either player can score points during this playing process.

After each player has played his or her four cards, each player determines the point value of their four cards plus the starter card. Then the dealer determines the score of the crib plus starter card.

In brief summary, the game:

1. Involves randomness in using a shuffled deck of cards.
2. Involves strategy in deciding which two cards to discard into the crib. The strategy a player selects depends on whether the player will get the crib (that is, score the crib for him or her self) or the player's opponent will get to score

the crib. Randomness is involved because the scoring is based on the four cards in the crib plus the starter card that has not yet been turned up.

3. Involves strategy in the play of the cards.
4. Involves counting the value of one's hand and the crib.

Figure 6.14 shows some of the rules for scoring during play, one's hand, and the crib. Notice that two of a kind (pairs), three of a kind (triples) and a variety of other combinations score points. There is a strong resemblance to various Poker games.

	Points Earned	
Cards	**During Play**	**Hand or Crib**
Two of a kind (pair)	2	2
Three of a kind (triple)	6	6
Four of a kind (quadruple)	12	12
Straights of three or more cards: per card	1	1
15-count (sum of any combination of cards)		2
Four-card flush (only in the hand)		4
Five card flush		5

Figure 6.14. Some of the rules for scoring in cribbage.

Cribbage is a competitive game that includes some randomness, a variety of strategies, and certain aspects of "bluffing." The Wikipedia site http://en.wikipedia.org/wiki/Cribbage#Tactics contains examples of some strategies (tactics) that are specific to cribbage. That is, through learning and appropriately using some of these strategies, you can significantly improve the level of your play. However, these strategies tend to not transfer to other games or to non-game problem-solving situations.

Activities for the Reader

1. Consider how your brain/mind processes a spoken or written sentence. An idea or thought is transformed into an oral or written utterance. Pay particular attention to the pattern processing skills involved, much like the pattern processing that goes on when a skilled player is playing checkers or chess. Then do a compare/contrast between developing a computer program to play a good game of checkers or chess, and developing a computer program to carry on an oral or written dialog with a human.

2. While some authors still use pencil (or pen) and paper to write books, I author at a computer keyboard. As I write, I take advantage of the spelling checker, grammar checker, software to measure readability level, dictionary, and thesaurus built into the word processor. I generate the table of content entries and index entries, and do the detailed layout for desktop publication as I write. I make frequent use of the Web, and occasional use of email (to get information and ideas from colleagues) as I write. Compare/contrast this with the idea of super chess developed by Kasparov, or with some other example of human and machine working together to solve a complex problem or accomplish a complex task.

Activities for use with Students

1. If some of your students know how to play dots and boxes, have them teach the rest of the class. If you don't have any dots and boxes players in your class, then provide whole class instruction or take some other approach so that all of your students know the rudiments of the game. After all have had an opportunity to play the game quite a few times, give the following writing assignment:

    > Explain how to play dots and boxes. Your explanation should include both the rules of the game and some of your ideas on how to make good moves. You may also want to write about how well you currently play the game and how you might go about getting better at playing the game.

2. Repeat (1) above for some other game, such as hangman. This activity can be used many times. It gives students practice in organizing their knowledge and understanding of a game. It is a writing challenge to write the rules of a game in a manner that others can read and understand them. It is a challenge to figure out how to make good moves, and then to tell (in writing) how to make good moves. It is important to learn to do metacognition and self-assessment to figure out one's level of competence and how to get better.

Chapter 7

Games for Small and Large Groups

This chapter explores some multiplayer games. In some of the games, each player plays as an individual, competing against other individuals playing the game. This is typical in board games such as Monopoly or in the card game Hearts. In other games, such as pinochle and Bridge, teams compete against other. The rules of the game allow some sort of communication among the two or more members of a team in such a game. Often the allowable communication is quite limited, and part of the process of learning the game is learning how to communicate effectively subject to severe restrictions.

Monopoly

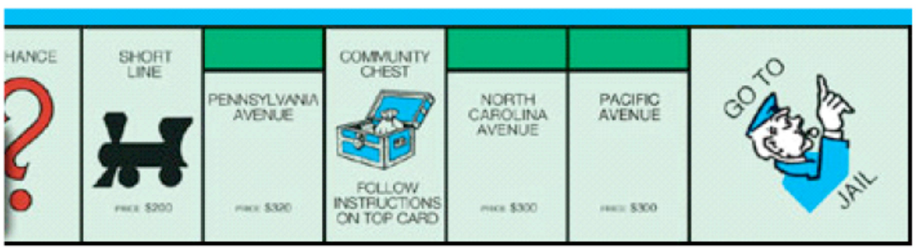


Figure 7.1. Piece of a Monopoly board. Copied from http://www.hasbro.com/monopoly/.

Quoting from http://en.wikipedia.org/wiki/Monopoly_(game):

> Monopoly is one of the best-selling commercial board games in the world. Players compete to acquire wealth through stylized economic activity involving the buying, rental and trading of real estate using play money, as players take turns moving around the board according to the roll of the dice. The game is named after the economic concept of monopoly, the domination of a market by a single seller.
>
> According to Hasbro, since Charles Darrow patented the game in 1935, approximately 750 million people have played the game, making it "the most played [commercial] board game in the world."

There are a huge number of board games that have some of the characteristics of Monopoly. Monopoly has a square board, with each side having 10 squares on which a player's piece can land. Each player has a marker—perhaps a figurine—to mark his or her position of the board. A player rolls a pair of dice and moves the total of the two dice. Randomness is also involved in the two shuffled decks of cards called Chance and Community Chest.

The play of the game involves making a variety of decisions, such as buying or not buying property, houses, and hotels, mortgaging property, making trades, and so on. Players are actively engages in receiving and paying out money in buying and selling, and keeping track of their money and property. A player gradually learns effective strategies useful in becoming a better player. See, for example, http://boardgames.about.com/cs/monopoly/a/monopoly101.htm.

Many other board games have some of the same characteristics. Players deal with a set of rules, with money, dice, making decisions, and striving to win the game. A substantial amount of learning occurs in such environments.

For example, a young child learning to play Monopoly rolls the dice and laboriously counts the dots. A more proficient player or mentor helps the child learn to recognize without counting the number of dots corresponding to 1, 2, 3, 4, 5, and 6. The young child might then learn to count on (count upward) from the recognized number on one die, to add in the value of the second die. With still more instruction and practice, the child learns to mentally add the values of the two dice.

Somewhat similarly, the young child laboriously counts out each space of a move. Eventually a child's number skills advance to a level where a dice total of 10 leads to moving 10 spaces (one fourth of the length of the board) without counting. A dice throw of 12 might be moved as 10 and two more, while a move of 9 might be made as a 10 and one less. Gradually the child develops a mental model of numbers used in moving around the board.

The money to be counted, paid out, and received provides a good environment for learning to deal with integer amount of money—up to $2,000 for the rent on the Boardwalk property with a hotel —and the wealth that the player has accumulated.

The game involves some reading, such as following a simple instruction "Go to jail." And following more complex instructions on the Chance and Community Chest cards.

Finally, the game involves following rules, taking turns, and interacting in a civil manner with other players.

When all of these learning and socialization opportunities are combined, the result is a very good learning opportunity. Learning how to play Monopoly has an added value of learning a game that your parents and perhaps your grandparents played. In some sense, Monopoly is part of the culture in many families and communities.

Hearts

Many multi-player card games involve each player playing a card, and one play winning this round of play. Rules for what cards can be played and who winds the "trick" vary with the card game. Hearts is a good card game for learning about this type of card playing and trick taking.

Quoting from http://www.pagat.com/reverse/hearts.html:

> Hearts is a trick taking game in which the object is to avoid winning tricks containing hearts; the queen of spades is even more to be avoided. The game first appeared at the end of the nineteenth century and is now popular in various forms in many countries. This page describes the American version first. Some remarks on other variations will be found at the end.

Hearts is usually a four-person game, although it can be played with fewer or more players. It is played with a standard 52-card deck, with the deuces being the lowest ranked cards and Aces the highest ranked cards. Lowest to highest within a rank are club, diamond, heart, and spade. Note that these rules tend to hold in many different card games, such as in pinochle, Bridge and many versions of Poker.

The dealer deals one card facedown per person in a clockwise direction, until each of the four players has 13 cards. Most players will sort their cards by suit and within suit by rank. This is not required, but most people find that it reduces the cognitive load as they proceed in playing the game. Note that cognitive load is an important consideration in learning and in human problem solving.

In many games, the goal is to get as high a score as possible. There are some exceptions, such as in Hearts and golf. There, the goal is to get as low a score as possible. In Hearts, if you win a trick, then each heart in the trick adds one point to your score. If the trick contains the queen of spades, it adds 13 points to your score. Since your goal is to get as low a score as possible, the usual strategy is to avoid taking tricks that contain hearts or the queen of spades.

However, there is one rule that helps make the game interesting and provides a way to have your opponents score a large number of points. If you manage to take tricks containing all 13 hearts and the queen of spades, than you get a score of zero and each of your opponents gets a score of 26. This is called **shooting the moon.** Remember, your goal is to get as low a score as possible. Thus, shooting the moon, which gives a score of zero for you and 26 points for each of your opponents, is a highly desirable accomplishment!

After the cards have been dealt, each player selects three cards from his or her hand to give to one of the other players. On the first hand, each player passes the three cards facedown to the player to their left. When passing cards, you must first select the cards to be passed and place them facedown, ready to be picked up by the receiving player; only then may you pick up the cards passed to you, look at them and add them to your hand.

On the second hand, each player passes three cards to the player to their right. On the third hand, each player passes three cards to the player sitting opposite. On the fourth hand, no cards are passed at all. The cycle is repeated until the end of the game. The game ends according to some agreed upon rule, such as one player achieving a score of 100 or above.

There are a variety of strategies players following in making a decision of which three cards to pass. The strategies are designed to help you achieve as low a score as possible. For example, suppose your hand contains the queen of spades, and your analysis of your overall set of cards leads you to believe that you will not try to shoot the moon. The question is, do you pass the queen of spades, or do you keep it. If you keep it, can you avoid winning a trick with it? This thinking suggests two strategies:

1. I will keep the queen of spades, so I have some control over when it is played and who gets it. For example, if I can achieve a void (no cards) in one suit and have a couple of smaller spades, I will pass cards to achieve the void and I will keep the queen of spades. I will then be able to play the queen of spades when my void suit is led by an opponent. Of course, this planning might get messed up if the three cards I receive contain cards in the suit I am trying to void.
2. I will pass the queen of spades, and try to make sure that I do not win a trick that contains it. Thus, for example, in this case I probably do not want to keep the ace or king of spades in my hand. This strategy may be helped by having lots of low cards in my hand, and thus by also passing high cards from other suits.

The person who holds the 2 of clubs must lead it to start the play on first trick. In each trick, the other players, in clockwise order, must play a card of the suit that was led if possible. If they do not have a card of that suit, they may play any card. The person who played the highest card of the suit led wins the trick and leads to start play on the next trick.

It is illegal to lead a heart until after a heart has been played (as a discard) to another trick, unless your hand contains nothing but hearts. Discarding a heart, thus allowing hearts to be led in future, is called **breaking hearts**. Suppose that you are in the lead (that is, get to play the first card in a trick) after hearts have been broken, and you are not trying to shoot the moon. A good strategy might be to lead a low heart with the expectation that one of your opponents will have to play a higher heart and win the trick.

The rules of Hearts are simple enough so that it doesn't take very long to learn to make legal moves and thus to participate in playing the game. However, the strategies in selecting three cards to pass to an opponent and in playing the tricks are many and varied. Implementation of some strategies takes careful planning ahead, remembering the cards that have been played, remembering the cards you have received from an opponent (which might help you to know what your opponent's plan is), and so on. Through study and practice, one can develop a high level of expertise in playing Hearts.

In Hearts, as in may other competitive games, there are a number of strategies that are specific to the game. Often several strategies are applicable in a particular situation as you do the thinking required to make a good decision. Over time, as you gain experience in playing the game, you will gradually develop insights into when a particular strategy is apt to prove fruitful. Your mind/brain, working at a subconscious level, will begin to learn patterns and then recognize the patterns in a manner that helps make good moves. This general occurrence is part of increasing your level of card sense expertise.

Card Sense

My 1/29/07 Google search on the quoted phrase *"card sense"* produced about 15,100 hits. Some aspects of card sense readily transfer from one card game to another. For example, a person learns some of the probabilities of occurrence of various combinations of cards, and these are applicable in many different card games. Other aspects of card sense are relatively specific to a particular card game. The two terms *card sense* and *intuition*, when applied to playing a card game, are closely related. Card sense, or intuition within a card game, comes from long hours of careful thinking (reflective analysis) while playing and studying a game. Other related terms include *horse sense* and *playing a hunch*.

The game of Hearts, like other relatively challenging games discussed in this book, helps to illustrate the overall process of learning and developing an increasing level of expertise within a particular domain. There is the initial challenge of learning some of the rules, enough of the rules so that one can participate in a game. There is the challenge of dealing with playing poorly relatively to one's opponents who have had much more experience and have achieved a higher level of expertise. There is the rapid growth in expertise level that comes through the first few hours of playing the game. This growth is helped by having helpful mentors (friendly opponents) who help you by sharing their insights and by teaching you some initial strategies.

Many games are complex enough so that a player will continue to gain in expertise even after hundreds or thousands of hours of playing and studying the game. Here is a personal example. By the time I began college, I had lots of experience playing many different card games. My dad taught me how to play Poker, and I played a lot of Poker with my siblings and friends. I thought I was a good Poker player.

In college, I became friends with a fellow student through a sequence of physics and math courses that we took together. He told me that he sometimes played Poker for real money, at a gambling place where this was legal. With my usual self-confidence in academic things (being a math and physics major), I challenged him to a game of Poker. It was fortunate that we were not playing for real money. He massacred me! Although I was at least as smart as him in physics ad math, he had a far higher level of expertise in Poker playing. There is much more to being a good Poker player than just knowing the rules and being good at math. If you are interested in one person's pathway to becoming a successful professional Poker player, see http://www.bostonphoenix.com/archive/features/98/08/06/CARD_SHARK.html.

Oh Heck: A Trick-Taking Card Game

Hearts is an example of a trick-taking card game. There are a large number of card games that involve trick taking. The Wikipedia site http://en.wikipedia.org/wiki/Category:Trick-taking_card_games lists 42 different games, including Hearts, Oh Heck, and Bridge. Oh Heck goes by a variety of names and is quite easy to learn to play.

Playing Oh Heck involves bidding (trying to make a good estimate of how many tricks you will take) and playing to take or not take tricks. The taking or not taking of tricks is done exactly as in Hearts.

Bidding is an important and challenging dimension in trick-taking games that have bidding. It takes considerable knowledge and experience to become accurate at bidding. This topic is discussed more in the section on Bridge.

There are many different variations of the rules. The following common set of rules is adapted from http://en.wikipedia.org/wiki/Oh_Hell.

The Deal and Play

> Oh Heck can be played with almost any number of players, although 4-7 is considered optimal. The game is played using a standard 52-card deck, with ace being the highest rank, two the lowest.
>
> The first hand is played with one card dealt to each player. On each succeeding deal, one more card is dealt out to each player, until there aren't enough cards for another round. After this, the number of cards per player *decreases* by one every round. The game is complete when the last round (with one card per player) has been played. For example, a four-player match of Oh Heck consists of twenty-five deals, from hand size 1 up to 13 and back down to 1.
>
> The dealer deals out the cards one by one, starting with the player to the left, in a clockwise direction, until the required number of cards has been dealt. After the dealing is complete, the next card is turned face up, and the suit of this card determines the trump suit for the deal. (If there are no unused cards, the hand is played without a trump suit.)
>
> Each player is now obliged to bid for the number of tricks he believes he can win. The player to the left of the dealer bids first. Bidding is unrestricted except that the total number of tricks bid cannot equal the number available. That is, the last bidder (the dealer) must make a bid so that the total number of bids is different from the number of cards each player has received. For example, if five cards are dealt to each player, and the first three bids are two, zero, and one, then the dealer may not bid two. However, if five cards are dealt, and the first three bids are three, one, and two, then the dealer is free to make any bid.
>
> When every player has made a bid, the player to the left of the dealer places the opening lead. Play then proceeds as usual in a trick-taking game, with each player in turn playing one card. Players must follow suit,

> unless they have no cards of the lead suit, in which case they may play any card. The highest card of the lead suit wins the trick unless ruffed (trumped), when the highest trump card wins. The player who wins the trick leads for the next trick.

Scoring

There are a variety of ways to score the game of Oh Heck. A simple way to score the game is by use of a single scoring rule, such as:

> Each player scores the number of tricks he or she takes. A player that wins the exact number of tricks bid receives an additional 10 points for making the contract.

A variation on this is:

> A player who makes the exact number of tricks bid scores 10 plus the amount bid. Players who overbid or underbid score nothing.

It turns out that —on average— the easiest bid to make is a bid of zero. Thus, sometimes the following scoring rule is added to which ever of the two rules given above is being used:

> Making a zero contract scores only five points.

Whist: A Trick-Taking Card Game

The Horatio Hornblower seafaring books by C.S Forester have provided me with a great deal of reading enjoyment. These stories take place starting about 200 years ago and including many exciting sea battles and other adventures. The protagonist, Horatio Hornblower, enjoys playing a card game named Whist. I have included the game here just for my own edification.

Quoting from Wikipedia http://en.wikipedia.org/wiki/Whist:

> Whist (a trick-taking game) is a classic card game that was played widely in the 18th and 19th centuries and was a development of an older game Ruff and Honours. Although the rules are extremely simple, there is enormous scope for scientific play and since the only information known at the start of play is the player's thirteen cards (plus possibly the turned up trump card from the dealer's hand), the game is difficult to play well.
>
> In its heyday, a large amount of literature was written about how to play Whist. Edmond Hoyle, of "according to Hoyle" fame, wrote an early popular and definitive textbook. By the late 19th century an elaborate and rigid set of rules detailing the laws of the game, its etiquette and the techniques of play had been developed that took a large amount of study to master. In the 20th century, Bridge, which shares many traits with Whist, has displaced it as the most popular card game amongst serious card players. Nevertheless, Whist continues to be played in Britain, often in local tournaments called "whist drives".

The following set of rules is condensed from Wikipedia http://en.wikipedia.org/wiki/Whist.

Whist is a four-player played with a standard 52-card deck of cards. The cards in each suit rank from highest to lowest: A K Q … 4 3 2.

The four players play in two partnerships, with the partners sitting opposite each other. Players cut or draw cards to determine partners and the first dealer.

The deck of cards is shuffled and cut. The dealer deals the cards one at a time so that each player has thirteen cards. The final card, which belongs to the dealer, is turned face up to indicate the trump suit. This card remains face up on the table until it is dealer's turn to play to the first trick.

The player to the dealer's left leads to the first trick; any card may be led. The other players, in clockwise order, each must follow suit by playing a card of the suit led if they have one. A player with no card of the suit led may play any card from his or her hand. The trick is won by the highest card of the suit led, except if a trump is played. In that case, the highest trump wins. The winner of the trick leads to the next trick.

After all 13 tricks have been played, the side that has won the most tricks scores one point for each trick in excess of six. Thus, only one team scores for the play of a hand, and the most points a team can score is seven.

All of the skill in Whist is shown in the play of the cards, attempting to take as many tricks as possible. Since there is no bidding, the only information available to players before the play of the first card is the trump suit and one trump card that the dealer has. The dealer has the advantage of having at least one trump card (some players may have none), and the other three players gain a slight advantage by knowing one of the cards in the dealer's hand.

As the play proceeds, the players gain information from each card played. A good Whist player will remember every card played and the order in which each card is played. If a player is talented in this task, then the memorization occurs with little or no conscious effort. This information will be combined with card sense to help make good decisions during the play.

Many competitive games, including Whist and poker, involve learning to "read" opponents. A 1/29/07 Google search of the quoted phase *"reading your opponent"* produced about 875 hits. There are a number of books on this topic, covering topics as diverse as poker, marital arts, and basketball. Learning to read a human opponent is, of course, quite different from learning to read a computer opponent. However, there are likely to be some characteristics built into a computer program (some patterns of playing behavior) that can be learned by careful analysis of the play.

Bridge: A Trick-Taking Card Game

Bridge is a four-person card game in which a team of two players competes against another team of two players. Bridge was derived from Whist and uses a standard 52-card deck of playing cards. While the taking of tricks is the same as in Whist, bridge includes a sophisticated system of bidding that occurs before the play.

The bidding process begins with the dealer. It leads to the determination of the trump suit (or, that there will not be a trump suit) and a goal of meeting or exceeding the number of tricks specified in the highest bid. In brief summary, quoting from http://www.bartleby.com/65/br/bridge-crd.html:

> After all cards are dealt, so that each player holds 13 cards, the dealer begins the auction, which proceeds in rotation to the left. Each player must bid, pass, double (increase the value of the previously stated contract), or redouble (only after a double, further increasing the point value of the contract). A bid is an offer to win a stated number (over six) of tricks with a named suit as trump or with no trump. The lowest bid is one, the highest seven. Each bid, i.e., "one diamond," "one no-trump," "four hearts," must be higher than the preceding bid, with no-trump ranking above spades. Artificial bids are those that convey certain information to a partner and are not meant to be taken literally. The highest bid of the auction becomes the contract after three consecutive passes end the bidding. The player who first named the suit (or no-trump) specified in the winning bid becomes the declarer. The player to the left of the declarer leads any card face up, and the next hand, that of the declarer's partner, is placed face up on the table, grouped in suits. This is known as the dummy, and the declarer selects the cards to be played from this hand. The object of the game for both partnerships is to win as many tricks as possible, a trick being the three cards played in rotation after the lead. Suits must be followed, but a player who has no cards in the suit led may play any card. Highest trump or, if no trump card is played, highest card of the suit led wins.

Each bid conveys some information to your partner and to your opponents. Over the years, a number of quite sophisticate bidding conventions (sets of agreed upon meanings for bids) have been developed. A specific bid in two different bidding systems may convey different information. For example, in one bidding system an opening bid of "one club" may mean: "I have a reasonably good hand and clubs is my best suit." In a different bidding system, the same first bid might mean: "I have a very strong hand and later in the bidding I will indicate my strong suit or suits."

The general rules of Bridge require a team to explain their bidding system to their opponents. If a team is using a widely used bidding system, they can convey this information by merely naming the system. If they have developed a variation of a widely used system, or if they have developed an entirely new system, then they must provide the details to their opponents. Needless to say, a good memory and the ability to quickly learn the meaning of one's opponents bidding system are essential to playing Bridge well.

The scoring in Bridge is more complex than in Whist. In Whist, each trick won in excess of six tricks counts one point. In Bridge, each trick won in excess of six may count 20 points or 30 points—with the exception of a no-trump contract in which the first trick above six counts as 40 points and each subsequent trick counts as 30 points. Scoring is also affected by whether a contract has been doubled, or doubled and redoubled, and by a number of other considerations. In total, learning to score in Bridge is a significant challenge.

Bridge is far more complex and challenging than Whist because of the bidding and because of differences in scoring. The game is played competitively as local, regional, national, and international levels. A ranking system has been developed so that a player can achieve a competitive rank through the accrual of points in certain sanctioned Bridge-playing events. For some details on this, read about American Contract Bridge League (ACBL) master points at the http://www.acbl.org/about/masterpoints.html.

Massively Multiplayer Online Games (MMOG)

My older daughter, Beth Moursund, spends a great deal of time playing various Massively Multiplayer Online Games (MMOG). One of my reasons for writing this book was her continually pointing out to me some of the educational values of games and the educational implications of MMOGs.

If you own and use a credit card, you are a participant in a massively multi-user online financial system. If you use email, you are a participant in a massively multi-user online communication system. If you use the Web, you are a participant in a massively multi-user online virtual library system. If you make online purchases from Amazon or other large online businesses, you are a participant in a massively multi-user business.

Nowadays, it is no big deal for many thousands of people to be making simultaneous use of a computer system that processes business transactions, communication transactions, or game moves. In such a game, a player controls one or more virtual characters. Some of the games that have been developed can have tens of thousands of simultaneous players.

In many online games, players organize themselves into teams. A team, consisting of cooperating humans each running an individual character within the game, carries out activities that may include fighting or in some other way competing against other teams being run by human players, against teams being run by a computer, or perhaps just in overcoming major challenges being generated by the computer system.

It is easy to draw parallels between this and a team of workers in a company competing against workers from other companies and participating in the overall world of business to develop products that capture market share and make profit for the company. It is now common for a team of researchers, located throughout the world, to work together on a project. Indeed, it is now common for certain types of jobs to be filled by telecommuters located thousands of miles from their employers and customers.

The following quoted paragraph from Young et al. (2006) provides insight into MMOGs in education:

> Yes, video games are mainly for play and fun. But video games are educative as well as interesting and engaging—something that we all hope that more classrooms could be. Many of today's students spend more time playing video games than they do watching television, reading books, or watching films**. Massively multiplayer online games (MMOGs)—long and surprisingly complex gaming environments that normally require over forty hours to get beyond novice levels (Squire 2004)—represent the latest development in the history of video game technology (Exhibit 1).** Success in a MMOG requires developing new literacies, understanding intricate and intersecting rule sets, thinking creatively within constraints, collaborating with other participants towards shared goals, and perhaps most importantly, taking on new identities as players (via their avatars) inhabit game spaces (Gee 2003). Such properties offer significant potential for educational contexts, as indicated by the emergence of MMOGs specifically designed to enable student interactions and centered on instructional topics (e.g., *Quest Atlantis*, *AquaMoose 3D*, and *RiverCity*). [Bold added for emphasis.]

Notice the "forty hours" in the bolded part of the quoted material. Research suggests that many game players enjoy the challenge, the many hours of learning, and the resulting level of expertise that results from such dedication. Players of such games become thoroughly immersed in the game. They talk about characters in the game (such as their characters) in the same way they talk about other people in their lives.

I enjoyed reading the following newspaper article:

> Regan, Tom (June 14, 2006). What if civics class were an online game? The Christian Science Monitor. Retrieved 6/14/06: http://www.csmonitor.com/2006/0614/p17s01-cogn.html.

Quoting from the article:

> My 10-year-old son belongs to an online community called Runescape, a world that resembles something you might find in "Lord of the Rings." Runescape is an MMORPG—a massively multiplayer online role-playing game. He and his friends often race home after school to "meet" one another online, in the guise of the characters they have created. Unlike single-player games, MMORPGs create a "persistent world," one in which the online community continues to evolve and grow even when your character (or my son's, in this case) is not online.
>
> I checked out the community before allowing my son to join it. Bad language is forbidden, as is abusive conduct and a slew of other obnoxious or dangerous behaviors. There is a method for reporting those who break the rules, if they are not noticed by the game's operators first.
>
> In other words, if you are going to be a citizen of this online world, you must follow certain rules. True, this online society is not one you'd find in the "real" world, but the code of citizenship in Runescape is similar to traditional ideas of what it means to be a good citizen (along with all the dragon and goblin fighting, of course).

As suggested above, a virtual reality learning-environment can be effective even it is not quite close to the real reality. However, there are many virtual reality learning-environments that are essentially indistinguishable from real reality. Good examples are provided by the simulators used to help train astronauts, airplane pilots, military tank crews, and a surgeon learning to perform complex laparoscope surgery, perhaps working in cooperation with a sophisticated robot, There are a steadily growing number of such educational simulations.

As might be expected, as more jobs require working through and with a computer-based game-like interface, there is some incidental transfer of learning from game playing into such jobs. A good example is provided by laparoscopic surgery.

> All those years on the couch playing Nintendo and PlayStation appear to be paying off for surgeons. Researchers found that doctors who spent at least three hours a week playing video games made about 37 percent fewer mistakes in laparoscopic surgery and performed the task 27 percent faster than their counterparts who did not play video games. (Dobnik, 2004)

There is a growing body of research on the value of learning communities. The Bill and Melinda Gates Foundation has been making major financial contributions designed to divide large schools into smaller, community-like schools. The teams in a MMOG have some of the characteristics of a small learning community. More generally, it is now common in distance learning to have groups of students working together via the Internet. In some sense, a group of students working together in a distance-learning course become a community.

Small learning communities tend to place considerable emphasis on the social dimensions of education. Some game researchers are taking a similar approach. Quoting from Terdiman (2006):

> The PARC team--Bob Moore, Nicolas Ducheneaut and Eric Nickell, plus Stanford's Nick Yee--have spent the better part of three years studying the social dimensions of so-called massively multiplayer online games (MMOs) to better understand the design challenges behind creating satisfying face-to-face avatar and other interactions in such environments.
>
> But along the way, the group says, it has encountered one substantial hurdle: conventional wisdom in the games industry that development resources should be spent on content, since content is what players want.
>
> "When faced with the decision, 'Do I put in another dungeon or do I improve the experience for (groups of players)?'" said Ducheneaut, publishers often say "'I'll put in another dungeon.' I think that's incredibly shortsighted."

Star Trek's Holodeck

I have been a Star Trek fan since its early days. I am particularly enamored by the Holodeck, because it provides an interesting vision of the future of education. In the Star Trek science fiction, a Holodeck creates a virtual reality in which one can interact with virtual people, places, and things. For example, a student could talk with Albert Einstein, take piano lessons from Ludwig van Beethoven, be a player on a sports team made up of great figures from the past, and so on.

Some aspects of a Holodeck now exist. Quoting from the http://en.wikipedia.org/wiki/Virtual_reality:

> Virtual reality (VR) is a technology which allows a user to interact with a computer-simulated environment. Most 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 and experimental systems have included limited tactile information, known as force feedback. Users can interact with a virtual environment 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/or 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.

I find it interesting to try to separate the digital graphics effects in films from the rest of a film. Is it real water in a real storm, or is it computer-generated water in a computer-generated storm? Nowadays, real humans in a video may have both a (human) stunt double and a computer graphic double. The DVD videos that I buy or rent often contain a "behind the scenes" section that provides detail on how the computer graphics used in a film have been generated.

As the compute power available in computer games continues to grow rapidly, the characters and actions that must be generated in real time get better and better. However, the field of artificial intelligence has a very long way to go before a human participant will be able to physically participate in a game and carry on oral conversations with computer-generated characters in the game, as is common on a Holodeck.

Final Remarks: Moursund's 7-Step Advice

Some of the ideas from game playing carry over to general problem solving and decision-making. In many situations, there is the learning that can occur in advance of being faced by the problem, and the learning or data gathering that occurs immediately at the time of the problem or during the process of attempting to solve the problem. In summary, here is Moursund's 7-step problem-solving advice. A good problem solver:

1. in problem-solving situations involving working with or in competition with other people, draws upon and cultivates the ability to "read" people, to collaborate, and to compete.
2. knows his or her problem-solving strengths and weaknesses. Draws upon the strengths and circumvents the weaknesses.
3. brings to bear general knowledge as well as general problem solving strategies and experience.
4. brings to bear domain-specific knowledge as well as domain-specific solving strategies and experience.
5. draws upon and develops an ability to quickly assess the problem situation and begin gathering relevant information.
6. draws upon and develops an ability to acquire new information during the problem-solving activity and integrate it with all of the above.
7. recognizes the need for and value of experience in all phases of problem solving and in many different problem-solving situations and environments. This experience, along with reflective thinking, helps to build intuition (card sense, horse sense, hunch sense, etc.)

This is a high-road transferable strategy or set of advice that is applicable in a wide range of problem-solving situations. As a teacher, you will want to help your students acquire this strategy and incorporate it into their general approach to learning and using their learning.

Activities for the Reader

1. Think about the ideas of card sense, horse sense, intuition, and hunch. They are all related to decision making where there is uncertainty. Reflect on when you make decisions under uncertainty, and the role these four terms (four ideas) play. Then reflect on or discuss with a partner what you want students to learn about these ideas and why.
2. Take another look at Moursund's 7-step strategy for getting better at problem solving. Identify one topic that you feel is one of your strengths and one that you feel is one of your weaknesses. Suggest some reasons why the one seems so much more useful or relevant to you than the other.

Activities for use with Students

1. Find out from your students which ones have seen a Star trek episode in where the Holodeck was used. Then have these students explain what a Holodeck is, including its capabilities and limitations. Finally, engage the whole class in a discussion of whether Holodeck is just "pure" science fiction, or whether some aspects of Holodeck now exist.
2. Have the whole class work together to develop a list of card games that various members of the class have played, and how many have played each of the games. Then select one of the more popular games. Lead a whole-class discussion on why this game is popular and what one learns by playing the game. Repeat for a second game and a third game as time permits.
3. Many card games begin with shuffling the deck. Have your class work in teams to figure out a research method for determining how well shuffling actually randomizes the cards in a deck. Note that this is a hard research question, but that children can learn by attempting to solve it.

Chapter 8

Lesson Planning and Implementation

People often talk about strategy as if it were some kind of chess match. But in chess, you have just two opponents, each with identical resources, and with luck playing a minimal role. The real world is much more like a Poker game, with multiple players trying to make the best of whatever hand fortune has dealt them. (David Moschella)

If at first you don't succeed, try, try again. Then quit. No use being a damn fool about it. (W. C. Fields)

One of the focuses in this book is on developing and learning to use a repertoire of general-purpose problem-solving strategies. A strategy is a plan of action. Effective use of strategies requires understanding of the strategies and careful thinking while implementing the strategies.

A lesson plan is a strategy designed to help solve a teaching and learning problem. This chapter presents some ideas on developing and implementing game-based lesson plans. Such lesson plans will likely have several different goals. For example, a lesson may be designed to teach some general problem-solving strategies, to teach a specific game, and to help students experience the process of gaining an increased level of expertise in an area. Whatever the goals in such a lesson, they should be made explicit both in the lesson plan and to the students.

Roles of a Teacher

With the background you have gained by reading the previous chapters, you can now better understand roles of a teacher in helping students get better at problem solving. Students can discover strategies on their own, read about them in a book or from the Web, or be told them by a fellow a fellow student, parent, or teacher. However, without explicit instruction, few students will attempt to generalize such strategies for possible inclusion in their repertoire of high-road transfer strategies

> For an informal environment to be fully effective as a learning activity, it often must be augmented by tutorial guidance that recognizes and explains weaknesses in the student's decisions or suggests ideas when the student appears to have none. This is a significant challenge requiring many of the skills analogous to those of a coach or laboratory instructor. The tutor or coach must be perceptive enough to make relevant comments but not so intrusive as to destroy the fun inherent in the game. (Burton and Brown, 1982)

The teaching technique emphasized in this book is a combination of seizing the teachable moment and teaching for high-road transfer. Whatever you are helping students to learn, keep *problem solving* in mind. Each teaching/learning situation is an opportunity for students to get better at problem solving:

- Within the specific domain, discipline, or activity being studied.
- In a manner that cuts across many domains, via high-road transfer of learning.

You want to help your students to increase their repertoire of domain-specific and domain-independent problem-solving strategies. High-road transfer to increase a student's repertoire of general-purpose problem-solving strategies consists of:

1. Identify a strategy and give it a short, descriptive, easy to remember name.
2. Help students to understand the strategy in the context of the learning and problem-solving situation they are currently engaged in.
3. Help each student to identify personal applications of this strategy to other problem-solving situations. The goal is to help each student to develop (construct) a personally relevant understanding of uses of the strategy in a variety of situations. This is an example of constructivist teaching.
4. Repeat steps 1-3 frequently, both for new strategies and for strategies that have already been introduced. Whatever you are teaching, use this approach as an opportunity to reinforce student understanding and use of underlying problem-solving strategies. Provide students with multiple opportunities to reflect on strategies that they are using. Get your students used to the idea of identifying, learning, and explicitly, reflectively using such strategies.

Some teachers will immediately jump to the approach of having students memorize a long list of strategies. They will make use of fill in the blank, matching, and other short answer techniques to assess this memorization. **Please do not do this!**

This approach misses the whole idea of reflective thinking, situated learning, personal construction of knowledge and understanding, and high-road transfer of learning. Think instead about what might make a significant, lasting contribution for a student. Suppose a student really masters one new strategy per month. or nine during a school year. For many students, this would more than double their repertoire in a single year!

Based on research in adding to a student's functional vocabulary, a good approach might be to introduce three or four strategies per month, with substantial repetition in their use. You should not have an expectation that each student will learn all of the strategies that are introduced, nor that most of the students will learn the same strategies. The strategies that a particular student will learn depend considerably on the individual student and past learning. You should consider it a considerable success if a student "masters" one new strategy per month.

Learning to Learn

Your mind/brain knows how to learn. Learning is an ongoing, automatic process. When we talk about learning to learn, we are talking about how to improve the learning process. One of the goals of education is to help students learn to learn more efficiently and effectively.

The totality of human knowledge is huge and is growing very rapidly. A person has no hope of learning everything. Indeed, it is now a major challenge just to develop a high level of expertise in one or two disciplines.

Thus, as you work to educate yourself and others, you need to think carefully about what to learn and how to use learning time and effort efficiently and effectively. Let's use science as an example. Science encompasses many different disciplines, such as biology, chemistry, geology, physics, and so on. In any of these disciplines, it is possible to earn a doctorate, specializing in a small part of the discipline.

Science is all around us. Thus, each of us learns a lot of science at a subconscious level, just by functioning in the world and processing the steady stream of input to our senses. One of the interesting things that educational researchers have found is that each person constructs their own mental models and theories of various aspects of science. Some of these models are correct enough so that they require little change over time, as we learn more and more about the science aspects of the world we are growing up in. Others do not fit well with what we observe as we grow older and with what is being taught to us in school.

Piaget used the terms assimilation and accommodation to describe how some new information can be assimilated into the models and theories we have already developed, while other information and ideas requires developing new mental models. Thus, one important aspect of learning science is to develop general mental models that are robust enough to assimilate the science we will encounter in our future experiences and more formal learning opportunities.

As a very young child, you certainly did not have an inherent understanding that a key aspect of science is developing very accurate descriptions (for example, of things that one sees in nature) and predictive/descriptive theories (for example, that the moon rotates around the earth and reflects light from the sun). Our informal and formal educational system has helped you to develop an internal (constructed collection of mental models) that you bring into play as you think about the meaning of science, what scientists do, and so on.

Our educational system faces the challenge of helping each student develop a general understanding of science, learn some specific science, and learn to learn science. In the past, our educational system has tended to place considerable emphasis on the first two challenges, and less emphasis on the third. Even as our understanding of the theory and practice of learning has grown, we have tended to expect that students will figure out on their own how to learn a particular discipline. After all, each person is unique; each brain/mind is unique. Each brain/mind knows how to learn and can assimilate new learning challenges into its repertoire of learning skills.

While each student will indeed learn to learn whatever we attempt to teach in school, many students will develop quite ineffective and inefficient methods for learning. Moreover, they will not even be aware that they are developing ineffective and inefficient methods. Here is a two-part approach to solving this teaching/learning problem:

1. Incorporate the best of our learning to learn theory and practice into teaching in each discipline area. Explicitly teach this to students.
2. Actively engage all students in the study of their own learning styles, capabilities, and limitations. Over the years of formal schooling, help each student to gain a steadily increasing understanding of themselves as a learner and how to become a more effective and efficient learner.

There is a lot or research and practice literature on learning to learn. A Google search using the term *"learning to learn"* will give you hundreds if thousands of hits.

Games provide a good environment in which to help students learn about learning and learn about themselves as learners. This one of the justifications for making use of games in education. As you help students learn a game, you can make it clear that a game has rules that must be learned. You can make it clear that there are a number of learning and playing strategies that are useful both in lots of different game settings and in lots of different non-game settings. You can make it clear that each game tends to have some specific strategies that make a significant contribution toward increased expertise in playing the game. You can make it clear that the same "specific strategies" situation holds for developing an increased level of expertise in each discipline.

One of the advantages of a game environment is the relatively short period of time required to move from a being a person first being exposed to a game to a person with a reasonable of expertise in playing the game—a person who can play for enjoyment and for learning while playing. This is in marked contrast to much of traditional learning in school.

Lesson Plan Ideas

Each of the preceding chapters includes some activities for teachers and others who are using this book in a course or for independent study. In addition, each contains activities to be used with students. Thus, by browsing these chapter materials, you may come up with a number of ideas for lesson plans.

Another starting point is to browse a modest length list of goals of education, looking for **big ideas** that you feel need increased emphasis in your curriculum.

The research on use of games in education strongly supports the value of having clear learning goals in mind and of specifically teaching to these goals. Here is a short list of possible goals for making educational uses of games in a classroom setting.

1. To help students learn more about themselves in areas such as:
    a. Learning to learn and understanding how concentrated, reflective effort over time leads to an increasing level of expertise.
    b. Learning about one's cooperative versus independence versus competitive inclinations both in learning and in demonstration or use of one's learning.
    c. Learning about oneself as a giver of feedback to others, and as a receiver of feedback from others. This includes learning to do and make use of both self-assessment and peer-assessment.
2. To help students better understand problem-solving strategies and to increase their repertoire of and use of problem-solving strategies.
    a. Learning about low-road and high-road transfer of learning, especially as they apply to problem solving.
    b. Learning how to recognize/identify a problem-solving strategy and explore its possible use across many different problem domains.

   c. Learn how to do high-road transfer of learning of problem-solving strategies that cut across many domains.
   d. Increase fluency in making effective use of one's repertoire of domain-independent problem-solving strategies.
3. To help students learn some games and increase their understanding of historical and current roles of games and game playing in our society. This includes:
   a. Learning games as an aid to social interaction in small and large groups.
   b. Learning games as part of the culture and history of a family or community.
   c. Learning games as environments that facilitate communication, collaboration, and peer instruction.
   d. Learning how to help other people learn a new game. (Think of the idea that every student plays both learning and teaching roles in life.)

Development of a game-based lesson plan can begin with the selection of an age-appropriate game, or it can begin with the selection of some specific learning goals such as those listed above. Thus, for example, you may think of a game that you thoroughly enjoyed playing as a child. You may decide that your students or children would likely enjoy learning to play the game. Before introducing the game to your students or children, think about your educational goals. If you are a parent, for example, you might decide the main goal is to help your children understand a bit of your childhood and the culture/environment that you grew up in.

If the beginning point is a learning goal, such as learning about a particular strategy and high-road transfer of this strategy, then the next step is to identify an appropriate game or set of games that employ the strategy. Be sure to think about how you will use this teaching/learning situation to help students learn to recognize strategies, make use of strategies, and learn high-road transfer of domain-independent strategies.

In all teaching/learning situations, a lot of *incidental learning* goes on. As a teacher or parent, when you see a good example of such incidental learning, make it explicit to the learners. For example, suppose that a teacher is making use of the following instructional strategy:

> Begin the lesson by role modeling the idea of thinking out loud as you solve a couple of different puzzles. Then divide your class into groups of two or three, and provide each group with a variety of developmentally appropriate puzzle problems. One member of the group thinks out loud while attacking a puzzle problem. The other member or members of the group are silent observers, perhaps taking notes on what they observe. If the puzzle solver successfully solves the puzzle, the observers than lead a debriefing interaction, talking about what they observed and whey learned in the overall process. If the puzzle solver gets stuck, a short debriefing occurs, and then another member of the team takes over and works to solve the puzzle problem. Remember, only one person works on the puzzle at a time. The other members of the team are silent observers, possible taking notes on what they are observing and their own person thoughts about what is going on.

As you (the teacher) wander around the classroom observing the various teams at work, you may happen to see an observer taking good notes and writing down a suggestion of a strategy he or she would use. That would be a good time to interrupt the class. Point out the good activity you observed, and suggest that observers may want to think about and write down strategies that they see being used and their suggestions of other strategies that hey feel would be useful.

Note that the same set of ideas can be used in any problem solving activity. That is, the problem need not be a puzzle problem. The activity could be based on a science problem, a social science problem, a math problem, and so on. (Note to teachers: Probably you have already thought of this. If not, here is a good chance to practice high-road transfer of learning. The teaching/learning strategy illustrated can be called the *think out loud strategy*. It is useful in group problem-solving settings, and it is a useful component of many lesson plans.

More Specific Educational

The table in Figure 8.1 lists some of the possible specific learning goals that might be applicable to a student engaging in playing a game. As you explore learning goals, keep in mind one of the overriding principles of good educational practices: Lessons should be challenging and rigorous. Thus, as you think about a specific goal, think about how your lesson will approach this goal in a challenging and rigorous manner. The next section of this chapter provides additional ideas on challenge and rigor.

Goals: Students will learn:	**Points**
1. Declarative knowledge about the game—rules, vocabulary, objectives, history.	
2. Procedural knowledge about the game—using procedural thinking in making good moves. Knowledge and understanding of algorithmic and heuristic procedures relevant to making good moves.	
3. How to learn a game. How expertise increases through gaining improved declarative and procedural knowledge, through practice, through metacognition, and through reflective analysis.	
4. How to obtain and use feedback from oneself, the computer (if playing in a computer environment), and one's fellow players (if playing with and/or against others). Often this requires careful record keeping and then reflective analysis of moves made in a game.	
5. To practice the high-road transfer of learning heuristics of developing an overall long-range strategy and making use of look ahead.	
6. How to appropriately interact with fellow players and opponents. This includes learning the culture and social skills of game playing in general, as well as for the particular game being played.	
7. The thrill of victory, the agony of defeat (if it is a competitive game).	
8 How to help others learn to play the game; how to be a teach/mentor in a game learning and game playing environment.	
9. Self assessment and peer assessment. Receiving and giving feedback from oneself and others that can be used to improve the level of one's expertise.	
10. Etc.	
The total of the points must add up to →	100

Figure 8.1. Goals in a Game-playing "Lesson"

You may think it was rather silly of me to provide a column for points. The purpose is to encourage some quantitative thinking. Suppose, for example, you are developing a lesson plan with four goals. Are all goals of equal importance from your point of view or from your students' points of view? If you don't provide your students with information about the relative importance of various goals, how will the students self-assess or do peer assessment?

It is useful to analyze some of the possible goals and to think about the nature of learning that might occur in a gaming environment.

1 and 2. A gaming environment tends to have less clutter and complexity than the school environment typically available as one studies a traditional school discipline. Thus, a gaming environment may be well suited to helping a student learn about declarative and procedural knowledge, and procedural thinking. A procedure can be classified as an algorithm (proven to solve a specific type of problem or accomplish a specific type of task), or heuristic (such as a rule of thumb that is designed to solve or help solve a problem, but is not guaranteed to be successful). Learn more about procedures and procedural thinking in Chapter 4 of Moursund (2005).

3 If you are a person who is apt to be learning many different games during a lifetime, it is beneficial to learn to learn games. In addition, many non-game problems have much in common with game problems. Thus, there can be considerable transfer of learning from the process of learning a game to the process of dealing with such real world problems.

4. Feedback is important in any learning and problem-solving situation. Part of the learning process is to develop skill in obtaining and using feedback from self, others, the problem-solving situation, and so on. This is the basis for an important high-road transfer of learning heuristic. When attempting to solve a problem, make a list of possible sources of feedback that can provide information on the progress you are making in solving the problem.

5. Game playing often lends itself to developing and using a long-range strategy. Long-range strategic planning is such a widely useful heuristic that it should be part of the problem-solving repertoire of all students. A similar statement holds for the look-ahead strategy. Such strategies can be learned in a widely applicable manner through appropriate teaching for high-road transfer. (Note also that a person can learn to recognize opportunities for high-road transfer and then do the steps needed to help increase high-road transfer—a teacher may be helpful, but certainly is not a necessary requirement. TAG students tend to be good at this.)

6 There are many different learning theories. Lev Vygotsky's learning theory (http://chd.gse.gmu.edu/immersion/knowledgebase/theorists/constructivism/vygotsky.htm) is called social constructivism. It is a social development theory, quite a bit different than Piaget's cognitive development theory. The social aspects of a learning situation are a key aspect of social constructivism. Many people play games because they enjoy being in the social setting that the environment provides. In an educational setting, metacognition might help game players learn some things about their social skills, likes, and dislikes.

7. Some games are competitive, some are collaborative, some are both (a team working together, competing with another team), and so on. Many games provide an opportunity to experience the thrill of victory and the agony of defeat—and to learn about how one deals with winning and losing.
8. I believe that all people are "naturally" both learners and teachers. Through informal and formal education, we all get better at learning and teaching. Game-playing environments tend to provide a good opportunity to help others learn. For example, a game player might be engaged in both teaching and learning why asking another player a question such as, "Can you explain to me what you had in mind when you …(question asker describes a particular move or action by the other player)?
9. Learning to self assess is an important goal in education. Games provide an environment in which one can practice self-assessment, peer assessment, and giving and receiving feedback based on such assessments.

The types of learning goals listed in Figure 8.1 are not automatically achieved by students who play games. Quoting from Conati and Klawe (2000):

> These results indicate that, although educational computer games can highly engage students in activities involving the targeted educational skills, such engagement, by itself, is often not enough to fulfill the learning and instructional needs of students. This could be due to several reasons.
>
> One reason could be that even the most carefully designed game fails to make students reflect on the underlying domain knowledge and constructively react to the learning stimuli provided by the game. Insightful learning requires meta-cognitive skills that foster conscious reflection upon one's problem solving and performance [2, 4, 24], but reflective cognition is hard work.

Goals of Education: Rigor on Trial

As a teacher, I often have trouble thinking about my lessons from a student point of view. Thus, I was impressed by the work being done by Tony Wagner and others as they explored lesson plans from a student point of view (Wagner, 2006). The emphasis in this work was on exploring the rigor of classroom instruction and learning. Quoting from Wagner's article:

> We began to realize that rigor has less to do with how demanding the material the teacher *covers* is than with what *competencies* students have mastered as a result of a lesson. We were able to agree on this because, in our journey, we had gone from creating a series of *teacher-centered* observations to reaching consensus on a set of questions we would ask *students*. … The seven questions that emerged from this work are the following:
>
> 1. What is the purpose of this lesson?
> 2. Why is this important to learn?
> 3. In what ways am I challenged to think in this lesson?
> 4. How will I apply, assess, or communicate what I've learned?
> 5. How will I know how good my work is and how I can improve it?
> 6. Do I feel respected by other students in this class?
> 7. Do I feel respected by the teacher in this class?

One of the most important goals in education is to help students learn to take a steadily increasing level of personal responsibility for their own education. The list of seven questions given above is a piece of an overalls strategy for doing this. When you (as a teacher) develop and use a lesson plan, do a whole class debriefing at the end of the lesson. Engage your students in questions such as those given in the list. Help them to learn that these are good questions to use any time—at the beginning of a lesson, during a lesson, or at the end of a lesson. Use this activity to learn to become a better teacher!

Rubrics

Almost all teachers make use of rubrics as they assess student work and provide feedback to students. Typically, a rubric is aligned with goals in a unit of study, a lesson, or a specific assignment. Sometimes a rubric is designed just for the use of the teacher. At other times, a rubric is designed for use both by the teacher and by the teacher's students.

In the latter case, it is essential that the students be able to understand the rubric and to self-assess. There is considerable literature on the value of involving students in the development of rubrics. Such involvement may increase student motivation and serves as a good approach to helping students understand a rubric.

Teachers know that students vary widely in their backgrounds and interests. In teacher-centered education, the teacher and higher-level components of the school system are apt to specify rubrics and relative weights to be given to the assessment of various components of a graded activity.

Contrast this with assessment in student-centered education. There, one might facilitate students in developing their own rubrics. Within a range of goals decided upon by the teacher (or, teacher and students working together), each individual student might develop their own specific rubric or a part of a rubric to fit their own individual interests and needs.

Activities for the Reader

1. Do some quick brainstorming, either individually or in a small group. Brainstorm goals of education that you feel might be approached through use of games.
2. Do some quick brainstorming, either individually or in a small group. Compile a list of games, each accompanied by an appropriate educational goal that might fit well in a lesson based on the game.
3. In a small group, share your thoughts on allowing students to help develop rubrics and perhaps even individualizing a teacher-developed or whole class-developed rubric to better fit his or her interests and needs.

Activities for use with Students

1. Reread the section *Goals of Education: Rigor on Trial* given earlier in this chapter. Then try out the ideas of this section with your students.
2. Experiment with the idea of involving your students in developing rubrics, and with the idea of individualization or rubrics to fit the interests and needs of individual students.

Chapter 9

Miscellaneous Other Topics

> If life doesn't offer a game worth playing, then invent a new one. (Anthony J. D'Angelo; Founder of The Collegiate EmPowerment Company and creator of The Inspiration Book Series)

This is a collection of topics that were identified as being relevant and important to the themes of the book, but that are not included in previous chapters. My goal was to have this book be relatively short. Therefore, I decided to lump all of these topics together into a final chapter. One way to think about this chapter is that it consists of a large number of mini-chapters. Alternatively, think of this chapter as a future writing challenge to the author. Each section of this chapter could be developed into a complete chapter.

When I write a book on a particular topic, I spend a lot of time reading and talking to people about the topic. Eventually, I begin to get an idea for the topics I want to include in the book. As I work on organizing the topics, I continue to search for other possible topics.

I know that I have a good organization for the book when each new topic that I find fits into the general structure that I have developed. For this book on games in education, I continued to find topics that did not fit very well. So (much like I do when I am playing some games against a computer), I have decided to cheat. This chapter contains several very important topics that do not fit well into the general outline provided by the first eight chapters. I have lumped them and some other topics under the title Miscellaneous.

Women and Gaming

Women and gaming is a huge topic. A recent Google search of *women and computer games* produced over 62 million hits. For a "typical" overview (non research) article, see:

> Woudhuysen, James (23 March, 2006). Why don't women play computer games? Retrieved 1/29/07: http://www.spiked-online.com/articles/0000000CAFDF.htm.

Quoting from the article:

> Right now, a number of attempts are being made, in both Britain and America, to integrate computer games into the fabric of secondary education. In the USA, where such efforts are particularly advanced, there are fears that the size of Lara Croft's breasts will not just put girls off computer games, but off IT as a discipline. Henry Jenkins, director of comparative media studies at the Massachusetts Institute of Technology, argues that, being the first introduction girls have to computers, sexist computer games are partially responsible for the gender gap in the whole of US computer science.

For a fairly recent book on women and computer games see:

> Ray, Sheri Graner (2004). Gender inclusive game design: Expanding the market. Hingham: Charles River Media.

Quoting from a book review retrieved 6/13/06: http://www.game-research.com/art_review_granerray.asp:

> Sheri Graner Ray gives the reader an overview of what she sees as some of the central game design issues developers need to take into account if they want to really tap into a larger, more diverse market for their products. She suggests that there is a latent female audience basically waiting for developers to wise up and start providing a wider range of titles that cater to a variety of tastes. One of the best things about this book is the way Graner Ray puts responsibility back on game companies for the markets they have… or lack. As she formulates it:
>
>> It's going to take designers that are willing to look at different conflict resolution styles and different learning styles. It's going to take artists that are willing to rethink how they present avatars. It's going to take design teams that keep the broad market in mind from the very first lines of the design document, it's going to take development houses that are willing to examine their hiring practices and make sure they are an option for potential female industry candidates. In short, it's going to take an industry that is willing to step back and look at their titles, and ask themselves, "But what if the player is a female?"

There are a number of organizations and conferences for women in gaming. See, for example:

> Women in games International (n.d.). Retrieved 1/29/07; http://www.womeningamesinternational.org/.

Quoting from the Website:

> Women In Games International was founded in 2005 in response to a growing demand around the world for the inclusion and advancement of women in the game industry.
>
> Women In Games International is managed by a steering committee comprised of like-minded individuals, is supported by corporate and media sponsors, and directed by a global advisory board. The organization has been developed in partnership with the Women in Games Conference in Dundee, Scotland.

A variety of projects make use of game creation activities to get more girls interested in going into the field of computer science. See, for example: http://www.youthlearn.org/afterschool/GirlsCreatingGames3.htm, http://www.actapress.com/PaperInfo.aspx?PaperID=21551, and http://www.cse.ohio-state.edu/~bbair/WIC/games4girls/.

Student Creation of Games

As you watch small children at play, you see that they are adept at creating games they find entertaining and attention holding. Many students enjoy creating games for themselves and others. This can be a valuable educational experience. Quoting from Yasmin Kafai (2001):

> We have only begun to build a body of experience that will make us believe in the value of game activities for learning. Obviously, the image of children building their own games is as much a "knee-jerk reflex" for constructionists as making instructional games is for instructionists. In the case of instructional games, a great deal of thought is spent by educational designers on content matters, graphical representations, and instructional venues. **The greatest learning benefit remains reserved for those engaged in the design process, the game designers, and not those at the receiving end, the game players.** [Bold added for emphasis.]

The last sentence in the quote applies to most project-oriented educational activities. It provides a good summary of the case for integrating project-based learning as a routine component of instruction in schools.

Here is another quote from Yasmin Kafai (2001):

> We know that as many children enjoy playing games according to given rules, they are also constantly modifying rules and inventing their own. Piaget (1951) claimed that these modifications reflected children's growing understanding of the world. The process of game construction represented for Piaget the ultimate effort by children to master their environment in creating their representations of the world. Turkle (1984) pointed out an interesting parallel between the attractions of playing games and of programming computers. She saw programming as a way for children to build their own worlds. Within this context, children could determine the rules and boundaries governing the game world and become the makers and players of their own games. In contrast, when children play a video game, they are always playing a game programmed by someone else; they are always exploring someone else's world and deciphering someone else's mystery. Turkle saw that what she called the holding power of playing purchased video games could be applied to the making or programming of video games.

It is possible to create an interactive computer game in any general-purpose computer programming language designed to facilitate interactivity. BASIC and Logo are programming languages that millions of students have learned and that are quite suitable for game development. Both commercial and free versions of each of these programming languages are available. The Website http://www.thefreecountry.com/compilers/miscellaneous.shtml is a useful starting point for finding free versions of these and other programming languages.

Squeak is a more recently developed computer programming language that is designed for students. It provides an excellent environment for creating games. It is available free at http://www.squeak.org/Features/ for both Mac and Windows platforms.

An alternative approach is to make use of software that has been specifically designed for game development. Game Maker is available free on the Web and provides a good example of such software (Overmars, n.d.). Quoting from Mark Ovemars' Website:

> Did you always want to design computer games? But you don't want to spend a lot of time learning how to become a programmer? Then you came to the right place. *Game Maker* is a program that allows you to make exciting computer games without the need to write a single line of code. Making games with *Game Maker* is great fun. Using easy to learn drag-and-drop actions you can create professional looking games in little time. You can make games with backgrounds, animated graphics, music and sound effects. And once you get more experienced there is a built-in programming language that gives you full flexibility. What is best, *Game Maker* can be used free of charge. And you can use the games you produced in any way you like. You can even sell them!

There are many other game-creation resources available. See for example: http://www.ambrosine.com/resource.html. The Website provides many examples of free software available for creating computer games.

Games and the Aging Brain

During the past five years, I have become quite interested in brain science and how it relates to education. Also, as I have continued to grow older, I have developed an interest in capabilities of the aging brain.

During the past two decades, there has been substantial progress in brain research. Largely, this has occurred using non-invasive brain scanning equipment. This equipment depends heavily on computer hardware and software. The steady increase in the speed and the cost effectiveness of computer systems has been a major factor in improvement of brain imaging equipment.

It has long been understood that "use it or lose it" applies to one's physical body. Now, it is also understood that this applies to one's mind and brain. Gene Cohen is the Director of the

Center on Aging, Health, and Humanities at George Washing University. Quoting from Cohen (2006):

> An important 2003 study identified five leisure activities that were associated with a lower risk of dementia and cognitive decline. In order of impact (from highest to lowest), the winners were dancing, **playing board games,** playing musical instruments, **doing crossword puzzles,** and reading. Risk reduction was related to the frequency of participation. For example, older persons who did crossword puzzles four days a week had a risk of dementia 47 percent lower than subjects who did puzzles only once a week. [Bold added for emphasis.]

The Fall 2005 article at http://www.gwu.edu/~magazine/2005_research_fall/features/feat_aging.htm discusses Cohen's work:

> They have found that sleep and mood disorders can be alleviated by stimulating the brain; that vocabulary expands well into the 80s among people who continually challenge themselves through reading, writing, and **word games**; and that an active lifestyle can boost the immune system. [Bold added for emphasis.]

Gene Cohen is now involved in developing games designed to exercise the aging brain. Research in this area seems somewhat limited. The commercial Website *Acuity Games* http://www.acuitygames.com/research.html includes links to various research studies. (As of 1/29/07 all of the references were 2004 and older.)

If you are "into" physical exercises, then you probably know quite a bit about how often to work out, how long to work out, how hard to work out, and so on. That is, the science of physical workouts is quite well developed. This is not the case for mental workouts.

Artificial Intelligence

Throughout my professional career, I have been interested in artificial intelligence. The following is quoted from my 2005 book *Brief Introduction to Educational Implications of Artificial Intelligence.* The entire book is available free at http://darkwing.uoregon.edu/~moursund/Books/AIBook/index.htm.

> Artificial intelligence (AI) is a branch of the field of computer and information science. It focuses on developing hardware and software systems that solve problems and accomplish tasks that—if accomplished by humans—would be considered a display of intelligence. The field of AI includes studying and developing machines such as robots, automatic pilots for airplanes and space ships, and "smart" military weapons. Europeans tend to use the term machine intelligence (MI) instead of the term AI.
>
> The theory and practice of AI is leading to the development of a wide range of artificially intelligent tools. These tools, sometimes working under the guidance of a human and sometimes without external guidance, are able to solve or help solve a steadily increasing range of problems. Over the past 60 years, AI has produced a number of results that are important to students, teachers, our overall educational system, and to our society.

Each computer game makes use of some aspects of AI. For example, when you are playing a computer game, you decide on a move and communicate this to the computer. You might do this by use of a keyboard, mouse, joystick, or verbal command. In some sense, the computer "understands" your specification of a move and checks to see if it is a legal move. If it is not a legal move, the computer tells you so. If it is a legal move, the computer makes the move. It takes a certain amount of intelligence to receive a specified move, decide if is a legal move, and then take appropriate action.

Many computer games make use of considerably more AI. For example, in computer games that require two or more players, the computer may serve as some (or all) of these players. If you like to play games such as checkers and chess, you can play them against a computer opponent. The chances are that this computer opponent has enough checker-playing or chess-playing intelligence to defeat you.

You may have noticed that the definitions of AI do not talk about the computer's possible sources of knowledge. Two common sources of an AI system's knowledge are:

- Human knowledge that has been converted into a format suitable for use by an AI system.
- Knowledge generated by an AI system, perhaps by gathering data and information, and by analyzing data, information, and knowledge at its disposal.

While most people seem to accept the first point as being rather obvious, many view the second point only as a product of science fiction. Many people find it scary to think of a machine that in some sense "thinks" and thereby gains increased knowledge and capabilities. To learn more about this topic see Chapter 7 of Moursund (2005).

Many real world problems or problem situations are very large, complex, and interdisciplinary. The translation of speech from one natural language to another provides a good example. While some progress is being made in this area, bilingual humans are far better at such translation than are artificially intelligent computer systems.

There are other more limited and less challenging problem areas in which AI systems are quite successful. Examples include processing loan applications, certain types of medical diagnostic work, and in some Highly Interactive Intelligent Computer-Assisted Learning systems. Computer systems that handle voice input (for example, receiving voice input and producing text as output) are now accurate enough so that many people use them.

The point is, AI is an increasingly important use of computers that affects everyday life in our society. Thus, it is important that students learn some of the characteristics, capabilities, and limitations of AI systems. Games can be a useful part of an environment to study and experiment with AI. A Google search of *games and artificial intelligence* produces millions of hits. Browsing a few of these hits will give you increased insight into AI and roles of AI in computer games.

Dangers of Too Much Game Playing

It is clear that computers, cell phones, digital cameras, video games, and other aspects of ICT are "here to stay." Moreover, it is clear that children growing up in this environment tend to be more comfortable with it than many of today's adults. ICT has already substantially changed the day-to-day life patterns of many people. For example, as I watch college students moving from class to class, I am beginning to wonder if having a cell phone or a music player is now an integral component of walking!

Video games are steadily moving in the direction of having the video and story line quality of broadcast television, along with steadily improving interactivity that allows the viewer to be an active participant in the story. In that sense, a video game can be thought of as video plus interactive participation. It is not surprising that large numbers of children spend more time playing video games than they do watching (non interactive) television.

There is a substantial and growing literature on actual and possible harms of children and adults spending so much time playing video games and making other uses of ICT. My personal collection of such materials can be accessed at http://otec.uoregon.edu/arguments_against.htm.

Such arguments against use or over use of ICT tends to fall into two major categories:

1. Arguments that use or overuse of ICT causes physical and/or mental damage. For example, huge numbers of people develop carpel tunnel syndrome. There is growing evidence of increasing obesity in children due to not getting enough physical exercise. There are continuing concerns that cell phones may cause brain damage; there is strong evidence of loud audio devices causing hearing damage.
2. Arguments that video games and other ICT are addictive and take time away from other activities that are important parts of becoming a well rounded, responsible adult, and productive adult.

Schools are struggling with how to make appropriate use of ICT as an aid to learning and, at the same time, restrict or prohibit use of ICT that draws student attention away from learning the content being taught in schools, is disruptive in classrooms, is used to cheat on tests, is used to harass students, is used by stalkers, and so on.

Douglass Gentile (n.d.) discusses some of the standard arguments against young children spending too much time playing video games. His brief article concludes with the statement:

> It's important to remember, however, that video and computer games aren't all bad. Quality games give children the opportunity to practice problem solving and logic skills. They increase fine motor and coordination skills and foster an interest in information technology. And, if you are playing the games with your child — something I highly recommend — they provide an occasion for you to do something together. Your best bet is to limit video game playing now while your child is still young. In addition, be a smart consumer and choose video games for your child that are age appropriate and that aren't sending the wrong message.

Knowledge-Building Communities

A number of people are doing research in the field of games in education. Scardamalia and Bereiter (1994) provides a good foundation for some of this research. Their article includes a focus on three important aspects of education that are also important aspects of using games in education;

1. Intentional learning. Quoting from their article:

   > Although a great deal of learning is unintentional, important kinds of school learning appear not to take place unless the student is actively trying to achieve a cognitive objective—as distinct from simply trying to do well on school tasks or activities (Bereiter & Scardamalia, 1989; Chan, Burtis, Scardamalia, & Bereiter, 1992; Ng & Bereiter, 1991).

   As pointed out elsewhere in this book, effective use of games in education requires that they be used in an intentional learning environment.

2. Expertise is a process. Quoting from Scardamalia and Bereiter (1994):

   > Although expertise is usually gauged by performance, there is a process aspect to expertise, which we hypothesize to consist of reinvestment of mental resources that become available as a result of pattern learning and automaticity, and more particularly their reinvestment in progressive problem solving—addressing the problems of one's domain at increasing levels of complexity (Bereiter & Scardamalia,

> 1993; Scardamalia & Bereiter, 1991b). Progressive problem solving characterizes not only people on their way to becoming experts, but it also characterizes experts when they are working at the edges of their competence. Among students, the process of expertise manifests itself as intentional learning.

We want students to develop their levels of expertise in many different areas. Research indicates that students should understand this educational goal, understand the meaning of expertise, and be actively engaged in developing their own expertise.

3. Schools as knowledge-building communities. Quoting from Scardamalia and Bereiter (1994):

> The process of expertise is effortful and typically requires social support. By implication, the same is true of intentional learning. Most social environments do not provide such support. They are what we call first-order environments. Adaptation to the environment involves learning, but the learning is asymptotic. One becomes an old timer, comfortably integrated into a relatively stable system of routines (Lave & Wenger, 1991). As we explain further in later sections, there is good reason to characterize schools of both didactic and child-centered orientations as first-order environments. In second-order environments, learning is not asymptotic because what one person does in adapting changes the environment so that others must readapt. Competitive sports and businesses are examples of second-order environments, in which the accomplishments of participants keep raising the standard that the others strive for. More relevant examples in education are the sciences and other learned disciplines in which adaptation involves making contributions to collective knowledge. Because this very activity increases the collective knowledge, continued adaptation requires contributions beyond what is already known, thus producing non-asymptotic learning. The idea of schools as knowledge-building communities is the idea of making them into second-order environments on this model.

One of the key ideas here is that of a steadily rising bar. The totality of human knowledge is steadily growing. Many people talk about the idea of an information overload—that there is too much information that we need to deal with. Our schools should be helping students learn to deal with this information overload.

In some sense, the world we live in is growing more complex. The problems an ordinary person faces in day to day living are growing more complex. I like to think of this as a problem overload. I am continually bombarded by problem situations, in a manner suggesting I should take ownership and accept the problem situations as personal problems. A couple of hours of watching commercial television and news, and I am overwhelmed. Some of the world's best marketing people are doing their best in feeding me problem situations (be it bad breath, heartburn, starving children through the world, crime in my own city, and so on) that I must do something about immediately.

In some sense, the difficulty is not an information overload. It is a lack of easily accessible information to deal with the problem overload. I lack the information to quickly and easily deal with all of these problem situations that are being forced upon me!

Static and Virtual Math Manipulatives

Math educators often make use of math manipulatives in helping their students to better understand mathematics. Many of these manipulatives have game-like characteristics. A brief discussion of computer-based math manipulatives (virtual manipulatives) and links to a number of virtual manipulative Websites are available at http://otec.uoregon.edu/virtual_manipulatives.htm. Quoting from the Website http://www.ct4me.net/math_manipulatives.htm:

> In *What are Virtual Manipulatives?*, Patricia Moyer, Johnna Bolyard, and Mark Spikell (2002) define a virtual manipulative as "an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" (p. 373). Static and dynamic virtual models can be found on the Web, but static models are not true virtual manipulatives. … The key is for students to be able to construct meaning on their own by using the mouse to control physical actions of objects by sliding, flipping, turning, and rotating them.

Many virtual manipulatives are computer simulations of physical manipulatives. This situation provides a good example of the "computational" in sub disciplines such as computational math, biology, and physics. It also helps to illustrate computational thinking. If I can develop a computer model of a problem situation I am thinking about or some project I am doing, I can take advantage of the computer model in doing the thinking and the project. Part of computational thinking is to think about use of computational modeling when faced by challenging problems and tasks.

Tangram serves as a nice example of a physical and virtual manipulative. This is a Chinese puzzle consisting of a square cut into five triangles, a square, and a rhomboid, to be reassembled into different figures with no overlapping pieces (Tangram, n.d.). Figure 9.1 shows the seven pieces and the pieces arranged into a running person. Tangram is available for free online play at http://www.apples4theteacher.com/tangrams.html. (Ten examples are shown. Use the **Help** button for directions.)

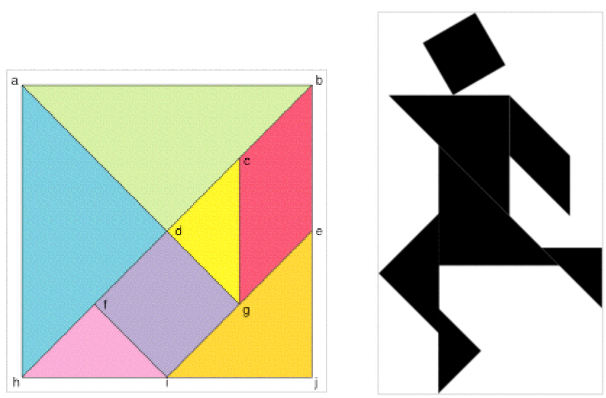


Figure 9.1. The seven Tangram pieces and a running person.

Research on Games and Gaming

Many people view computer games as an opportunity to help improve our educational system. James Paul Gee is a professor of reading at the University of Wisconsin-Madison and a leader in educational uses of computer games. He notes that computer games are often quite complex and present a serious learning challenge. Quoting from (Gee, 2004):

> For people interested in learning, this raises an interesting question. How do good game designers manage to get new players to learn their long, complex, and difficult games—not only learn them, but pay to do so? It won't do simply to say games are "motivating". That just begs the question of "Why?" Why is a long, complex, and difficult game motivating? I believe it is something about how games are designed to trigger learning that makes them so deeply motivating.

Two researchers at Brunel University recently reported on their three-year study of gaming (Brunel University, 2006). Quoting from the press release:

> Brunel academics today unveil the results of a three-year study into online gaming communities, which defies the traditional educationalists' negative perception of gaming. The academics believe that computer games have a central role to play in the education and development of young people, contributing to the Qualifications and Curriculum Authority's strategy of work related learning, which helps children make an effective transition from school to work.
>
> The study, which took the form of qualitative research into a community of players of the online game Runescape shows that gaming is far from being a frivolous diversion from homework. The research shows how the online worlds created by the gamers mirror many aspects of material society helping teenage gamers to make the transition from school to work. For example, gamers are invited to join 'Klans' - highly disciplined co-operatives in which they share a common set of goals, they adopt identities such as merchant or warrior and they divide their time online between work and leisure. Most importantly, skills are learnt which are highly valued, with experienced players tailoring their 'training' to acquire the 'desirable' skills—a clear example of 'work related learning'.

Many of today's popular computer games are multiplayer, first person shooter (FPS) games. In such games, a game player controls a "person" or avatar that is a member of a team, playing against the computer and/or against other teams (Wright et al., 2002). The referenced article includes an emphasis on the social interaction that goes on in such a game. Quoting from this research article:

> Play is not just "playing the game," but "playing with the rules of the game" and is best shown in the diversity of talk, the creative uses of such talk and player behavior within the game, plus the modifications of game technical features. Of course, the playing of the game also produces changes in one's own subjectivity making it a pleasurable experience if one is accomplished (Myers 1992). In essence, the game is a platform for showing off human performances in a mock combat setting. But, all is not combat or simply shooting a virtual enemy. And, as in any human performance, creativity of execution is the norm.
>
> From our text files we identified 39 possible coded talk categories which fit into the following five general categories: 1) creative game talk, 2) game conflict talk, 3) insult/distancing talk, 4), performance talk and 5) game technical/external talk. These were the categories that appeared to exhibit the greatest frequency of use among players.

A number of people and groups are now engaged in research and development of educational computer games. Kurt Squire at the University of Wisconsin-Madison is a leading researcher in this field. Quoting from Massachusetts Institute of Technologies' *Games-to Teach* Website (Squires, n.d.)

> The most under-examined potential of games may be their impact as an educational medium. Playing games, I can relive historical eras (as in Pirates!), investigate complex systems like the Earth's chemical & life cycles (SimEarth), govern island nations (Tropico), manage complex industrial empires (Railroad Tycoon), or, indeed, run an entire civilization (Civilization series). Did I forget to mention travel in time to Ancient Greece (Caesar I,II, & III), Rome (Age of Empires I, and II), relive European colonization of the Americas (Colonization), or manage an ant colony, farm, hospital, skyscraper, theme park, zoo, airport, or fast food chain? As my opening anecdote suggests, the impact of games on millions of gamers who grew up playing best-selling games such as SimCity, Pirates!, or Civilization is starting to be felt.

Squire's paper contains an extensive bibliography and provides good evidence of the growing research literature in this discipline.

Serious Games

The term *serious games* is now used to describe games that are designed for educational purposes. Quoting from Katrin Becker (n.d.):

> The use of computer and video games for learning is an emerging area of research, and interest is growing rapidly. As a sub-field of Serious Games, digital game-based learning poses some unique problems and challenges. As more and more young people grow up with digital games as one of their primary forms of entertainment, it behooves us to become familiar with this genre, how it affects people, and how we might use it for educational goals. Computer technology has advanced to the point where it is feasible (we now have the horse-power to accomplish this) to use games in a classroom setting. "Computer pioneer Alan Kay (DARPA in the '60s, PARC in the '70s, now HP Labs) declares 'The sad truth is that 20 years or so of commercialization have almost completely missed the point of what personal computing is about.' He believes that PCs should be tools for creativity and learning, and they are falling short."

If you are interested in some of the current Serious Games ideas and research, you might enjoy reading the notes published by an attendee at the two-day Serious Games Summit held October 31 and November 1, 2005. The notes are available at http://www.mcmains.net/ruminations/2005/11/01. The posting starts with Day 2, but contains Day 1 later in the posting.

Marc Prensky's Website is an excellent resource on serious games. Quoting from http://www.socialimpactgames.com/:

> Welcome to our revised site, which now boasts an index (see left). All the content on this site (except comments) is available without logging in. We have now identified over 500 serious games, which we are in the process of adding to this list."

Additional resources from Prensky are available at http://www.marcprensky.com/writing/default.asp, http://www.gamesparentsteachers.com/, and http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Game-Based%20Learning-Ch5.pdf. The first Website contains chapters 1-3 and the third reference contains chapter 5 of Prensky's 2001 book *Digital Game-Based Learning.* Quoting from chapter 5 of his 2001 book:

1. Games are a form of **fun.** That gives us ***enjoyment and pleasure.***
2. Games are form of **play**. That gives us ***intense and passionate involvement.***
3. Games have **rules.** That gives us ***structure.***
4. Games have **goals.** That gives us ***motivation.***
5. Games are **interactive.** That gives us ***doing.***
6. Games are **adaptive.** That gives us ***flow.***
7. Games have **outcomes and feedback.** That gives us ***learning.***
8. Games have **win states.** That gives us ***ego gratification.***
9. Games have **conflict/competition/challenge/opposition.** That gives us ***adrenaline.***
10. Games have **problem solving.** That sparks our ***creativity.***
11. Games have **interaction.** That gives us ***social groups.***
12. Games have **representation and story.** That gives us ***emotion.***

Activities for the Reader

1. Engage your students in a discussion about why girls and boys don't necessarily like the same types of games. You might want to do whole class or small group braining storming about what might make a game more appealing to girls than boys, or vice versa.

2. Chapter 5 of Marc Penzsky's 2001 book contains a list of 12 characteristics of games. Select some traditional school academic discipline or topic that you teach. Analyze it in terms of the 12-item. One way to do this would be to develop a 5-point scale, ranging from very low to very high. Select a game that you know well, and school discipline or topic that you know well. Rate the game and the school topic on each of the 12 items in the list.

Activities for use with Students

1. Working in teams of two or three, create a game. One possible starting point is to make a list of characterizes that make a game "fun" to members of the team, and then to design a game that has a number of these characteristics. During the game developmental process, a team may want to try out some of their ideas with members of other teams. After each team has created a game, the teams can demonstrate and teach their games to the whole class.
2. Do whole class brainstorming on what makes a game fun. After a large number of characteristics have been developed, pair the list down to a half dozen or so, perhaps by using a voting technique in which each student is given a limited number of sticky dots to place on their top choices. Then divide the class into small teams, with each team being given a subject that they are studying in school. Each team is to analyze their subject and the way it is being taught in terms of the characteristics that make a game fun.

Appendix 1

Summary of Problem-solving Strategies

We all make use of strategies as we attempt to solve problems and accomplish tasks. The research literature in problem solving indicates that most people have a relatively limited repertoire of problem-solving strategies. This research suggests that it is helpful to increase one's repertoire. Teaching for high-road transfer of learning is an effective method of helping students to increase their repertoire.

However, increasing the size of one's repertoire of problem-solving strategies is only one part of increasing one's level of expertise in problem solving. Problem solving in a specific domain requires knowledge that is specific to the domain. Increasing expertise in problem solving in a domain requires substantial cognitive effort. It does little good to memorize a bunch of strategies. One must consciously practice using the strategies and reflect on the results over a large range of problems.

The following alphabetical list contains problem-solving strategies that cut across many problem-solving domains. Most are discussed and illustrated earlier in this book. The teaching of such strategies can be integrated throughout the daily curriculum

backtracking. Taking back or undoing one or more moves that one has made in playing a game or in attempting to solve a problem. This is especially easy to do when the steps being taken are "virtual" steps, working with a computer representation of the problem and the steps being taken. Backtracking is an important aid to editing and revising one's writing.

backward. See *work backward.*

bottleneck. Identify components of a problem-solving task that severely impede progress toward solving the problem. Particularly useful in problems where certain resources such as time or materials are severely restricted or a goal is to minimize their use.

brain aids. Many computer games include built in aids to a player's brain/mind. Thus, it is now commonplace for a game player to think about having the computer aid in playing the game. There are many articles about the nature and extent of the artificial intelligence (AI) built into various games. In some instances, such uses of AI as an aid to problem solving illustrate or are somewhat parallel to uses of AI to help solve non-game types of problems.

breaking a problem into smaller problems. See *divide and conquer.*

build on previous work. See *reinvent the wheel*.

collaboration and cooperation. There are many problem-solving situations where "two heads are better than one." Indeed, many problems and tasks require the work of large teams of people together over a period of years.

collect data. Think of playing a game or attempting to solve a problem as a research process. Think of yourself as a "scientific" researcher, carefully gathering data about the moves you are making or thinking about making and the strategies you are using, and then analyzing the results that are obtained from a particular move. You can see that this is essentially the same process as the *scientific method* that researchers use. Thus, this is an excellent opportunity for high-road transfer of learning.

create a simpler problem. When faced by a problem that you cannot solve, create a somewhat similar or related problem that is challenging, but perhaps not as difficult. Working to solve the new problem may give you insights that will help you to solve the original problem.

divide and conquer. Divide a large problem into smaller sub-problems that are more manageable. Do this in a manner such that once the sub-problems are solved, it is relatively easy to put the pieces together to solve the original problem. Note the value of having a large repertoire of "sub-problems" that one can readily solve. Often, some of the sub-problems can be solved by a computer or other machine.

domain-specific. Most of the strategies listed in this appendix are applicable in many different game and non-game problem-solving situations. Within any problem-solving or game domain, there are strategies that are quite specific to the domain. These are called domain-specific problem-solving strategies For example, play in the center square if you are the first player in a TTT game. This is a good TTT strategy because if your opponent responds by playing in the center of any of the four edges, you can then force a win. If your opponent plays in a corner, you can easily avoid losing.

don't box yourself into a corner. See *mobility.*

elimination. In many problems, it is possible to relatively quickly and easily eliminate certain categories of potential solutions or approaches. This narrows the things that one needs to think about or try out in an attempt to solve the problem.

exhaustive search. Many problems can be solved by trying out all possible (allowable, applicable) moves or sequences of moves. If the number of possibilities is relatively small, a person or team of people might be able to carry out such an exhaustive search in a timely fashion. If the search process can be carried out by a computer, it may be possible to explore many millions of possible solutions or sequences of moves.

explore solvability. Many of the situations that people call problems are actually not clearly defined and understandable problems. Rather, they are problem situations. One of the first steps to take when faced by a problem situation is to explore whether it is actually a clearly defined problem (given initial situation, clear goal, resources, ownership). One does not solve a problem situation, one solves a problem. Next, spend some time exploring whether you actually understand the problem. If you don't understand the given initial situation, the goal, and the resources, you are not in a good situation to attempt to solve the problem. One way to increase your understanding of a problem is to consider whether the problem might not have a solution. Think to yourself: "how would I recognize a solution if I happened to find one?"

good start. Quoting Aristotle, "Well begun is half done." Quoting Lao Tzu, "A journey of a thousand miles must begin with a single step." In problem solving, a good start or a good first step is one that is likely to make a significant contribution to solving the problem. In competitive two-player games such chess, many thousands of person hours of effort have gone into analyzing opening sequence of moves. Knowledge of and use of “good” openings can give a player a substantial advantage over an opponent who is less familiar with this form of accumulated knowledge.

guess and check. See *guess and learn.*

guess and learn. Many problems can be approached by making a guess (sometimes called an “educated guess”) at a solution or a possible approach to obtaining a solution. If the guess provides a correct solution or a correct pathway to obtaining a solution, that is well and good. If it doesn’t, then one still gains useful information about the problem. For example, if one makes a guess of a solution and the guess is incorrect, one learns that the guess is incorrect. However, in many problem-solving situations, one gains additional information that helps in making a better guess or helps in developing a better plan. Generally speaking, increasing one’s expertise in problem solving in a particular domain includes getting better at making educated guesses and making guesses that are useful aids to learning more about how to solve a problem in the domain.

hill climbing. See *incremental improvement.*

incremental improvement. Some problems can be solved through a sequence of incremental improvements. This is somewhat akin to walking to the top of a mountain by making sure each step moves you uphill. However, many problems cannot be solved by incremental improvement (think of climbing a mountain and having to move down hill from time to time). Thus, incremental improvement is often a poor strategy, wasting time and other resources, and contributing little to actually solving the problem.

information retrieval. See *reinvent the wheel.*

learn to fill in the details. A powerful alternative to rote memory is to learn/understand general approaches to solving certain types of problems, accomplishing certain types of tasks, and making certain proofs. With the general understanding, one can then fill in the details. This is a common teaching technique in math and is applicable to any problem solving instruction.

letter frequency. Data has been collected on the frequency of use of each letter of the English alphabet in typical writing. Also, data has been collected on most frequent beginnings of words and end of words, most common bigrams, most common trigrams, and so on. A person can memorize such detailed data, and it can be incorporated in computer programs. The data is useful in cryptography, working to identify the author of a manuscript, and in a variety of games. Use of letter frequency is a good example of building on the previous work of others.

long-range planning. This is often called *long-range strategic planning.* It refers to developing a broad, strategic plan that provides a good sense of direction of where one is heading in trying to solve a particular problem. Often a long-range strategic plan is accompanied by shorter-range plans and strategies, and by detailed tactics that are designed to accomplish the short range plans.

look ahead. Typically, solving a problem involves a sequence of steps or moves. In there is an opponent involved, then moves are followed by responses that might well affect one's next move. In attempting to solve real-world problems, each step or action makes a change in the problem situation. Failure to anticipate major changes often leads to failure to solve a problem.

look before you leap. See: *think before you act; look ahead; good start.*

memorize when personally effort-effective. This is a strategy applicable to a wide variety of problem-solving situations. Memorized information can be thought of as solutions to specific sub-problems or problems. People vary considerably in terms of how quickly and accurately they can memorize a particular set of materials, and how long and accurately they retain the memorized information. A rule of thumb is to memorize information that one needs to use frequently enough, and in a time-dependent manner, to make the memorization effort worthwhile. Keep in mind the capabilities of a computer system to store the full contents of millions of books, and the abilities of search engines to aid in retrieval of information stored in a computer.

mental aids. Reading, writing, arithmetic, books, and computers are all examples of mental aids. They help to overcome limitations of one's brain. They are resources that can be applied to problems in every domain. See *modeling and simulation.*

metacognition. Metacognition is thinking about—analyzing, reflecting on—one's thinking. It is a highly effective strategy in improving one's problem-solving and learning skills.

metaphor. See *modeling and simulation*. A metaphor is "the application of a word or phrase to somebody or something that is not meant literally but to make a comparison, for example, saying that somebody is a snake" (Encarta® World English Dictionary © 1999 Microsoft Corporation). In some sense, most written and oral language is metaphorical. It is an attempt to provide a written or oral representation of something, where the words and sounds are not the actual thing being represented. When describing and thinking about a problem, metaphors can be a powerful aid to understanding or constructing understanding, thinking, and thinking outside the box.

mobility. As you work to solve a challenging problem, don't close off options that may later prove to be fruitful. Don't box yourself into a corner where you have very few or no options.

modeling and simulation. The development of models and then the use of these models (for example, develop a model of an airplane and test it in a wind tunnel) has long been a powerful tool in problem solving. Computer modeling and simulation is such a powerful aid to problem solving that it has added a new dimension to how science is done. Nowadays, science is done experimentally (designing and carrying out experiments), theoretically (developing theories, such as Einstein's theory of relativity), and computationally (developing and using computer models). Spreadsheet software is a powerful aid to modeling many business problems and then answering "What if?" types of questions.

Moursund's 7-step strategy. This is a seven-part set of advice that can be used to get better at solving a wide range of problems. It summarizes ideas such as learning general knowledge and strategies, learning domain-specific knowledge and strategies, and learning during the process of solving a problem.

patterns. This is a short name for strategies such as *look for patterns* and *make use of patterns.* I find it helpful to think of randomness as being the absence of patterns. The human brain can be thought of as an organ for the input, storage, processing, and use of patterns. (That statement is quite similar to the statement that an electronic digital computer is a machine for the input, storage, processing, and output of data and information.) The identification and use of patterns is a key aspect of problem solving in every discipline.

problem situation. Many of the things that people describe as problems are actually problem situations. They lack one or more of the characteristics (givens, goal, resources, ownership) to be clearly defined problem of personal interest. Polya's six-step strategy begins with understanding the problem—determining if one actually has a clearly defined problem that he or she is interested in solving.

random. See *patterns.* Somewhat surprisingly, the use of random moves or random activity can be a useful approach in many different problem-solving situations. Of course, many games make use of randomness. For example, one shuffles the cards in card-based games of solitaire and in many other card games. One makes use of a spinner or dice into generate moves in many different games. At a deeper level, randomness can be used in modeling and simulation as an aid to solving a wide range of problems in science and other areas. For a more mundane example, imaging a person playing a game such as Tic-Tac-Toe by making completely random moves. The results can be used to establish baseline data on how well a person plays the game before developing or learning any strategies that lead to an improved level of play.

record one's moves. See *collect data.* See *mental aids*.

reinvent the wheel. This strategy takes two forms: 1) **don't** reinvent the wheel; 2) **do** reinvent the wheel. In the first instance, the idea is to build upon work that you and others have done in the past. Use Web and other resources of stored information—do library research—to find out what is already known about how to solve a particular problem. In the second instance, the idea is to not be boxed in by conventional approaches to the problem. This approach is also a key in learning how to solve problems. There, the goal is to improve one's level of expertise in solving novel, challenging problems.

score and then improve your score. See *good start.* There are many real-world problem-solving situations in which a score of zero is explicitly or implicitly given for not making a reasonable attempt, or completely failing in one's attempts. In many tests, one can get partial credit for a good start, even if one fails to actually solve the problem.

sequence of moves. See *look ahead.* In many card and board games and in many puzzles it is important to think in terms of sequences of moves. Through training and experience, one can become quite skilled at mentally (in one's mind's eye) examining a sequence of possible moves.

simpler problem. See *create a simpler problem*. When faced by a challenging, complex problem, create a simpler but closely related problem and attempt to solve it. The goal is to gain insight into the original problem. For example, instead of thinking about how to reduce hunger in the United States, think about reducing hunger in your state, or in your city, or in one small area in your city, or the hunger that you know exists for one student in a class you are teaching. For another example, consider the problem of learning the rules of a complex game. Set yourself the simpler problem of learning the rules for making your first move.

strategize. The list of high-road transferable problem-solving strategies illustrated in this book is deigned to help you get better at developing and using problem-solving strategies. A strategy can be thought of as a plan of action to be used in attempting to achieve a goal. Some strategies are general purpose, useful over a wide range of problems. However, typically it takes considerable domain-specific knowledge and skills to solve a challenging problem within a specific domain. As one develops such domain-specific knowledge and skills, one develops specific strategies (or, fine tunes general strategies) to better fit the problem-solving requirements of the domain.

think before you act. This is sometimes *called look before you leap*, or *engage brain before opening mouth.* Some problem-solving situations require immediate (stimulus-response; intuitive) actions be taken. There is no time to think. The strategy that is emphasized in such situations might be called *act before you think.* Of course, the actions you take may be based on a huge amount of training and practice. Many problem-solving situations do not require immediate, split second responses and actions. In these situations, there is time to mull over possible actions, to think before taking an action.

think out loud. When a team of two or more people are working on a problem, it is often helpful to have one member of the teach think out loud about the problem, while the other team members merely listen and perhaps take notes. A different approach is to have two or more members of the team thinking out loud, interchanging possible strategies and ideas, as they explore and work on the problem.

think outside the box. When faced by a problem, most people have a strong tendency to use the approaches and take the types of problem-solving steps that are familiar and comfortable to them. If this does not work, a standard next step is seek help from others, perhaps directly from other people or through library research. There are many problems where these approaches do not work. Solving the problems requires developing new ideas, new ways of thinking, new inventions. It may involve deliberately ignoring ideas and approaches that first come to mind, or that others have developed. Individual and group brainstorming can sometimes be an effective aid to thinking outside the box.

work backward. Start at a solution and move back one or more steps in a manner such that it is easy to see how to move forward to a solution. In essence, the strategy is to create a new problem to solve, with the new problem having the characteristic that once it is solved, it is easy to solve the original problem. See *simpler problem.*

References

Adler, Allan (n.d.). What is a Magic Square? Math Forum. Retrieved 1/30/07: http://mathforum.org/alejandre/magic.square/adler/adler.whatsquare.html.

Aldous, David and Diaconis, Oersi (July 21, 1999). Longest increasing subsequences: From Patience sorting to the Baik-Deift-Johansson theorem. Bulletin of the American Mathematical Society. Volume 36, Number 4, Pages 413-432. Retrieved 1/30/07: http://www.ams.org/bull/1999-36-04/S0273-0979-99-00796-X/S0273-0979-99-00796-X.pdf.

Boulter, Jeff (1995). Tic-Tac-Toe. Retrieved 1/30/07: http://boulter.com/ttt/.

Brown, John Seely; Collins, Allan; and Duguid, Paul (1989). Situated cognition and the culture of learning. *Educational Researcher.* Retrieved: 1/30/07: http://www.sociallifeofinformation.com/Situated_Learning.htm.

Brunel University (2006): Learn as you play: *Brunel study shows positive role of computer games*. Retrieved 1/30/07: http://www.brunel.ac.uk/news/pressoffice/cdata/work+not+play. See related article at http://news.bbc.co.uk/1/hi/technology/4774534.stm.

Burton, Richard, and John Seely Brown (1982). An investigation of computer coaching for informal learning activities. Printed *in Intelligent Tutoring Systems,* Edited by D. Sleeman and J. S. Brown. London/New York: Academic Press.

C.O.P.E. (n.d.). Content, organization, preference, evaluation: Review of the literature. Retrieved 1/30/07: http://www.scils.rutgers.edu/~kvander/gender_project/litreview.htm.

Calvin, Duif (n.d.). How do you read chess notation? Retrieved 1/30/07: http://www.jaderiver.com/chess/notate.html.

Campbell, Anne (February, 2004). Female competition: causes, constraints, content, and contexts. *Journal of Sex Research.* Retrieved 1/30/07: http://www.findarticles.com/p/articles/mi_m2372/is_1_41/ai_n6032939.

Cohen, Gene (January 16, 2006). The myth of the midlife crisis. *Newsweek.* Retrieved 1/30/07: http://www.msnbc.msn.com/id/10753221/site/newsweek/.

Costikyan, Greg (1994). I have no words and I must design. *Interactive Fantasy # 2*. Retrieved 1/30/07: http://www.costik.com/nowords.html.

Dillion, Teressa (n.d.). Adventure games for learning and storytelling. A Futurelab prototype context paper. Retrieved 1/30/07: http://www.nestafuturelab.org/download/pdfs/research/project_reports/Adventure_Author_context_paper.pdf. See also: http://www.nestafuturelab.org/research/projects/adventure_context_04.htm.

Dobnik, Verena (April, 2004). *Surgeons may err less by playing video games.* Associated Press. Retrieved 1/30/07: http://msnbc.msn.com/id/4685909/.

Games-to-Teach Project (n.d.). Retrieved 1/30/07: http://icampus.mit.edu/projects/GamesToTeach.shtml.

Gardner, Howard (2003). Multiple Intelligences after twenty years. Retrieved 1/30/07: http://www.pz.harvard.edu/PIs/HG_MI_after_20_years.pdf.

Gee, James Paul (2004). *Learning by design: Game as learning machines.* Retrieved 1/30/07: http://www.gdconf.com/conference/archives/2004/gee_james.pdf.

Gentile, Douglass (n.d.). Can spending too much time playing video games hurt my child? Retrieved 1/30/07: http://parentcenter.babycenter.com/expert/preschooler/pgames/69631.html.

Kafai, Yasmin B. (October 27, 2001). The educational potential of electronic games: From games-to-teach to games-to-learn. *Cultural Policy Center, University of Chicago.* Retrieved 1/30/07:

http://culturalpolicy.uchicago.edu/conf2001/papers/kafai.html. See also: http://www.gseis.ucla.edu/faculty/kafai/.

Kirriemuir, John and McFarlane, Angela (2002). Literature review in games and learning: A report for NESTA Futurelab. Retrieved 1/30/07: http://www.nestafuturelab.org/research/reviews/08_01.htm.

Kirschner, Paul; Sweller, John; & Clark, Richard (2006). Why minimal guidance during instruction does not work; An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2). 75-86. Retrieved 1/30/07: http://www.cogtech.usc.edu/publications/kirschner_Sweller_Clark.pdf.

Lewis, Andrew (December 2005). Computer games technology and public libraries. Retrieved 1/30/07: http://www.rbwm.gov.uk/public/051201_libs_rbwm_multi-lib-2-2_computer-games-libraries_302.pdf.

McLeod, John (n.d.) *Patience/solitaire*. Retrieved 1/30/07: http://www.pagat.com/patience/patience.html.

M/Cyclopedia of New Media (n.d.). Computer games–ethics: Educative potential. Retrieved 1/30/07: http://wiki.media-culture.org.au/index.php/Computer_Games_-_Ethics:_Educative_Potential.

Michigan State University (n.d.). Games and learning resources. Retrieved 1/30/07: http://mindgames.msu.edu/?page_id=16.

Mitchell, A and Savill-Smith, C (2004). The use of computer and video games for learning: A review of the literature. Learning and Skills Development Agency; Ultralab; m-learning. Retrieved 1/28/07: http://www.m-learning.org/docs/The%20use%20of%20computer%20and%20video%20games%20for%20learning.pdf.

Moursund, D.G. (2004). Brief introduction to roles of computers in problem solving. Access at http://uoregon.edu/~moursund/ Books/SPSB/index.htm.

Moursund, D.G. (2005). Brief introduction to educational implications of Artificial Intelligence. Access at: http://uoregon.edu/~moursund/Books/AIBook/index.htm.

OTEC (n.d.). *Learning theories and transfer of learning.* Retrieved 1/30/07: http://otec.uoregon.edu/learning_theory.htm.

Pegg, Ed (2005). Math games. Sudoku variations. Retrieved 1/30/07: http://www.maa.org/editorial/mathgames/mathgames_09_05_05.html.

Perkins, David (1992). Smart schools: Better thinking and learning for every child. NY: The Free Press.

Perkins, David and Salomon Gavriel (September 2, 1992). *Transfer of Learning: Contribution to the International Encyclopedia of Education, Second Edition.* Oxford, England: Pergamon Press. Retrieved 1/30/07: http://learnweb.harvard.edu/alps/thinking/docs/traencyn.htm.

Peterson, Ivars (May, 2003). Measuring with jugs. *Science News Online.* Retrieved 1/30/07: http://www.sciencenews.org/articles/20030531/mathtrek.asp.

Prensky, Marc (2001). *Digital game-based learning.* McGraw-Hill. Chapters 1, 2, and 3 of this book can be accessed online via links at : http://www.gamesparentsteachers.com/. Chapter 5 can be accessed at http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Game-Based%20Learning-Ch5.pdf.

Prensky, Marc (n.d.). *Social impact games. Entertaining games with non-entertainment goals (a.k.a Serious Games).* Retrieved 1/30/07: http://www.socialimpactgames.com/.

Ranpura, Ashish (n.d.). Navigating space: How your brain knows where you are. *Brain Connection.com*. Retrieved 1/30/07: http://www.brainconnection.com/topics/?main=fa/navspace-hippocampus.

Royle, Gordon (n.d.). *Minimum Sudoku.* Retrieved 1/30/07: http://www.csse.uwa.edu.au/~gordon/sudokumin.php.

Scardamalia, M. and C. Bereiter (1994) Computer support for Knowledge-Building Communities. *The Journal of the Learning Sciences*, 1994. Retrieved *6/12/06*: http://carbon.cudenver.edu/~bwilson/building.html.

Tangram (n.d.). *Wikipedia, the free encyclopedia*. Retrieved 1/30/07: http://en.wikipedia.org/wiki/Tangram

Terdiman, Daniel (June 8, 2006). Making virtual worlds more lifelike. CNET News. Retrieved 1/30/07: http://news.com.com/Making+virtual+worlds+more+lifelike/2100-1043_3-6081306.html.

Tucker-Ladd, Clayton E. (2000). *Psychological self-help.* Retrieved 1/30/07: http://mentalhelp.net/psyhelp/.

Wagner, Tony (January 11, 2006). Rigor on trial. First published in *Education Week*. Retrieved 1/30/07: http://www.schoolchange.org/content/blogcategory/69/12/.

Wing. Jeannette M. (March, 2006) Computational thinking. *Communications of the Association for Computing Machinery*. Retrieved 1/30/07: http://www.cs.cmu.edu/afs/cs/usr/wing/www/publications/Wing06.pdf.

Wright, Talmadge; Boria, Eric; and Breidenbach, Paul (2002). Creative player actions in FPS online video games: Playing Counter-Strike, Retrieved 1/30/07: http://www.gamestudies.org/0202/wright/

Young, Michael; Schrader, P.G.; and Zheng, Dongpine (April/May, 2006). MMOGs as learning environments: An ecological journey into *Quest Atlantis* and *The Sims Online*. *Innovate.* Retrieved 1/30/07: http://www.innovateonline.info/index.php?view=article&id=66.

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