Brief Introduction to Educational Implications of Artificial Intelligence

The real problem is not whether machines think
but whether men do. (B. F. Skinner)

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Abstract

This book is designed to help preservice and inservice teachers learn about some of the educational implications of current uses of Artificial Intelligence as an aid to solving problems and accomplishing tasks. Humans and their predecessors have developed a wide range of tools to help solve the types of problems that they face. Such tools embody some of the knowledge and skills of those who discover, invent, design, and build the tools. Because of this, in some sense a tool user gains in knowledge and skill by learning to make use of tools.

This document uses the term “tool” in a very broad sense. It includes the stone ax, the flint knife, reading and writing, arithmetic and other math, the hoe and plough, the telescope, microscope, and other scientific instruments, the steam engine and steam locomotive, the bicycle, the internal combustion engine and automobile, and so on. It also includes the computer hardware, software, and connectivity that we lump together under the title Information and Communication Technology (ICT).

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 50 years, AI has produced a number of results that are important to students, teachers, our overall educational system, and to our society.

This short book provides an overview of AI from K-12 education and teacher education points of view. It is designed specifically for preservice and inservice teachers and school administrators. However, educational aides, parents, school site council members, school board members, and others who are interested in education will find this booklet to be useful.

This book is designed for self-study, for use in workshops, for use in a short course, and for use as a unit of study in a longer course on ICT in education. It contains a number of ideas for immediate application of the content, and it contains a number of activities for use in workshops and courses. An appendix contains suggestions for Project-Based Learning activities suitable for educators and students.

Chapter 1: Intelligence and Other Aids to Problem Solving

This short book is about how humans are using artificial intelligence (AI; also known as machine intelligence) as an aid to solving problems and accomplishing tasks. The book places specific emphasis on educational applications and implications of AI.

This first chapter provides background needed in the remainder of the book. The background includes:

- Several definitions of artificial intelligence.
- A discussion of human intelligence.
- A brief introduction to problem solving.

What is Artificial Intelligence?

There is a huge amount of published research and popular literature in the field of AI (Artificial Intelligence-a & b, n.d.; Minsky 1960; AI Journals & Associations, n.d.). John McCarthy coined the phrase Artificial Intelligence as the topic of a 1956 conference held at Dartmouth (Buchanan, n.d.).

Here are three definitions of AI. The first is from Marvin Minsky, a pioneer in the field. The second is from Allen Newell, a contemporary of Marvin Minsky. The third is a more modern, 1990 definition, and it is quite similar to the earlier definitions.

> In the early 1960s Marvin Minsky indicated that "artificial intelligence is the science of making machines do things that would require intelligence if done by men." Feigenbaum and Feldman (1963) contains substantial material written by Minsky, including "Steps Toward Artificial Intelligence" (pp 406-450) and "A Selected Descriptor: Indexed Bibliography to the Literature on Artificial Intelligence" (pp 453-475)
>
> In Unified Theories of Cognition, Allen Newell defines intelligence as: the degree to which a system approximates a knowledge-level system. Perfect intelligence is defined as the ability to bring all the knowledge a system has at its disposal to bear in the solution of a problem (which is synonymous with goal achievement). This may be distinguished from ignorance, a lack of knowledge about a given problem space.
>
> Artificial Intelligence, in light of this definition of intelligence, is simply the application of artificial or non-naturally occurring systems that use the knowledge-level to achieve goals. (Theories and Hypotheses.)
>
> What is artificial intelligence? It is often difficult to construct a definition of a discipline that is satisfying to all of its practitioners. AI research encompasses a spectrum of related topics. Broadly, AI is the *computer-based* exploration of methods for solving challenging tasks that have traditionally depended on people for solution. Such tasks include complex logical inference, diagnosis, visual recognition, comprehension of natural language, game playing, explanation, and planning (Horvitz, 1990).

In brief summary, AI is concerned with developing computer systems that can store knowledge and effectively use the knowledge to help solve problems and accomplish tasks. This brief statement sounds a lot like one of the commonly accepted goals in the education of humans. We want students to learn (gain knowledge) and to learn to use this knowledge to help solve problems and accomplish tasks. Goals of education are discussed in chapter 2 of this book.

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. However, this is an important aspect of AI. We will discuss it more in chapter 7.

The Web has a type of intelligence and learning capability. The sense of direction of Web developers is to make the Web more intelligent—to create a Semantic Web. Tim Berners-Lee, the inventor of the Web, is leading this endeavor. (See http://www.w3.org/People/Berners-Lee/.) The underlying idea is that each person adding content to the Web is helping to increase the knowledge of the Web (Gibson, 2005).

What is Human Intelligence?

The study and measurement of intelligence have long histories. For example, Alfred Benet and Theodore Simon developed the first Intelligence Quotient (IQ) test in the early 1900s. Chances are, you have taken several IQ tests, and perhaps you can name a number that was your score on one of these tests. Likely, you feel it is very strange to think that a single number is a useful measure of a person's cognitive abilities. Many people argue that a person has multiple intelligences, and that no single number is an adequate representation of a person's intelligence.

IQ is a complex concept. There is no clear agreement among IQ experts as to what constitutes IQ or how to measure it. (Most people are not satisfied by the statement "IQ is what is measured by an IQ test.")

Howard Gardner (1993), David Perkins (1995), and Robert Sternberg (1988) are researchers who have written widely sold books about intelligence. Of these three, Howard Gardner is probably best known by K-12 educators. His theory of Multiple Intelligences has proven quite popular with such educators (Mckenzie, n.d.). However, there are many researchers who have contributed to the extensive and continually growing collection of research papers on intelligence (Yekovich 1994).

The following definition of intelligence is a composite from various authors, especially Gardner, Perkins, and Sternberg.

Intelligence is a combination of the abilities to:

1. Learn. This includes all kinds of informal and formal learning via any combination of experience, education, and training.
2. Pose problems. This includes recognizing problem situations and transforming them into more clearly defined problems.
3. Solve problems. This includes solving problems, accomplishing tasks, and fashioning products.

There is a near universal agreement among researchers that some aspects of our intellectual abilities depend heavily on our experiential histories, and some aspects depend on our genetic makeup. Thus, a person's cognitive abilities are a combination of nature and nurture.

From a teacher's point of view, it is important to understand that a person's life experiences—which include formal and informal education—contribute to the person's intelligence. Education is very important!

We know that we can improve a child's developing intelligence by avoiding drug and alcohol damage to the fetus, by providing appropriate vitamins, minerals, and nutrition to support growth of a healthy mind and body, and by protecting the child from the lead that used to be a common ingredient of paint and leaded gasoline.

The above definition and discussion focuses on cognitive intelligence. Emotional intelligence is also a type of intelligence that is important in the study of AI (Mendiratta, n.d.). The idea of emotional intelligence (EI) has been developed over the past two decades (Hein). Quoting Steve Hein:

> Here I will discuss only the definition of emotional intelligence as proposed by Mayer, Salovey and their recent colleague David Caruso. (Referred to below as MSC.)
>
> MSC suggest that EI is a true form of intelligence which has not been scientifically measured until they began their research work. One definition they propose is "the ability to process emotional information, particularly as it involves the perception, assimilation, understanding, and management of emotion." (Mayer and Cobb, 2000)
>
> Elsewhere they go into more detail, explaining that it consists of these "four branches of mental ability":
>
> 1. Emotional identification, perception and expression. This involves such abilities as identifying emotions in faces, music, and stories.
> 2. Emotional facilitation of thought. This involves such abilities as relating emotions to other mental sensations such as taste and color (relations that might be employed in artwork), and using emotion in reasoning and problem solving.
> 3. Emotional understanding. This involves solving emotional problems such as knowing which emotions are similar, or opposites, and what relations they convey
> 4. Emotional management. This involves understanding the implications of social acts on emotions and the regulation of emotion in self and others.

Some AI researchers are working in the area of EI. At the current time, humans are far superior to computers in terms of EI performance.

Some of Marvin Minsky's insights into human and machine intelligence are provided in a 1998 interview (Sabbatini, 1998). This interview helps to flesh out the definitions given above. Quoting the first part of the interview:

> **Sabbatini: Prof. Minsky, in your view, what is the contribution that computer sciences can make to the study of the brain and the mind?**
>
> Minsky: Well, it is clear to me that computer sciences will change our lives, but not because it's about computers. It's because it will help us to understand our own brains, to learn what is the nature of knowledge. It will teach us how we learn to think and feel. This knowledge will change our views of Humanity and enable us to change ourselves.
>
> **Sabbatini: Why are computers so stupid?**
>
> Minsky: A vast amount of information lies within our reach. But no present-day machine yet knows enough to answer the simplest questions about daily life, such as:
>
> > "You should not move people by pushing them."
> >
> > "If you steal something, the owner will be angry."
> >
> > "You can push things with a straight stick but not pull them."
> >
> > "When you release a thing [you are] holding in your hand it will fall toward earth (unless it is a helium balloon)."

"You cannot move an object by asking it "please come here."

No computer knows such things, but every normal child does.

There are many other examples. Robots make cars in factories, but no robot can make a bed, or clean your house or baby-sit. Robots can solve differential equations, but no robot can understand a first grade child's story. Robots can beat people at chess, but no robot can fill your glass.

We need common-sense knowledge—and programs that can use it. Common sense computing needs several ways of representing knowledge. It is harder to make a computer housekeeper than a computer chess-player, because the housekeeper must deal with a wider range of situations.

A brief summary of the history of AI is given in Kurzweil (1991). He uses the term machine intelligence to refer to the general field of AI. Kurzweil has made many important contributions to the field. For example, many years ago he developed a text to speech machine for the blind.

An Introduction to Problem Solving

This section contains a very brief introduction to problem solving. A more detailed introduction is available in Moursund (2004).

The terms *problem* and *problem solving* are used throughout this document. We use these terms in a very broad sense, so that they include:

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

Problem solving 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 1.1 graphically represents the concept of problem solving. Usually the term *problem* is used to refer to a situation where it is not immediately obvious how to reach the goal. The exact same situation can be a problem for one person and not a problem (perhaps just a simple activity or routine exercise) for another person.

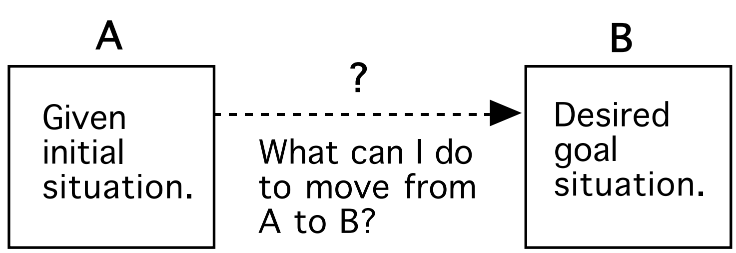

Figure 1.1. Problem solving—how to achieve the final goal?

There is a substantial amount of research literature as well as many practitioner books on problem solving (Moursund, 2004). Here is a formal definition of the term problem. You—personally—have a formal, well-defined (clearly defined) 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—including your personal knowledge and skills— that may be applicable in helping you move from the given initial situation to the desired goal situation. There may be specified limitations on resources, such as rules, regulations, and guidelines for what you are allowed to do in attempting to solve a particular problem.
4. You have some ownership—you are committed to using some of your own resources, such as your knowledge, skills, and energies, to achieve the desired final goal.

The resources (part 3 in the definition) available to a person certainly include their mind and body. A carpenter typically has a wide range of hand and power tools, along with acquired knowledge and skill in how to use the tools. In this book, we are particularly interested in ICT—especially, AI—as one of the resources in problem solving. ICT systems can solve or help solve a number of problems of interest to humans. From an educational point of view, this raises two questions:

- If a computer can solve or substantially aid in solving a type of problem that students are studying in school, what should students be learning about solving this type of problem? (For example, should they be learning to compete with computers or work cooperatively with computers?)
- Are there topics that should be eliminated from the curriculum or topics that should be added to the curriculum because of the capabilities of computers to solve problems and/or to assist in solving problems?

Think about these questions as you read this book. As a reader, one of your goals should be to form well-reasoned answers for yourself. In addition, you should pose other, equally complex questions that are of interest to you and others.

Key Ideas in This Chapter

The following diagram helps to summarize some of the ideas of this chapter.

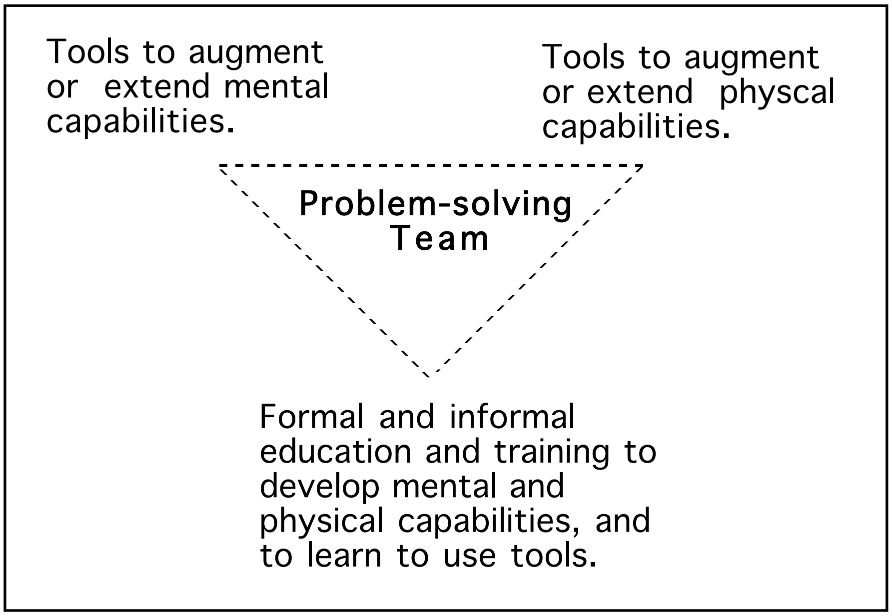

Figure 1.2. Problem-solving team.

At the center of the diagram is a team consisting of one or more people working to solve a problem or accomplish a task. The team makes use of tools that extend their mental capabilities (such as reading, writing, arithmetic, calculators, and computers) and tools that extend their physical capabilities (such as a carpenter's tools, cars, and airplanes). The team has had education and training in using available resources to solve problems and accomplish tasks. The overall capabilities of the team are improved by providing the team with better tools, better education, better training, and additional experience.

Over the centuries, humans have made substantial progress in producing tools to supplement their physical capabilities. People routinely use eyeglasses, binoculars, telescopes, and microscopes to augment and extend their eyesight. People routinely use bulldozers and trucks to augment and extend their muscle power. However, we do not use the terms **artificial eye, artificial body,** or **artificial muscle** to describe the theory and practice of developing and using such tools. For the most part, people do not debate whether artificial muscle is as good or better than "real, human" muscle. They do not think that a school that teaches people to drive large trucks or bulldozers is inherently suspect, and that it would be better if such schools taught the basics of moving goods and dirt by hand.

In retrospect, John McCarthy's 1956 choice of the term **artificial intelligence** may have done a disservice to the field. For many people, the term AI tends to be an emotion-laden term that is suggestive of developing Frankenstein-like monsters that will replace humans.

This book explores the capabilities and limitations of ICT systems to process and use data, information, knowledge, and wisdom to help automate cognitive tasks. It also explores the use of such ICT in machines such as robots. Throughout this book we will use the term AI, although from time to time we will use the term **machine intelligence** to help stress that we are talking about something that is quite different than human intelligence.

Personal Growth Activities for Chapter 1

Each section of this document contains one or more suggestions for reflection and possible conversations based on the ideas covered in the section. The intent is to get you actively engaged in learning and using the materials that you are reading.

1. Engage some of your colleagues in a conversation about cognitive intelligence and emotional intelligence. Your goal is to explore your insights and your colleagues' insights, especially as they apply to students. After you have practiced talking about cognitive intelligence and emotional intelligence, engage some of your students in a conversation about these topics. Your goal is to gain increased insight into how your students view and understand these topics and how they relate to schooling.
2. Think about "intelligent-like" things that you have seen machines do. For example, perhaps you have seen talking toys that respond to a child. Perhaps you have used a computer that displays some intelligent-like behaviors. Talk to someone (a friend, a child, etc.) about the nature of the machine intelligence that you have observed and that they have observed. Focus on the capabilities and limitations that the two of you have seen, and how this machine intelligence has affected your worlds. It is particularly helpful to talk to primary school children on this topic. A child's view of machine intelligence may be quite a bit different from yours. If this topic interests you, visit Sherry Turkle's Website (Turkle, n.d.). She has spent most of her professional career studying computers from a child's point of view.

Activities for Chapter 1

Activities are for use in reflection and self-study, for use in workshops and small group discussions, and for use as written assignments in courses. In almost all cases the Activities focus on higher-order "critical thinking" ideas.

1. Think about a shovel. A person using a shovel may well be able to accomplish a digging task faster and with less effort than a person who does not have access to the tool. Discuss how a shovel in some sense contains or embodies some of the knowledge and skills of its inventors, developers, and manufacturers. Does this mean that in some sense a shovel has some level of machine intelligence?
2. Think about an electronic digital watch. Analyze it from the point of view of its capabilities and limitations in problem solving. In what sense is an electronic digital watch "intelligent?" As you respond to this question, include an analysis of this machine intelligence versus human intelligence within the area of the specific problems that the watch is designed to help solve.
3. Briefly summarize how reading, writing, and arithmetic are mind tools that extend the capabilities of the human mind. Then reflect on whether having knowledge and skills in reading, writing, and arithmetic makes a person more intelligent. As you address this task, you are delving into the deep area of "What is intelligence?" From your point of view, what does the word *intelligence* mean?
4. Consider the definitions of intelligence and emotional intelligence given in this chapter. In your personal opinion, how should our educational system take into consideration the widely differing (cognitive) intelligence and emotional intelligence of students?

5. Select a subject area that you teach or are preparing to teach. Name a general type of problem that students learn to solve because of instruction in this area. Make sure that the general type of problem you name satisfies the first three parts of the definition of a formal problem given in this chapter. Then discuss the "ownership" part of the definition from the point of view of students. If students lack personal ownership in the types of problems they are learning to solve, how does this affect their intrinsic and extrinsic motivation?

Chapter 2: Goals of Education

One of the main goals of this book is to explore the current and potential impact of AI on our educational system. Will (and/or should) AI have a significant impact on our educational goals and objectives? This chapter discusses general goals of education, and it provides background needed as we explore applications of AI that are related to these goals.

Three General Goals of Education

Each person has their own ideas on what constitutes appropriate goals for education. Thus, this topic can lead to heated debate and is currently a major political issue. Curriculum content, instructional processes, and assessment are all controversial issues. What constitutes a "good" education or a "good" school?

David Perkins' 1992 book 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 the following three major goals of education (Perkins, 1992, p5):

1. Acquisition and retention of knowledge and skills.
2. Understanding of one's acquired knowledge and skills.
3. Active use of one's acquired knowledge and skills. (Transfer of learning. Ability to apply one's learning to new settings. Ability to analyze and solve novel problems.)

These three general goals—acquisition & retention, understanding, and use of knowledge & skills—help guide formal educational systems throughout the world. They are widely accepted goals that have endured over the years. They provide a solid starting point for the analysis of any existing or proposed educational system. We want students to have a great deal of learning and application experience—both in school and outside of school—in each of these three goal areas.

All three goals use the term *knowledge and skills.* Later in this chapter we will take a closer look at the terms data, information, knowledge, and wisdom. For now, it suffices to think of the term *knowledge* as encompassing the full range of data, information, knowledge, and wisdom. The term *skills* is taken to mean both physical skills and mental skills. Thus, the term *knowledge and skills* is intended to encompass the full range of physical and mental development.

You will notice that Perkins' three goals do not speak to the specifics of curriculum content, instructional processes, student assessment, teacher education, and other major—often controversial—issues in education. The generality of the three goals makes them quite useful in discussions about Information and Communication Technology and other potential change agents in education. However, remember, "the devil is in the details."

The next three sections expand on the three goals stated by Perkins. These sections capture the essence of changes that Perkins, your author, and many others feel are needed in our educational system.

Education Goal # 1: Acquisition and Retention

Much of our current educational system can be described as "memorize, regurgitate, and forget." Students learn to "study for the test." Often the test is one in which memorization and regurgitation works well. However, the human mind has a strong propensity to forget memorized information that it does not understand and that it does not frequently use. Thus, most of what is memorized for a test is quickly forgotten. The retention part of goal 1 is not well served by this approach to learning.

There is another difficulty with a rote memorization approach to learning. The totality of accumulated knowledge is increasing exponentially. Estimates of the doubling time vary, with some people suggesting a doubling of every 5 or 10 years, and some suggesting an even shorter doubling time. The increase in the total accumulated knowledge of the human race in just one week is far more than a person can memorize in a lifetime.

A somewhat similar analysis holds for skills that one might acquire. It takes a long period of study and practice to become reasonably skilled at archery, art, basketball, bowling, crocheting, cursive handwriting, dancing, drawing, fast keyboarding, guitar playing, piano playing, and so on. That is, there are many different areas in which, through study and practice, a person can gain a personally useful level of knowledge and skills. Nobody has the time to become highly skilled in every skill area.

Computers are very good in storage, retention, and regurgitation. When it comes to rote memory and retention, computers are far superior to humans. If one considers the types of skills that can be automated by computerized tools, then computers have the capability to acquire a great many different skills. Computer systems gain new skills through the development of new hardware and software.

Education Goal # 2: Understanding

In talking about understanding, it is helpful to consider the "scale" pictured below.

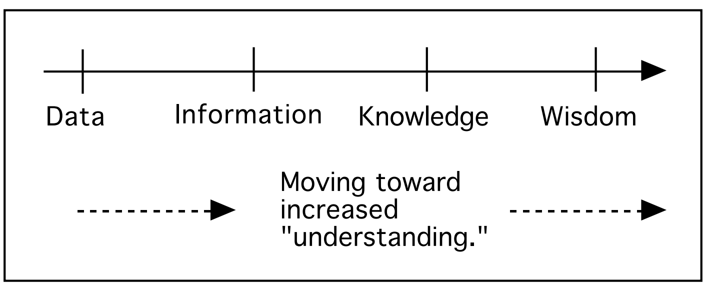

Figure 2.1. Data, Information, Knowledge, Wisdom, and Understanding

The following quotation provides definitions of the terms data, information, knowledge, and wisdom in the specific context of biology (Atlantic Canada Conservation Data Centre; n.d.). The ideas from this specific discipline easily carry over to other fields.

> Individual bits or "bytes" of "raw" biological **data** (e.g. the number of individual plants of a given species at a given location) do not by themselves inform the human mind. However, drawing various data together within an appropriate context yields **information** that may be useful (e.g. the distribution and abundance of the plant species at various points in space and time). In turn, this information helps foster the quality of **knowing** (e.g. whether the plant species is increasing or decreasing in distribution and abundance over space and time). Knowledge and experience blend to become **wisdom**--the power of applying these attributes critically or practically to make decisions.

A computer is a machine designed for the input, storage, manipulation, and output of data and information. It is clear that a computer system can store and process data and information. But, what about knowledge and wisdom? An electronic digital watch displays the time and date.

However, the watch has no understanding of the meaning of time and date. Knowledge and wisdom require understanding, not just rote memory.

One approach to thinking about possible meanings of *knowledge* is to consider uses that can be made of the knowledge. For example, suppose that a building contains a number of electronic digital thermostats that are connected to a computer that can turn on/off the heating and cooling units in individual parts of the building. The job of this computerized heating and cooling system is to maintain the temperature at a comfortable level in all parts of the building. This is to be done in a cost effective manner. The system might also contain sensing devices that can tell if people occupy a part of the building, and maintain lower temperatures in rooms that are not occupied.

This computerized heating and cooling system has the knowledge and skills that are needed to solve a quite complex problem. In a large building, it can surely outperform a group of humans attempting to accomplish the same task. That is, within its very narrow domain of expertise, the heating and cooling system has the knowledge and skills to accomplish a complex task—and can do it better than humans. You might want to refer back to the definitions of AI given in chapter 1 to see that this system satisfies definitions of AI. At the same time, you might think about whether the heating and cooling system has any "understanding" of what it is doing.

Understanding is a tricky issue. A young baby cries in response to some internal sensing of hunger, cold, wet bedding, etc. The crying often produces a response from the caregiver, and the problems are solved. Does the baby have an understanding of hunger, cold, wetness, and so on?

It is interesting to engage people in conversations about whether a computer can store and make effective use of knowledge or wisdom. Perhaps knowledge and wisdom require a level of understanding that is only available to human minds. Perhaps the "intelligence" of machines is limited to being able to process data and information somewhat in the same manner as students do who pass tests using rote memorization without understanding.

A conversation about the potentials of computers storing and using knowledge becomes more interesting as one introduces the idea that many businesses are now actively engaged in using computers for "knowledge management." Knowledge management is about the use of computers to process data and information in order to produce knowledge (ACM SIGKDD, n.d., Godbout,1999).

The recent development and rapid growth of the field of knowledge management suggest that many people feel computer systems can effectively deal with knowledge and make wise decisions.

Education Goal # 3: Active Use

One of the major goals in education is transfer of learning from a specific classroom-learning environment to other environments. We want students to be able to use their school-acquired knowledge and skills at home, at work, at play, and at school—immediately, and far into the future, and in varied settings.

In recent years the Science of Teaching and Learning has made significant progress (Bransford et al, 1999). New and better learning theories and transfer of learning theories have been developed. Computers are playing a significant role in both the development and implementation of these theories.

Recent research in situated learning theory indicates that much of what we learn is intricately intertwined with the environment or situation in which we learn it (Situated Learning Theory, n.d.). Thus, the learning environment needs to be designed to be relatively similar to the environments in which we want students to apply their learning.

A good example of situated learning is provided by the "Help" features that are part of many computer applications. We want students to become more self reliant in finding answers to the types of problems they encounter as they use sophisticated pieces of software such as a word processor. Thus, we can teach them to use the built-in help features of the software, knowing that such built-in help is available whenever and wherever they are making use of the software. You and your students should be aware that a well-designed help feature in software represents the effective storage of knowledge in a form that it is easy to retrieve and use by a human. Such systems make use of AI.

If you are a Star Trek fan, you know about the Holodeck, which is a very sophisticated computerized virtual reality environment. More generally, computer simulations—including virtual reality—are gradually becoming useful educational and research tools. Such simulations can engage a learner in actively using knowledge and skills that are being acquired. A virtual reality can be thought of as computer storage of data, information, and knowledge in a form that facilities a realistic, real-world-like interaction with a human. In this interaction, the human makes active use of knowledge and skills, and the human may well gain increased knowledge and skill. Because of the reality of the simulation, considerable transfer of learning occurs from use of the simulation to applications in the real world.

The past two decades have seen substantial progress in understanding transfer of learning and how to teach for transfer. A good example of this progress is provided by the high-road, low-road transfer theory developed by Perkins and Salomon (2002). Low-road transfer involves learning to a high level of automaticity, rather like the stimulus-response approach of behavioral learning theory. High-road transfer requires understanding and mindfulness. Many schools and school districts are placing increased emphasis on teaching for understanding. Computers are now extensively used in helping students learn certain facts (number facts, for example) to a high level of automaticity. A well designed "Intelligent" Computer-Assisted Learning (ICAL) system engages the learner in interactions in which the learner is making immediate and active use of what is being learned.

Lower-Order and Higher-Order Knowledge and Skills

Solving problems and accomplishing tasks requires an appropriate combination of lower-order and higher-order knowledge and skills. The following diagram (an expansion of figure 2.1) is useful in discussing lower-order knowledge and skills versus higher-order knowledge and skills.

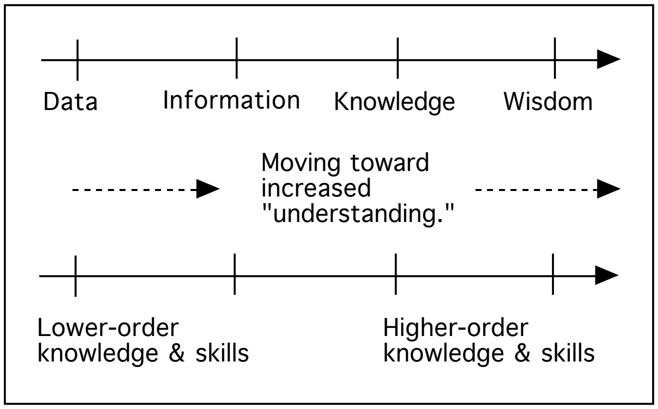

Figure 2.2. Lower-order and higher-order knowledge and skills.

This diagram suggests that lower-order knowledge and skills are heavily weighted on the side of data, information, and a low level of understanding. Higher-order knowledge and skills are heavily weighted on the side of knowledge, wisdom, and a high level of understanding.

The following Expertise Scale is useful in discussing lower-order and higher-order knowledge and skills. Pick any specific area in which a student begins with a very low level (a "novice" level of knowledge and skills), and then works toward acquiring a higher level of expertise. Think about designing and implementing a teaching/learning environment that efficiently and effectively helps a learner to gain increased expertise in the area.

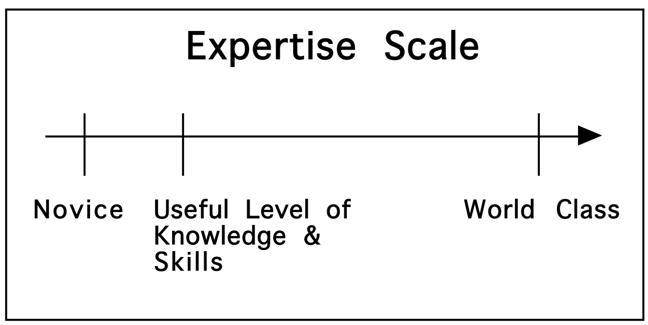

Figure 2.3. A general-purpose expertise scale.

At every grade level and in every subject area, student learning consists of some emphasis on lower-order knowledge and skills, and some emphasis on higher-order knowledge and skills. In simplified terms, the "back to basics" movement is one of placing a greater emphasis on learning lower-order knowledge and skills to a high level of automaticity. The underlying learning theory is behavioral learning theory or low-road transfer.

Other groups of educators want to tip the balance toward the higher-order knowledge and skills side of the scale. They feel that our school should provide an education that supports high-road transfer. Part of their argument is that computers and other tools can and should replace some of the emphasis currently being placed on lower-order knowledge and skills. There is a growing recognition that more school time needs to be spent on higher-order knowledge and skills, and less time should be spent helping students to learn to do things that computers can do more quickly and accurately than people.

Goals of ICT is Education

Historically, the computer field has included a major emphasis on *data processing.* Relatively early on, this changed to being an emphasis on *data and information processing.* Indeed, a commonly used definition is that a computer is a machine designed for the input, storage, manipulation, output of data and information. As computers have become rather commonplace in our society and the field of computer and information science has continued to grow, schools are faced by a triple challenge:

1. Determining what students should learn about the field of computer and information science as a discipline in its own right.
2. Determining what aspects of computer and information science can and should be integrated into the content of the traditional curriculum areas.
3. Determining appropriate roles of computers as an aid to teaching and learning. (There is steady progress in the development of highly interactive computer-assisted learning systems that make use of AI. This topic will be discussed more in chapter 7.)

Various professional societies have explored some or all of these issues (OTEC, n.d.). For example, the International Society for Technology in Education (ISTE) has developed National Educational Technology Standards for PreK-12 students, teachers, and school administrators (ISTE, n.d.). The National Council of Teachers of Mathematics addresses roles of calculators and computers in its standards documents (NCTM, n.d.).

Brittleness

AI researchers use the term *brittle* to describe software that may appear to be reliable, but that may fail badly under a variety of circumstances. The same idea can be applied to computer systems (hardware plus software) and to a person's education. Brittleness is an important idea in both AI and human intelligence.

You know that cells in your body die over a period of time and are replaced by other cells. Some of the neurons in your brain die over time, and some new neurons develop. (For a long time, brain scientists thought that no new neurons develop after birth. In recent years, this supposition has proven to be incorrect. However, as one grows old, it is likely the rate of death of neurons exceeds the rate of production of new neurons.)

Clearly, a human neuron and a transistor are not the same thing. If a transistor or other electronic component in a computer fails, this may well cause the entire computer to fail or to make errors as it continues to function. Thus, a modern computer includes self-checking provisions and some provisions for dealing with flaws that are detected. For example, if a computer disk develops a flaw, the computer system may just stop using this flawed portion of the disk. A computer system can be designed so that if a piece of its internal memory becomes flawed, the computer stops using this piece of memory.

However, consider another type of difficulty. As computer components such as transistors are made smaller and smaller, the likelihood of a component making a random error increases. For example, during a computation or storage/retrieval, a bit may change from a 1 to a 0 due to a random error in the hardware. It is possible to build hardware with enough error detection and error correction capabilities so that such a problem may be overcome, but this is expensive and not implemented in the types of computers than most people use.

One way to do this is to have three identical computers, all doing exactly the same computations. If all three agree on a result, this gives considerably increased confidence in the correctness of the computations. If two out of three agree, this is an indication that something may be wrong with the computer that produced the disagreement. If it is essential to make use of the computed result immediately, than likely one uses the result that two out of three computers agree on.

Next, consider software. A computer's operating system, as well as many of its application programs, contain programming errors. Thus, an application or operating system may "crash" unexpectedly. When I am writing a book, I have my computer system set to automatically save various files every few minutes. In addition, I do daily backups of my files. My computer system is designed to attempt to recover crashed application files, and the operating system has a certain level of ability to detect and correct flaws that develop in the system. Is spite of all of this, from time to time I lose small pieces of my work.

Such crashes are only a small part of the problem when dealing with complex computer programs that are designed to solve complex problems. An amusing example is provided by one of the early AI medical diagnostic systems. When the system was provided input that described a rusty car, the diagnosis was measles! Other amusing examples are provided by computer translations between natural languages. Quoting from Elaine Rich (*Artificial intelligence.* New York: McGraw-Hill, 1984, p.341):

> An idiom in the source language must be recognized and not translated directly into the target language. A classic example of the failure to do this is illustrated by the following pair of sentences. The first was translated into Russian [by a good human translator], and the result was then translated back to English [by a computer], giving the second sentence:
>
> 1. The spirit is willing but the flesh is weak
>
> 2. The vodka is good but the meat is rotten.

The Website http://ourworld.compuserve.com/homepages/wjhutchins/Myths.pdf suggests that this may be an apocryphal story. However, the current state of the art of computer translation of natural languages is still quite poor.

The crux of the matter is that we are steadily increasing our dependence on computer systems, and use AI is of steadily increasing. I thought about this recently as I was using computer software to help me do my Federal and State income tax returns. The software carefully led me through a step-by-step process, checked for errors, made some suggestions for how to reduce my taxes, and produced the final forms. I have a fair level of confidence in the calculations carried out by this tax-filing system, and the company even guarantees that the calculations are correct.

However, that is quite misleading. How about the logic behind the calculations? How about misinterpretations of the tax law? How about my lack of understanding of what data goes where in the overall process? I have some fears that the IRS may decide that my tax return has measles.

To close this section, this about the idea of the possible brittleness of a person's education. Education based on memorization without understanding is brittle. The smallest error in recall may lead to an error in solving a problem or accomplishing a task. This is an ongoing problem in the teaching and learning of math and in applications of math throughout the curriculum.

Personal Growth Activities for Chapter 2

1. Think about memorize and regurgitate as an approach to learning. Do you often use this approach in your own schooling? Do you use it outside of your formal schooling environment? Is this a standard student approach use in the courses you teach? Do you feel that your students make more or less use of this approach, as compared to the students of your fellow teachers? After you have reflected on memorization and regurgitation, discuss the topic with your colleagues and your students. Your goal is to gain increased insight into how they feel about this approach to "learning."
2. Make up your own, personal definition of lower-order and higher-order knowledge and skills. Illustrate using examples form your own personal knowledge and skills.

Activities for Chapter 2

1. The diagram given below is a combination of several diagrams given in this chapter. Select some area in which you have a high level of expertise. Using the various components of this diagram, analyze your expertise and how you acquired this expertise.

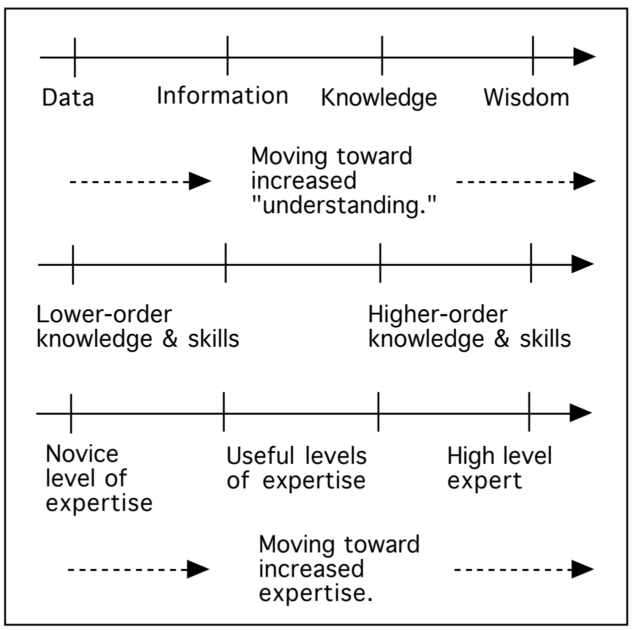

Figure 2.4. A combination of previous figures.

2. Repeat Activity 1 for an area in which you have a medium level (a useful level) of expertise.
3. Select an area where you currently have a novice level of expertise. Using the diagram from Activity 1, along with your insights into your personal learning characteristics, analyze what would best help you to move up the expertise scale.
4. The word "understanding" is used throughout this chapter, but is not defined in the chapter. What is your personal understanding of the meaning of understanding? Note that in developing lesson plans, some teachers make frequent use of the term, while

others carefully avoid using it. What are your thoughts on this? How can one readily assess a student's level of understanding of a topic that you are teaching.

5. Compare and contrast "Acquisition and Retention" from a human-as-learner and a computer-as-learner points of view. Earlier in this chapter we noted that memorize and regurgitate, with little or no understanding, is often considered a useful approach to solving the problem of getting a good grade on a test. That is, there are certain kinds of problem-solving situations in which rote memory is quite useful. Computer systems can have very large rote memories that can be designed so that the memorized (that is, stored) material is retained for days, week, months, or years. Thus, your compare/contrast analysis should include your insights into the value of this type of learning for people and for machines.

6. Memorize, regurgitate, and forget is useful outside of the formal school setting. For example, you are at a meeting or a party and you are introduced to a large number of people you don't know. It is helpful to quickly memorize names and to make use of the names during the meeting or party. People vary greatly in their ability to do this, and their ability to remember the names when meeting the people at a later date. Give some other examples of this sort of learning outside of a school setting. Analyze the situation from a personal point of view and from the point of view and from the point of view of possible uses of computer technology. (Someday not too far in the future people will have eye glasses with a built in video camera and face recognition system. The system will recognize faces and speak the names into a very small "hearing aid" that a person is wearing.)

Chapter 3: Computer Chess and Chesslandia

In Minsky's interview given in chapter 1, he noted that is much easier to program a computer to play chess than it is to develop a computerized robot that can do routine household work. Still, developing a computer program with a high level of chess expertise has proven to be a challenging AI task (Games & Puzzles, n.d.). This chapter explores this effort and some of its educational implications. In addition, it introduces Alan Turing and the Turing Test for computer intelligence.

Alan Turing and the Turing Test

Alan Turing (1912-1954) was a very good mathematician and a pioneer in the field of electronic digital computers. In 1936, he published a math paper that provides theoretical underpinnings for the capabilities and limitations of computers. During World War II, he helped develop computers in England that played a significant role in England's war efforts. In 1950, Alan Turing published a paper discussing ideas of current and potential computer intelligence, and describing what is now known as the Turing Test for AI (Turing, 1950).

The Turing Test is an imitation game. A person in the first of three isolated rooms has two computer terminals. One terminal is directly connected to a terminal being run by a second person, who is located in a second room. The other terminal is directly connected to a computer, located in a third room. The computer has been programmed to be able to carry on a written conversation via its terminal, imitating the written conversational capabilities of a human.

The first person carries on two written conversations (via terminals) with the second person and the computer, without knowing which is which. The first person's goal is to determine which written conversation is being carried out with a person, and which with a computer. Turing's 1950 paper predicted that by the year 2000 there would be computers that routinely fooled humans in this imitation game task.

Interestingly, the field of AI has not yet passed Turing's Test. A prize has been established and from time to time contests are held to see if a computer program has been developed that can pass the test (Loebner Prize, n.d.). At the current time, humans are far better than computers at carrying on a written conversation. Moreover, humans are still better at carrying on an oral conversation, far exceeding computers in this task. In both written and oral conversations, humans are far far better than computers at understanding the conversation.

Emergence of the Electronic Digital Computer Industry

Up until 1950, each electronic digital computer that was constructed was a "one of a kind" machine. By 1950, about 20 computers had been built. Technological progress in this field was so rapid that by the time a machine was completed it was nearly obsolete. The demand for computers was quite low. Here is a now-amusing quotation that represented an early estimate of the potential market demand for computers.

> I think there is a world market for maybe five computers.
>
> (Thomas Watson, chairman of IBM, 1943.)

Thomas Watson not withstanding, by 1950 it was clear that there was a rapidly growing market for computers. The first mass-produced computer in the United States was the UNIVAC I, first produced in 1951. The following quotation indicates the speed of this machine as well as the fact that only 46 were sold over a period of about six years.

> The UNIVAC I (the name stood for Universal Automatic Computer) was delivered to the [United States] Census Bureau in 1951. It weighed some 16,000 pounds, used 5,000 vacuum tubes, and could perform about 1,000 calculations per second. It was the first American commercial computer, as well as the first computer designed for business use. (Business computers like the UNIVAC processed data more slowly than the IAS-type machines, but were designed for fast input and output.) The first few sales were to government agencies, the A.C. Nielsen Company, and the Prudential Insurance Company. The first UNIVAC for business applications was installed at the General Electric Appliance Division, to do payroll, in 1954. By 1957 Remington-Rand (which had purchased the Eckert-Mauchly Computer Corporation in 1950) had sold forty-six machines. (UNIVAC)

Note that a modern laptop computer is about a million times as fast as the UNIVAC I, costs less than 1/2,000 as much (taking into consideration inflation), and weighs less than 1/2,000 as much. Raw speed, cost, and portability are important parts of an ICT system's capabilities. Note also that the early computers lacked connectivity (the Internet, along with email and the Web, did not exist) and did not have the applications such as word processor, spreadsheet, draw and paint graphics, database, and so on that we now take for granted.

Early electronic digital computers were often referred to as "electronic brains." As electronic digital computers became increasingly available in the late 1940s and early 1950s, a small number of people began to think about the possibility of developing a computer program that could play the game of chess. Since chess is an intellectual game, a chess-playing computer program would be a good demonstration of the brain-like capabilities of computers.

Computer Chess

Here is a brief chronology of some early aspects of computer chess (Wall, n.d.).

- In 1947, Alan Turing specified (in a conceptual manner) the first chess program for chess.
- In 1949 Claude Shannon described how to program a computer to play chess, and a Ferranti digital machine was programmed to solve mates in two moves. He proposed basic strategies for restricting the number of possibilities to be considered in a game of chess.
- In 1950, Alan Turing wrote the first computer chess program.
- By 1956, experiments on a MANIAC I computer (11,000 operations a second) at Los Alamos, using a 6x6 chessboard, was playing chess. This was the first documented account of a running chess program.
- In 1957 a chess program was written by Bernstein for an IBM 704. This was the first full-fledged game of chess by a computer.
- In 1958, a chess program beat a human player for the first time (a secretary who was taught how to play chess just before the game).

The last item on the list is particularly interesting. The secretary had received about one hour of instruction on how to play chess. The computer displayed a level of chess-playing expertise greater than a human could gain through one hour of individualized instruction. Thus, we have some of the first inklings of a tradeoff between human learning time and replacing this time and effort by an "intelligent" machine.

The early game-playing computer systems were of rather limited capability. In no sense were they able to challenge a human player with even moderate capability. However, over the years, more powerful computers were developed, and progress occurred in the underlying theory and practice of game-playing programs.

Slow but steady progress in computer chess playing has continued over the years. Tournaments were established so that computers could compete against other computers. Demonstrations were held, pitting human players against computers. Eventually computers were allowed to compete in some human chess tournaments.

Computer chess programs got better and better through a combination of greater computer speed and better programming. In May 1997, IBM's Deep Blue supercomputer played a fascinating match with the reigning World Chess Champion, Garry Kasparov. Although Kasparov was considered to be one of the strongest chess players of all time and the match was close, the computer won (Deep Blue, n.d.).

In early 2003, a six game match was played between Garry Kasparov and Deep Junior, the current reigning world computer chess champion. Deep Blue had long since “retired”. Deep Junior used a much slower computer than Deep Blue, but it employed much more sophisticated “intelligence” in its programming.

The computer that Deep Junior was running on was only 1/66 as fast as that used by Deep Blue. And, Kasparov was no longer the reigning human world chess champion. The six game match ended in a draw, with one victory for each player, and four tied games (Deep Junior, n.d.-).

Nowadays one can buy a variety of relatively good game-playing programs that run on a microcomputer. Quite likely such programs can easily beat you at chess, checkers, backgammon, bridge, and a variety of other games.

The message is clear. In the narrow confines of games and relatively similar real-world problem solving, computers now have a relatively high level of expertise. In some of these games, computer expertise now exceeds the highest level of human expertise.

Chesslandia

The educational implications of such computer expertise are quite interesting. The following is an editorial (still one of my favorites) that I wrote in 1987.

> Moursund, D.G. (March 1987). Chesslandia: A parable. *Learning and Leading with Technology*. Accessed 4/23/06: http://darkwing.uoregon.edu/~moursund/dave/LLT-Eds/LLT-V14-1986-87.html#LLTV14%236.
>
> **Chesslandia: A Parable**
>
> Chesslandia was aptly named. In Chesslandia, almost everybody played chess. A child's earliest toys were chess pieces, chess boards, and figurines of famous chess masters. Children's bedtime tales focused on historical chess games and on great chess-playing folk heroes . Many of the children's television adventure programs were woven around a theme of chess strategy. Most adults watched chess matches on evening and weekend television.
>
> Language was rich in chess vocabulary and metaphors. "I felt powerless--like a pawn facing a queen." "I sent her flowers as an opening gambit." "His methodical, breadth-first approach to problem solving does not suit him to be a player in our company." "I lacked mobility--I had no choice."
>
> The reason was simple. Citizens of Chesslandia had to cope with the deadly CHESS MONSTER! The CHESS MONSTER, usually just called the CM, was large, strong, and fast. It had a voracious appetite for citizens of Chesslandia, although it could survive on a mixed diet of vegetation and small animals.

The CM was a wild animal in every respect but one. It was born with an ability to play chess and an innate desire to play the game. A CM's highest form of pleasure was to defeat a citizen of Chesslandia at a game of chess, and then to eat the defeated victim. Sometimes a CM would spare a defeated victim if the game was well played, perhaps savoring a future match.

In Chesslandia, young children were always accompanied by adults when they went outside. One could never tell when a CM might appear. The adult carried several portable chess boards. (While CMs usually traveled alone, sometimes a group traveled together. Citizens who were adept at playing several simultaneous chess games had a better chance of survival.)

Formal education for adulthood survival in Chesslandia began in the first grade. Indeed, in kindergarten children learned to draw pictures of chess boards and chess pieces. Many children learned how each piece moves even before entering kindergarten. Nursery rhyme songs and children's games helped this memorization process.

In the first grade, students were expected to master the rudiments of chess. They learned to set up the board, name the pieces, make each of the legal moves, and tell when a game had ended. Students learned chess notation so they could record their moves and begin to read chess books. Reading was taught from the "Dick and Jane Chess Series." Even first graders played important roles in the school play, presented at the end of each year. The play was about a famous chess master and contained the immortal lines: "To castle or not to castle--that is the question."

In the second grade, students began studying chess openings. The goal was to memorize the details of the 1,000 most important openings before finishing high school. A spiral curriculum had been developed over the years. Certain key chess ideas were introduced at each grade level, and then reviewed and studied in more depth each subsequent year.

As might be expected, some children had more natural chess talent than others. By the end of the third grade, some students were a full two years behind grade level. Such chess illiteracy caught the eyes of the nation, so soon there were massive, federally-funded remediation programs. There were also gifted and talented programs for students who were particularly adept at learning chess. One especially noteworthy program taught fourth grade gifted and talented students to play blindfold chess. (Although CMs were not nocturnal creatures, they were sometimes still out hunting at dusk. Besides, a solar eclipse could lead to darkness during the day.)

Some students just could not learn to play a decent game of chess, remaining chess illiterate no matter how many years they went to school. This necessitated lifelong supervision in institutions or shelter homes. For years there was a major controversy as to whether these students should attend special schools or be integrated into the regular school system. Surprisingly, when this integration was mandated by law, many of these students did quite well in subjects not requiring a deep mastery of chess. However, such subjects were considered to have little academic merit.

The secondary school curriculum allowed for specialization. Students could focus on the world history of chess, or they could study the chess history of their own country. One high school built a course around the chess history of its community, with students digging into historical records and interviewing people in a retirement home.

Students in mathematics courses studied breadth-first versus depth-first algorithms, board evaluation functions, and the underlying mathematical theory of chess. A book titled "A Mathematical Analysis of some Roles of Center Control in Mobility." was often used as a text in the advanced placement course for students intending to go on to college.

Some schools offered a psychology course with a theme on how to psych out an opponent. This course was controversial, because there was little evidence one could psych out a CM. However, proponents of the course claimed it was also applicable to business and other areas.

Students of dance and drama learned to represent chess pieces, their movement, the flow of a game, the interplay of pieces, and the beauty of a well-played match. But such studies were deemed to carry little weight toward getting into the better colleges.

All of this was, course, long long ago. All contact with Chesslandia has been lost for many years.

That is, of course, another story. We know its beginning. The Chesslandia government and industry supported a massive educational research and development program. Of course, the main body of research funds was devoted to facilitating progress in the theory and pedagogy of chess.

> Eventually, however, quite independently of education, the electronic digital computer was invented.
>
> Quite early on it became evident that a computer could be programmed to play chess. But, it was argued, this would be of little practical value. Computers could never play as well as adult citizens. And besides, computers were very large, expensive, and hard to learn to use. Thus, educational research funds for computer-chess were severely restricted.
>
> However, over a period of years computers got faster, cheaper, smaller, and easier to use. Better and better chess programs were developed. Eventually, portable chess-playing computers were developed, and these machines could play better than most adult citizens. Laboratory experiments were conducted, using CMs from zoos, to see what happened when these machines were pitted against CMs. It soon became evident that portable chess-machines could easily defeat most CMs.
>
> While educators were slow to understand the deeper implications of chess-playing computers, many soon decided that the machines could be used in schools. "Students can practice against the chess-machine. The machine can be set to play at an appropriate level, it can keep detailed records of each game, and it has infinite patience." Parents called for "chess-machine literacy" to be included in the curriculum. Several state legislatures passed requirements that all students in their schools must pass a chess-machine literacy test.
>
> At the same time, a few educational philosophers began to question the merits of the current curricula, even those which included a chess-computer literacy course. Why should the curriculum spend so much time teaching students to play chess? Why not just equip each student with a chess-machine, and revise the curriculum so it focuses on other topics?
>
> There was a call for educational reform, especially from people who had a substantial knowledge of how to use computers to play chess and to help solve other types of problems. Opposition from most educators and parents was strong. "A chess-machine cannot and will never think like an adult citizen. Moreover, there are a few CMs that can defeat the best chess-machine. Besides, one can never tell when the batteries in the chess-machine might wear out." A third grade teacher noted that "I teach students the end game. What will I do if I don't teach students to deal with the end game?" Other leading citizens and educators noted that chess was much more than a game. It was a language, a culture, a value system, a way of deciding who will get into the better colleges or get the better jobs.
>
> Many parents and educators were confused. They wanted the best possible education for their children. Many felt that the discipline of learning to play chess was essential to successful adulthood. "I would never want to become dependent on a machine. I remember having to memorize three different chess openings each week. And I remember the worksheets that we had to do each night, practicing these openings over and over. I feel that this type of homework builds character."
>
> The education riots began soon thereafter.

The intended message of this editorial is that we need to carefully examine our education system, looking for places where we are currently teaching students to do things that machines can do well. The general idea present here is by no means new. See Peddiwell (1939) for a similar essay written before the development of electronic digital computers.

Tools can be mass produced and mass distributed. The education of students is, in essence, still a craft industry. Although our educational system has certain mass production, factory-like characteristics, learning is still an individual thing. Thus, we need to think very carefully about how to best use a student's learning capabilities and time. As suggested by the Chesslandia parable, there is potential peril in spending too much time and effort educating students to compete with machines!

Personal Growth Activities for Chapter 3

1. Share the Chesslandia parable with a friend. Then carry on a conversation that looks for parallels between this parable and certain aspects of our current educational

system. One of the problems of our current curriculum is that it is "full." Through such conversations, you may begin to identify parts of the current curriculum that are becoming increasingly unnecessary through changes in technology and our society.

2. Repeat Personal Growth Activity 1, but with some students. Your goal is to achieve increased insight into what aspects of the curriculum they feel is worthwhile, and what aspects they feel might be deleted.

Activities for Chapter 3

1. You have grown up with the idea that a car is faster than a person, an airplane is faster than a car, and a spaceship is faster than an airplane. Although Superman is "more powerful than a locomotive and faster than a speeding bullet," you know that ordinary people lack these capabilities. Explore your feelings and insights into the fact that a computer can play chess, checkers, backgammon, and a number of other games better than you. As you do this, compare and contrast with your feelings about cars, airplanes, and locomotives.
2. Historically, "having a good hand" (referring to neat penmanship) was considered a sign of a good education. Even the earliest typewriters made it possible for a person to learn to write faster and neater than by hand. A word processor is a still more powerful aid to "having a good hand." Discuss your feelings about schools spending time and effort on children developing good (by hand) penmanship versus having students learn to use a word processor. Do not couch your discussion in an either-or form. We might want students to learn to print legibly and use a word processor well.
3. Select a cognitive skill-based game in which you have a reasonably good level of expertise. Make a rough estimate of the number of hours it took you to achieve this level of expertise. Then give some arguments that this was a good use of your time, independently of whether a computer can play the game better than you. (For example, perhaps the game time was an important part of developing social skills and friends.)
4. This is a follow-up to (3) above. Discuss transfer of learning (your knowledge and skill) from the game you analyzed in (3) to real world problem-solving situations. Focus specifically on the nature and extent of transfer of your game playing knowledge and skills.

Chapter 4: Algorithmic and Heuristic Procedures

In this chapter, we use the term *procedure* to refer to a detailed set of instructions that can be carried out by a specified agent such as automated factory machinery, a computer, or a person. This chapter provides background information needed as we explore "intelligent-like" procedures that can be carried out by computers.

Procedure

At some time in your life, you learned and/or memorized procedures for multi-digit multiplication and long division, looking up a word in a dictionary or a name in a telephone book, alphabetizing a list, and to accomplish many other routine tasks.

In this bookt, we use the definition: *a procedure is a detailed step-by-step set of directions that can be interpreted and carried out by a specified agent*. Our focus is on procedures designed to solve or help solve a specified category of problems. Remember, our definition of *problem* includes accomplishing tasks, making decisions, answering questions, and so on. We are particularly interested in procedures that humans can carry out and in procedures that computers can carry out. Figure 4.1 is designed to illustrate the overlap between procedures that ICT systems can carry out and procedures that humans can carry out.

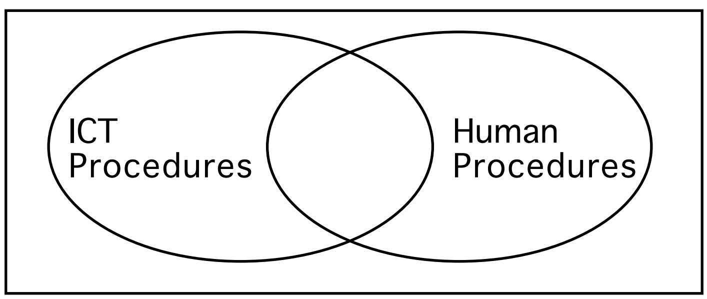

Figure 4.1. Procedures to be carried out by ICT systems and by humans.

In this chapter, we explore two types of procedures:

1. Algorithm. An algorithm is a procedure that **is guaranteed** to solve the problem or accomplish the task for which it is designed. You know a paper and pencil algorithm for multiplying multi-digit numbers. If you carry out the procedure (the algorithm) without error, you will solve the multiplication problem.
2. Heuristic. A heuristic is a procedure that is designed to solve a problem or accomplish a task, but that **is not guaranteed** to solve the problem or accomplish the task. A heuristic is often called a rule of thumb. You know and routinely use lots of heuristics. They work successfully often enough for you so that you continue to use them. For example, perhaps you have a heuristic that guides your actions as you try to avoid traffic jams or try to find a parking place. Perhaps you use heuristics to help prepare for a test or for making friends. Teachers make use of a variety of heuristics for classroom management.

The following quotation from Marvin Minsky (1960) indicates that early researchers in AI had a good understanding of the roles of heuristic programming in AI.

The problems of heuristic programming—of making computers solve really difficult problems—are divided into five main areas: Search, Pattern-Recognition, Learning, Planning, and Induction.

…

The adjective "heuristic," as used here and widely in the literature, means related to improving problem-solving performance; as a noun it is also used in regard to any method or trick used to improve the efficiency of a problem-solving system. **A "heuristic program," to be considered successful, must work well on a variety of problems, and may often be excused if it fails on some.** We often find it worthwhile to introduce a heuristic method, which happens to cause occasional failures, if there is an over-all improvement in performance. [Bold added for emphasis.]

ICT systems are very fast and accurate at carrying out algorithms. A mid-priced microcomputer can carry out more than a billion arithmetic computations per second. This is done without errors, following algorithms built into its circuitry. Computers can look up a word in a dictionary or alphabetize a list of names because programs have been written to carry out algorithms designed to accomplish these tasks.

AI programs make use of both algorithmic and heuristic procedures. Many of the problems being addressed using AI have the two characteristics:

1. The problems are very difficult from a human point of view, and a human world-class expert does not solve them perfectly. Indeed, many of the problems are beyond human (unaided by computers) capabilities.
2. The computer programs being written to address these problems make use of algorithms, heuristics, computer speed, computer storage capacity, and computer connectivity. This approach can produce ICT systems of increasing expertise within many different problem-solving areas of interest to people, but cannot guarantee success in solving all of the problems within each of these areas.

Think about the challenges of writing a computer program that can pass the Turing Test—that can carry on a good written conversation with a person. Many people have written computer programs that can carry on a written conversation via a computer terminal. Perhaps the most well known is a program named ELIZA written by Joseph Weizenbaum and published in 1966 (Weizenbaum). This heuristic program indeed carries on a written conversation. From time to time people using the program have actually believed they were conversing with another human being. However, the program is not nearly good enough to pass the Turing Test. The ELIZA program is available on the Web and many people find that it is fun to play with this program (ELIZA).

The following "conversation is quoted from Weizenbaum (1966). The capitalized text was written by the computer in response to the non-capitalized text provided by a human.

Men are all alike.

IN WHAT WAY?

They're always bugging us about something or other.

CAN YOU THINK OF A SPECIFIC EXAMPLE?

Well, my boyfriend made me come here.

YOUR BOYFRIEND MADE YOU COME HERE

He says I'm depressed much of the time.

I AM SORRY TO HEAR YOU ARE DEPRESSED

It's true. I am unhappy
DO YOU THINK COMING HERE WILL HELP YOU NOT TO BE UNHAPPY

I need some help, that much seems certain.
WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP

Perhaps I could learn to get along with my mother.
TELL ME MORE ABOUT YOUR FAMILY

My mother takes care of me.
WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU

My father.
YOUR FATHER

You are like my father in some ways.
WHAT RESEMBLANCE DO YOU SEE

You are not very aggressive but I think you don't want me to notice that.
WHAT MAKES YOU THINK I AM NOT VERY AGGRESSIVE

You don't argue with me.
WHY DO YOU THINK I DON'T ARGUE WITH YOU

You are afraid of me.
DOES IT PLEASE YOU TO BELIEVE I AM AFRAID OF YOU

My father is afraid of everybody.
WHAT ELSE COMES TO YOUR MIND WHEN YOU THINK OF YOUR FATHER

Bullies.
DOES THAT HAVE ANYTHING TO DO WITH THE FACT THAT YOUR BOYFRIEND MADE YOU COME HERE

The conversation rambles on in a rather pointless manner. The ELIZA program represents really clever thinking and programming for the time when it was written. You might enjoy carrying on a conversation with a more modern program. My students have enjoyed experimenting with IntelliBuddy (n.d.).

Handheld Calculators

In the remainder of this chapter, we will explore the capabilities of simple handheld math calculators. These calculators make use of algorithms. Our goal is to help you gain increased insight into what might be called *algorithmic intelligence*. People vary considerably in their ability to memorize an algorithm and carry it out rapidly and accurately. That is, people vary considerably in their algorithmic intelligence. With appropriate education, training, and experience, a person can increase his or her algorithmic intelligence.

Here, the term "intelligence" is used very loosely. If we think in terms of fluid and crystallized intelligence (gF and gI), then we can talk about innate intelligence related to learning algorithms versus one's accumulated algorithmic knowledge and skills. (Learn more about intelligence in Moursund, (2006, Chapter 2).) In any case, keep in mind that the "intelligence" of a handheld calculator designed to perform arithmetic calculations is a lot different than the type of intelligence that a person has. However, a person can be educated/trained to be relatively good at doing what a 4-function calculator can do.

A significant part of our current educational curriculum is devoted to helping students memorize algorithmic procedures and to develop speed and accuracy in carrying out these procedures. That is, we work to increase the algorithmic intelligence of students—we work to have students develop the type of intelligence that is built into handheld calculators. This is especially evident in our math curriculum and in other curricula that makes use of math.

The ordinary electronic digital calculators that most people own and use are limited purpose computers. That is, they are computers with quite limited capabilities. It is now possible to purchase a solar battery-powered calculator for less than five dollars. Such a calculator contains (built into the circuitry) algorithms for addition, subtraction, multiplication, division, and square root. It may have additional features, such as an "automatic constant" and a memory addressed by M+ and M- keys.

In exploring calculators and their algorithmic intelligence, it is helpful to have some historical background on the development of reading, writing, and arithmetic.

Brief History of Development of the 3 R's

Prior to about 11,000 years ago, all humans were hunter-gatherers. The earth's human population was perhaps 12 million people, which is less than some current cities. Between 10,000 and 11,000 years ago, people begin to develop the idea of ideas of farming—raising crops and animals. Over time, such agriculture practices allowed the development of larger communities of people, villages, and then cities.

Along with the increasing density of population came increased trading of goods and services, and increased bureaucracies in government. There was a steadily increasing need for keeping records of business and government transactions, such as goods sold and taxes paid.

This lead to the development of reading, writing, and arithmetic approximately 5,000 years ago. With the 3R's, people could store and retrieve information. The human race could accumulate knowledge that could be widely distributed and passed on to future generations. People could solve certain types of problems that could not previously be solved.

Schools were developed to help a small number of people learn the 3R's. Even a modest amount of such formal education was sufficient to substantially increase a person's ability to solve certain types of problems that businesses and governments needed to solve.

It is interesting to note that Thomas Jefferson, a historic figure from the time of the 1776 American Revolution and the third President of the United States, once proposed that the State of Virginia should provide public education up through the third grade. He felt that a third grade education was essential to being an informed citizen in a democratic society. His idea was considered too radical and was rejected by the Virginia Legislature. Now, of course, we tend to feel that a high school education is essential for all people. Times have changed over the past 230 years!

We all know that it takes a great deal of time and effort to develop a useful level of expertise in reading, writing, and arithmetic (math). In both reading/writing and in math there is the task of learning the subject and the task of using the knowledge to solve problems and accomplish tasks. Roughly speaking, we expect students to make the transition from learning to read to reading to learn by the end of the third grade. This is a difficult transition for many students, as reading to learn requires reading for understanding, a higher-order cognitive challenge. After students develop a useful level of expertise in learning by reading, much of their curriculum is based on learning by reading. Year after year, as they continue in school, students are expected to steadily increase their expertise in learning by reading.

There is an interesting and useful analogy between reading and math. Students learn to read, with a goal of learning to read to learn. Students learn "to math" and then they "math" to learn. "Mathing" to learn requires understanding, and many students have considerable difficulty in developing this understanding. For many students, the math curriculum does not do well in moving them beyond the "learning to math" stage. This can be viewed as a significant failure in our math education system.

> Author's note: The human brain is capable of memorizing detailed computational algorithms and carrying them out reasonably accurately. However, the memorization capability, speed, and accuracy of the human brain versus a computer in such endeavors is severely limited. Moreover, it takes considerable initial time and practice (along with continuing practice) for a human to maintain the initial level of speed and accuracy that can be achieved. In many math instruction situations, the process of helping students memorize algorithms and gain speed and accuracy in their use is only vaguely related to building understanding. Students are not receiving the help they need to learn to "math to learn."
>
> If this type of discussion interests you, then see my book *Improving Math Education in Elementary Schools: A Short Book for Teachers* that is available at http://darkwing.uoregon.edu/~moursund/dave/ElMath.html.

Calculators

For the remainder of this chapter, we will focus specifically on AI aspects of math and calculators. Figure 4.2 is a diagram that represents the steps that many people use when applying math to solve a typical math problem.

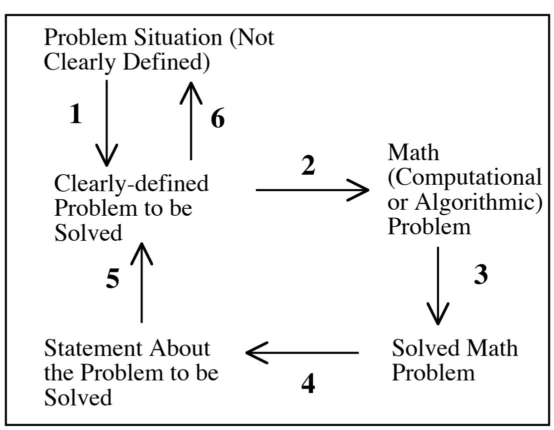

Figure 4.2. Six-step procedure for solving a math problem.

The six steps illustrated are 1) problem posing; 2) mathematical modeling; 3) using a computational or algorithmic procedure to solve a computational or algorithmic math problem; 4) mathematical “unmodeling;” 5) thinking about the results to see if the clearly-defined problem has been solved; and 6) thinking about whether the original problem situation has been resolved. Steps 5 and 6 also involve thinking about related problems and problem situations that one might want to address or that are created by the process or attempting to solve the original clearly-defined problem or resolve the original problem situation (Moursund, 2004).

Here is an example to illustrate the steps in the diagram. Mother hears her two young daughters, Mary and Sue, arguing about some marbles. Mary says, “I have six marbles, and all of them are mine.” Sue says, “I only have four marbles. It isn’t fair!”

This is a problem situation (not a clearly defined problem). Mother poses a clearly defined problem to herself: “If each child had the same number of marbles, how many would each have? She then translates this problem into the pure math (computational) problem “What is (6 + 4)/2?” She quickly computes the answer 5, and notes to herself that this is indeed the solution to the clearly defined math problem that she has stated.

She then begins to think about the original problem situation. Neither child has exactly five marbles. If she takes one marble away from Mary and gives it to Sue, the two children will each have five marbles. But, she remembers that yesterday she gave six marbles to each child. So …what should she do? Perhaps she should help the children search for the two missing marbles.

Notice the difference between the type of intelligence that the mother is displaying, versus the “ability” of a calculator to do arithmetic. In this particular problem situation, the arithmetic to be done was quite simple, and a calculator was not needed. In somewhat similar problems, a calculator might be useful. But it is the mother who understands the problem, represents it mathematically, and then interprets the results. These are all high-level cognitive activities—things that a calculator cannot do.

Notice that mother’s use of mathematics may have been helpful, but it did not resolve the original problem situation. This is often the case in addressing real-world problem situations. Moreover, the mother might have defined a completely different problem from the problem situation. She might have decided that her two children were arguing too loudly, thus disturbing the mother. A solution would be to ask the children to talk more quietly!

The diagram of figure 4.2 can be analyzed from the point of view of our K-9 math education system. Estimates are that about 75% of math education time at the K-9 level is spent on Step 3 of the diagram. Calculators and computers can do this step rapidly and accurately. This means that perhaps 25% of the math education time is spent on the other five steps. These steps require higher-order thinking and human judgment. Moreover, these steps are receiving increased emphasis in state and national assessments of student learning in mathematics.

Let me make the issue still more clear. It takes many hours of study and practice for a student to gain a reasonable level of speed and accuracy in doing paper and pencil arithmetic. Moreover, the speed and accuracy attenuates over time unless the skills are regularly used. The speed and accuracy that most students can achieve in a pencil and paper mode are not good relative to what they can achieve when using a calculator.

This sequence of observations led to the National Council of Teachers of Mathematics 1980 recommendation (which has been repeatedly reiterated since then) that schools should decrease the emphasis on paper and pencil arithmetic and increases their emphasis on the other five steps illustrated in the diagram.

From an AI point of view, an inexpensive calculator has sufficient algorithmic intelligence to support a major change in the math education curriculum. That is quite an achievement for a machine that has so little "intelligence-like" capabilities that few people would classify it as an example of AI.

The discussion of calculators given above was limited to inexpensive calculators designed to carry out addition, subtraction, multiplication, and division of decimal numbers. However, there are many thousands of other types of calculators that have varying types of algorithmic intelligence (Martindale's Calculators On-Line Center, n.d.). Here are a few examples:

- English Dictionary. Key in an English word, and the calculator provides a definition.
- Foreign Language to English Dictionary. Key in a word in a language such as French, and the calculator provides a definition in English.
- Measurement conversion. Key in a measurement in the metric system and the calculator provides the measurement in the English system, and vice versa.
- Fraction (does computations with fractions).
- Recipe calculations.
- Graphing and equation solving.

The point being made is that calculator-like devices that have algorithmic intelligence can replace a substantial amount of rote memory and algorithmic learning. Consider the example of a calculator that works with fractions. It is important for students to understand that there are different types of numbers, such as integers, fractions, and decimal (fractions). It is important for students to have a conceptual understanding that numbers can be added, subtracted, multiplied, and divided as an aid to solving various types of problems. However, students gain very little conceptual understanding of these different forms of number representation by memorizing computational algorithms and practicing them to gain speed and accuracy. Quite a bit of the time spent in such endeavors might better be spent in other math education or non-math education endeavors. This raises hard questions such as which is most important: memorizing algorithms for doing computations with fractions, learning to play a musical instrument, or …

Personal Growth Activities for Chapter 4

1. Explore your feelings about the idea of substituting use of handheld calculators for part of the paper and pencil computational curriculum in our schools. Then talk to a couple of your friends about this idea, sharing your feelings and exploring their feelings on the topic. Finally, explore the idea with students, to get their insights into the issues.

2. A multifunction calculator (such as a scientific calculator, that may well have more than a hundred built-in functions) has a considerable level of algorithmic intelligence. For example, it can quickly calculate the square roots of numbers "in it's brain." (Here, the term *brain* is used to refer to the central processing unit and memory built into the calculator.) How would you go about explaining to a grade school student the similarities and differences between the capability of a calculation brain and a human mind/brain?

Activities for Chapter 4

1. When you are doing a long division of multi-digit numbers using pencil and paper or a calculator, how do you tell if you have gotten a wrong answer? What can you do to increase the likelihood that you have a correct answer? (As you explore this question, you may want to think about mental estimation. How does one gain skill in mental estimation? Is there much transfer from learning pencil and paper computational algorithms to doing mental estimation?)
2. Refresh your mind on the definitions of AI given in chapter 1. Then discuss the extent to which calculators display intelligence. As you explore this topic, provide some insights into whether it makes sense to talk about "algorithmic intelligence." Note that Howard Gardner's list of Multiple Intelligences does not include algorithmic intelligence. Why do you think this is the case?
3. Perhaps you have a global position system (GPS) calculator, or have seen one. It uses algorithms to analyze radio signals broadcast from orbiting satellites in order to determine the GPS calculator's location on the earth's surface. Discuss the idea that a GPS has greater algorithmic intelligence than does a simple 4-function calculator.
4. An electronic digital watch displays time and date, and may also have stop-watch features. Some of these watches include a miniature numerical keypad and calculator functions. Argue for or against the idea that such a watch has greater intelligence (greater algorithmic intelligence) than a four-function calculator. Then use this activity as a starting point to discuss the limits of algorithmic intelligence. For example, what types of intelligent-like things can humans do that cannot be done by machines that have only algorithmic intelligence?
5. In the algebra courses that you have taken, you learned to solve a number of different kinds of equations and to graph a number of different kinds of functions. Now, for under $100, you can purchase a calculator that contains algorithms that can solve these types of equations and graph these types of functions. Discuss your thoughts and feelings on appropriate use of such calculators in algebra courses. In your discussion, consider learning algebra versus "algebra-ing to learn."

Chapter 5: Procedures Used by a Word Processor

The chances are that you make substantial use of a word processor. This tool is certainly useful to a person who needs to write a document and produce a final product of both high quality and good appearance. This chapter explores the algorithmic and heuristic intelligence of a word processor. The word processing examples used in this chapter are from Microsoft Word.

Process Writing: A Heuristic Procedure

Process writing is commonly taught in our schools and is considered an important approach to high quality writing. To get us started, review the six steps in process writing.

1 Decide upon audience and purpose, and brainstorm possible content ideas.

2 Organize the brainstormed content ideas into a tentative appropriate order. Attempts to do this may lead back to step 1.

3. Develop a draft of the document. Attempts to do this may lead back to steps 1 or 2.

4. Obtain feedback from self, peers, teacher, etc.

5. Revise the document to reflect the feedback. This may require going back to steps 1, 2, or 3.

6. Polish and publish the document.

This six-step outline of process writing can be thought of as a procedure to be carried out by a person. However, it is evident that it takes a great deal of instruction, learning, and practice to develop a useful level of expertise in carrying out this heuristic procedure. Moreover, there is no guarantee that if a person diligently follows this 6-step procedure, the result will be good writing. Thus, this six-step procedure is a heuristic procedure.

Many people agree that a word processor is a useful tool for writers. Of course, many people (including some very successful professional writers) do not use a word processor. Moreover, word processors did not exist at the time of Shakespeare and many other famous writers. Thus, we know that a word processor is not an indispensable tool for writers. However, the next several sections give examples of uses of a word processor. We are particularly interested in ways in which a computer can help a person make use of the 6-step process writing heuristic procedure.

Spell Checker

I am using a word processor to write this document. I keyboard the word "educatoin" in order to make a point to be illustrated in this paragraph. The particular word processor that I am using immediately underlines the word in red. That is, it poses the question: "Is this the correct spelling of the word that you intended to keyboard?" I can then ask the word processor for suggested corrections. In this case, my word processor suggests the correction "education." It is up to me to accept or reject the suggestion. I reject it because I specifically want to use the misspelled word.

When a spell checker seeks to detect spelling errors, it uses an algorithm. It compares each word against its internally-stored list of correctly spelled words. Any word in your document that is not in the spell checker program's list of correctly spelled words is marked as a possible misspelling. The chances are that your spell checker would mark my name, Moursund, as a possible misspelling. Also, the chances are that your word processor would mark as possible misspellings the words colour and organisation, which are correct British English spellings of color and organization.

A good spell checker includes provisions for easily adding to its list of correctly spelled words. Thus, I have added Moursund to the list in my spell checker. This is a small step toward personalizing the tool to better fit my needs. (Might one think of this as increasing the intelligence of the spell checker?) If I used British English, I would have my spell checker use British English spelling in its initial list of correctly spelled words.

When a spell checker detects a potential misspelling, it is often able to provide a list of possible intended words. How does it do this? Certainly it does not store every possible misspelled word, along with a list of possible "nearby" correctly spelled words. Instead, the spell checker uses heuristics to generate possible intended words that are in its list of correctly spelled words. These heuristics measure the closeness of the potentially misspelled word to a number of words in the list of correctly spelled. If I accidentally key in my name as Maursund, my spell checker both detects the (possible) error and lists Moursund as a suggested correct spelling.

Here is another example: My word processor provides the following list as possible alternatives to colour:

color

cooler

colors

co lour

These are listed in the order of the spell checker's best guess, with the best guess being first on the list. I find it fun to key in misspelled words and to see the list of suggestions that my spell checker generates. Often I am quite impressed by the heuristic intelligence that it displays.

Note that this AI is actually displaying a very low level of intelligence. The spell checker has no understanding of what I am writing or the intended meaning of the word I have written. Its intelligence consists only of some cleverly designed heuristics that are based on an analysis of common misspellings and common typos, plus measures of "closeness."

The spell checker in my word processor has some other useful features. For example, as I keyboard, I frequently make certain keyboarding errors, such as reversals in the letter combination "io." In my word processor, I have made a list of many of the words in which I make this typo. For the words in my list, the spell checker automatically detects this type of error and corrects it, without even bothering to tell me about it. This level of spell checker algorithmic intelligence is quite helpful to me except in situations where I really wanted to have the misspelled word in my document. Note that is this situation, I increase the "intelligence" of my spelling checker by giving it more misspelled or miss keyed words that I want it to automatically correct. A "smarter" spelling checker might keep a list of the words that I misspell along with the correct spellings that I select, and eventually add these words that I frequently misspell in a consistent fashion to its "automatically correct without telling me" list.

Some Other Features in a Word Processor

One of the "rules" of writing is that the first word in a sentence should begin with a capital letter. An option in my word processor is to have the computer automatically correct the possible error of a sentence not starting with a capital letter. With that setting turned on, I entered (using all lower case letters) the list given above for possible correct spellings of colour. The computer produced the following list:

Color

Cooler

Colors

Co lour

Thus, it automatically made changes to my text—changes that I consider to be errors. I really did want a lower case list. However, my computer cannot read my mind!

I have a friend who does not capitalize the first word of a sentence he is writing using a word processor. He has set his word processor so that it automatically detects and corrects this "error" without telling him about it. My friend slightly increasing his keyboarding speed by not keyboarding such capitalizations.

My word processor includes a grammar checker. As I enter text, this grammar checker underlines text that it feels may contain errors in grammar. Such grammar checking software has gradually improved over the years. It is heuristic software, and it still has a long way to go before it can compete with a good human proofreader. Still, I find it useful and I often accept its suggestions. This software is also useful to many students who are learning English as a second language.

My word processor has some additional features that I use from time to time. Examples include:

- Alphabetize a list. (This uses an algorithm.)
- Arrange a list in numerical order. (This uses an algorithm.)
- Look up a word in a dictionary or glossary. (This uses an algorithm.)
- Produce an Index from the words in my document that I have marked as Index Terms. (This requires the computer to search the entire document, select all Index Terms along with their page numbers, sort them alphabetically, and so on. All of these tasks are done by use of algorithms.)
- Produce a Table of Contents using the headings that I have marked as Table of Content entries in my text. (This uses algorithms.)
- Use a Style Sheet that I have specified. For example, a Style Sheet can specify the font, font size, and first line indent for my "standard" paragraph. It can specify details of the layout for quoted material and references. In some sense, specifying the details of a Style Sheet is programming the word processor. The computer is following algorithms as it implements a Style Sheet

The list given above suggests that a word processor has quite a bit of algorithmic intelligence. This algorithmic intelligence helps me as I write.

Other Features a Word Processor Can Provide

There are still other intelligent-like features that a word processor might contain. A commonly used accommodation for students with physical disabilities is to provide a word processor that uses predictive heuristics. The student starts to type a word, and the computer makes predictions on the intended word based on the first few letters the student enters. If the computer correctly predicts the intended word, the computer user can accept the prediction and move on to the next word to be entered.

Historically, it was deemed important that students develop a reasonable level of speed and quality in cursive handwriting. This goal is gradually disappearing from many school curricula because keyboarding and word processing are faster and produce text that is more legible than most people's cursive handwriting.

However, it takes a considerable amount of time and effort to develop good keyboarding skills. It takes less time to develop good voice input skills. Thus, we may eventually see schools spending less time on keyboarding instruction, and more time on learning to make effective use of voice input.

A word processor can be combined with a voice input system. AI progress on the voice input problem has been substantial, so that now many people use voice input in place of keyboarding. When you keyboard a word, your word processor stores the word in the document you are writing and displays the word as a part of the document you are writing. When you are using a voice input system to "write" a document, the computer system attempts to transform your voice input into words that are stored in your document and displayed on the screen.

You know that different people pronounce a word differently. Thus, many voice input systems include the ability to be trained to a particular voice in order to increase their level of accuracy. (You may find it interesting to think about a computer learning your particular regional accent.)

Voice input systems make substantial use of heuristics. Voice input systems have now become good enough so that they have many commercial uses. Many companies now use such systems to handle telephone inquiries. If the initial screening or interaction between the computer and the human does not resolve the question, then the computer connects the caller to a human to help resolve the question. To learn more about voice input, see http://www.catea.org/quickrefguides/guides/VoiceInput.php.

Personal Growth Activities for Chapter 5

1. Consider the range of word features that a word processing system might provide to a user. Introspect on which of these are available on the word processor(s) that you use, and which ones you actually use. If you think of some features that might be useful to you but you have not yet learned to use, ask yourself "why?" Then carry on conversations with your colleagues and students to gain increased insight into their understanding and use of such aids to writing.

Activities for Chapter 5

1. Many people feel that students should not be allowed to use a word processor or a spell checker when they are first learning to write and spell. They feel that use of a word processor and spell checker will be a major detriment to a student developing the traditional "by hand and mind" writing and spelling skills. Write a short paper exploring your personal feelings and experiences in this topic area. Then add to this paper some of the available educational research on this topic. For example, what does current research say about the effects of young students making use of a spelling

checker as they are learning to write? Does such an aid help or hinder students learning to spell?

2. Artistic penmanship has a long history. Calligraphy was once an important aspect of penmanship, but now is mainly viewed as an art form. Cursive writing is still an important component of the curriculum in most elementary schools. However, there is some movement toward replacing it by a combination of hand printing and use of word processors. Thus, sometime in the future cursive writing may become an art form. Select an elementary school or a school district that includes at least one elementary school. Explore the cursive penmanship policies and implementation of these policies, and whether they are changing.
3. After appropriate education, training, and experience, typical students can acquire a keyboarding speed that is far in excess of their hand writing speeds—and the keyboarded material is far more legible than most people's handwriting. Once students gain such keyboard skills, should they be allowed (and encouraged) to use these skills when taking written tests? If your answer is "yes," should the students be allowed to use a spell checker when taking written tests? Develop a position paper that explores and justifies your current position on these questions.
4. Explore the similarities and differences between the spell checkers in two different word processors. From your point of view, which seems to display the higher level of algorithmic and heuristic intelligence? When you buy a word processor, are you willing to pay more to get a high level of algorithmic and heuristic intelligence? For example, would you pay a little extra if the word processing software included voice input?

Chapter 6: Procedures Used in Game Playing

This chapter introduces the development of computer procedures that play chess, checkers, bridge, and other games that people have enjoyed playing over the years. Such game-playing computer programs typically make use of a combination of algorithmic and heuristic procedures.

There is a substantial amount of literature on roles of AI in computer games and in other aspects of our non-game world (Games & Puzzles, n.d.).

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.

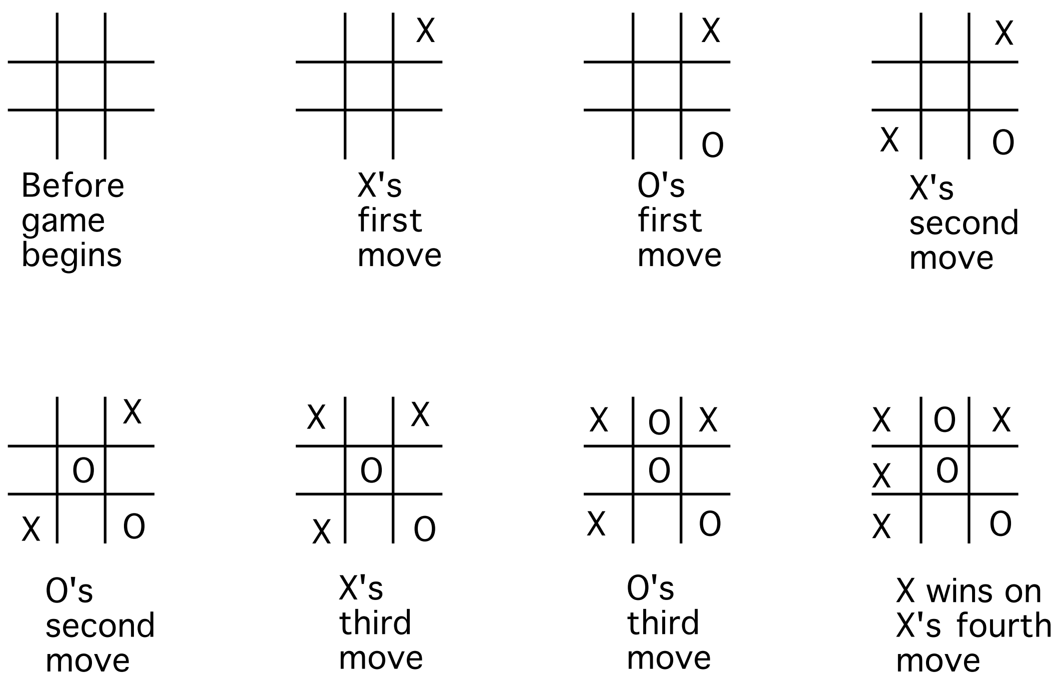

Figure 6.1. Example of a Tic-Tac-Toe game.

First, let's give a procedure that a human can carry out and in which the human's opponent makes random moves. (You might want to think of the latter as a simulation of a computer program that makes random moves.) 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:

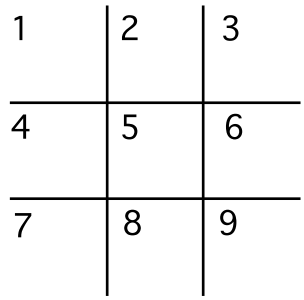

Figure 6.2. A TTT board with its squares numbered 1 to 9.

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 an algorithm adds a new dimension to the capabilities of algorithms. You have encountered such randomness when you play games that make use of a spinner, rolled dice, shuffled cards, coin flipping, and so on. Many people argue that a computer can only do what it has been told to do, and thus cannot (… here, the person makes a statement about the limitations of computers.) Such people sometimes have little insight into randomness.

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 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.

Look ahead (planning ahead) 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 predicts 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.

Look Ahead in Chess

TTT is a very simple game. Thus, it is relatively easy to consider your possible moves and the consequences of your moves (possible responses by your opponent), looking ahead clear to the end of the game.

Consider the same situation for chess. Chess is played on an 8x8 square grid. Each player starts with 8 pawns, 2 knights, 2 bishops, 2 rooks, 1 queen, and 1 king. In an average board situation that occurs in a game, a player has about 20 different possible moves. (For example, if a rook is positioned so that it can move forward 1, 2, or 3 spaces in a particular board situation, this would be counted as three possible moves for this piece.)

Suppose it is your turn to move. You examine approximately 20 possible moves. You then think about your opponent's response to each of your possible moves. If your opponent has about 20 different possible responses to each of your possible moves, then you need to consider about 20 x 20 = 400 possible board situations. You need some way to decide which of these (approximately) 400 board positions is most advantageous to you. This is not an easy decision to make. In the "turn" consisting of a move by you and a move by your opponent, you may have captured one of your opponents pieces and/or had one of your pieces captured. You may have improved your overall defensive and or offensive position. You may have made progress toward setting up a good move in the next turn, or you may have failed to do this.

If you have a good memory and fast mind, you might want to consider each of your possible responses to each of your opponent's possible responses. This requires you to examine approximately 20 x 20 x 20 = 8,000 board positions. Or, you could go a half turn further and consider each of your opponent's possible response to each or your (approximately 8,000) board positions. You would need to examine approximately 20 x 20 x 20 x 20 = 160,000 board positions. A well-trained human mind (such as a world class expert in chess) may be able to examine and evaluate a board position in a second or less. (Garry Kasparov once indicated he can evaluate approximately three board positions per second.) Note that 160,000 seconds is more than 44 hours. You can see why there are time limits placed on each player in a chess tournament!

Even with a full 2-turn look ahead, you will not play a very good game of chess. Moreover, unless you are in a "mate in 2" situation (that is, you are in a situation where you can force a win in your next two moves), you are still left with the need to evaluate board position, not knowing what will come next in the game.

This leaves us with the question of how a computer can be programmed to play a good game of chess. An answer consists of a combination of rote memory and heuristics.

There is a huge amount of chess information that has been developed by chess experts. For example, thousands of possible opening sequences and end-game situations have been carefully analyzed. A high-level chess expert studies and memorizes thousands of different variations on opening sequences and end games. Such rote memory gives a chess expert an advantage over opponents who have not accomplished this prodigious task.

One of the advantages that a computer has over a human in chess playing is that a computer can memorize (that is, store in its memory) many more opening sequences and end-game sequences than a human being. In essence, the computer becomes a more capable chess player just through rote memory of the results of the analysis done by thousands of human chess experts.

To quote many TV ads: "But wait—there's more." The previous paragraph indicates that a computer can store the results of the chess analysis done by thousands of human experts. Now, consider the idea that a computer can be programmed to analyze chess openings, end games, and other aspects of chess games that have been played by itself or by others. The computer than stores the useful results in its memory. Thus, the computer learns on its own.

Over a period of many years, many good chess players and computer programmers have worked together to develop heuristics for rapidly evaluating board positions. These heuristics make use of data and information such as the total value of the pieces that you and your opponent have remaining on the board, the mobility of these pieces, the amount of control of the center of the board, and a number of other characteristics. Such heuristics can be programmed into a computer.

In brief summary, a good chess-playing program:

1. Draws upon a very large “library” of opening sequences of moves and of end-game sequences of moves.
2. Uses the speed and storage capabilities of a computer to look as far ahead as time permits. Algorithms and heuristics are used to avoid wasting time looking at board positions that are not worth exploring.
3. Analyzes board positions using heuristics.
4. Selects its move based on the most favorable board position that can be achieved based on an assumption of the opponent playing as well as possible. That is, the computer does not select its move based under the assumption that its opponent will make a poor move. Of course, it is possible to develop a program that assigns certain probabilities to the possibility of an opponent selecting a less than optimal move, and takes this into consideration in selecting a move. In addition, if several possible moves are approximately equally good, the computer can be programmed to select one of them randomly.

In chapter 3, we noted that in 1997 IBM’s Deep Blue computer beat the human world chess champion in a six game match (Deep Blue, n.d.). Deep Blue was a computer system whose hardware and software were specifically designed to be very fast at look-ahead and in evaluating board positions. It could evaluate 200 million board positions per second!

This computer system was perhaps 70 to 100 million times as fast at generating and evaluating board positions as its human opponent Garry Kasparov. However, Garry Kasparov was much better at analyzing patterns and board positions. Thus, it was a close match. The human’s chess playing knowledge and skill—human expertise in chess playing—was nearly a match for its very fast, but relatively “dumb” opponent.

Keep in mind that the human player Garry Kasparov was one of the best human chess plays in all of chess history, and that he had spent perhaps 30,000 to 40,000 hours of study and practice gaining his chess expertise. This is very different from the early computer chess program that beat an opponent who had only one hour of chess training and experience.

Games provide a problem-solving environment is which the rules are carefully specified. Playing the game consists of making a sequence of moves. There are a limited number of actions that can be taken at each move. Many real-word problem situations have the same or nearly the same characteristics as games. Thus, research into computer game playing can be applied to developing computer programs that solve a variety of real-world problems. In many of these problems, a computer can outperform a typical human being.

Personal Growth Activities for Chapter 6

1. There is a close similarity between look ahead in game playing, and contemplating the consequences of actions that you are about to take in real-world situations. Introspect to gain some insights into your personal use of look ahead in routine decision making

situations. Then talk about this with some of your colleagues and students to gain increased insight into their use of look ahead as they make routine decisions.

Activities for Chapter 6

1. Play some games of TTT in which the moves of both X and O are completely random. Based on the data you generate, make an estimate of the percentage of games that X will win, that O will win, and that will end in a draw. Then have a number of people (for example all of the students in your class) do the same activity. Combine the results and write a report on what you and the students have learned by this activity.

   If you know how to program a computer, develop a computer program that makes random games of TTT and collects data on the outcomes. Have the computer play a large number of games. Compare the outcome with that achieved through the student activity given above.

2. Consider the possibility of writing down every possible TTT game. In some of these X will win, in some O will win, and some will end in a draw. Suppose this database of possible games is stored in a computer. How could X use this database to select moves in a manner so that the computer will never lose, no matter whether O is being played by a computer or by a human? This situation represents a very important idea in computer game playing and problem solving. In many games and in many real-world problems a computer can be programmed so that it can examine every possible situation than can arise. This "exhaustive search" can then be used to make the best possible moves in the game, or to solve the problem.

3. Probably you have heard of the idea that if one trained a large number of monkeys to do random typing on typewriters, then given enough time the monkeys would produce some really good original writing and would reproduce great writings of the past. This process can be computerized. Analyze the underlying math. For example, how many random combinations of 60 keyboard characters are there? Sixty characters is about the length of a 10 word sentence. Do a compare/contrast with that of using look-ahead as part of the process of writing a good chess playing program. You want to convince yourself that completely random computer generation of good writing is a far larger computational task and quite a bit different than computer chess playing.

Chapter 7: Machine Learning

In chapters 1 and 6, we noted that an artificially intelligent ICT system can make use of a combination of:

- Human knowledge that has been converted into a format suitable for use by an AI system;
- Knowledge generated by an AI system, perhaps by analyzing data, information, and knowledge at its disposal. This might be done, for example, by practicing on problems that have been handled by humans in the past, and comparing its performance to those of the humans. In a computer game setting, a computer might learn by analyzing games that it plays against itself.

The focus in this chapter is on machine learning via these two approaches.

Introduction

The following figure is from chapter 2, where the focus was on human learning. Many of the ideas of machine learning have come from a careful study of human learning. Indeed, such research has contributed to our understanding of human learning (Schank, n.d.).

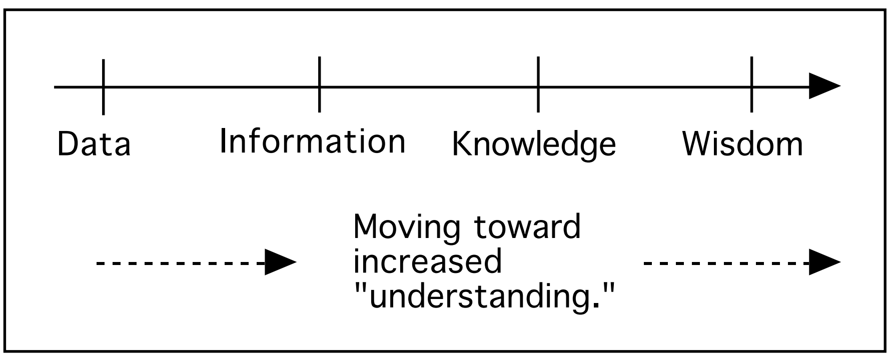

Figure 7.1. Data, Information, Knowledge, Wisdom, and Understanding.

We began this book with the observation that tools embody knowledge. We can analyze a tool in an attempt to determine the extent to which it embodies, contains, and/or uses data, information, knowledge, and wisdom, and the extent to which it has understanding. Here is a brief summary of some of the machine learning ideas that we have illustrated so far:

- We are quite used to the idea that certain manufacturing processes can be highly automated. An automated piece of factory machinery embodies the knowledge and skills to solve a particular type of manufacturing problem. It can do its job without human intervention. The automated machinery may have a combination of algorithmic and heuristic intelligence. However, we would probably be hard pressed to claim that such a piece of factory machinery has any sort of understanding of what it is doing.
- We are quiet used to the idea of people learning to use tools to augment and extend their physical capabilities. We also know that it can take a lot of education, training, and experience to develop a high level of expertise in using some of some tools—for example, a carpenter's hand and power tools. Such tools embody some of the knowledge

and skills of their developers. However, we would be hard pressed to claim that such tools have any sort of understanding of what they are doing.

- Reading, writing, and arithmetic are cognitive tools. They are an aid to the semi-automation or automation of a number of mental tasks. It takes a long period of education and experience to develop a high level of expertise in using these cognitive tools.
- A book, such as a math book, stores data and information. We don't want to think of such a book as being intelligent. However, the book and an appropriately educated person working together can out perform either alone in certain problem situations.
- ICT has made major contributions to our collection of cognitive tools. Moreover, more and more of these tools are "I can do it for you" ICT systems. That is, we have automated a number of cognitive tasks, in the same sense that we have automated a number of factory manufacturing tasks.
- Computers are designed for the input, storage, processing and use, and output of data and information. They do this following detailed step by step procedures that we call computer programs. Such procedures may be a combination of algorithms (guaranteed to solve a particular type of problem) and heuristics (designed to solve a particular type of problem, but not guaranteed to work all the time). Computer procedures, as well as computerized tools, are a new way to embody certain types of knowledge and skills.
- The capabilities of ICT systems are improved by improving the hardware, software, and connectivity. We are living at a time in which rapid progress is occurring in developing faster computers, larger computer memories, increased bandwidth in telecommunications systems, and better software.
- The capabilities of ICT systems are improved by developing better underlying theory (through research), both in ICT and also in the disciplines that contain or generate the problems.
- As progress continues to occur in AI, we are beginning to see some people providing well-reasoned arguments that perhaps such AI-based systems can be developed to have a certain type of wisdom and understanding. Some "far out" futurists are now suggesting that during the 21st century, we will develop ICT systems that are more intelligent than people. If this topic interests you may enjoy reading recent books and articles by Ray Kurzweil. (See http://www.kurzweiltech.com/aboutray.html.)

This chapter is divided into two major sections. The first focuses on the accumulation of human knowledge in a form that can be used by both ICT systems and people. The second focuses specifically on ICT systems that can partially and/or completely learn on their own.

Computer Use of Knowledge Developed by People

Chess Example and Some Implications

In chapter 6, we noted that one important aspect of developing a computer program that can play good chess is to provide it with a library of accumulated human knowledge of good opening sequences of moves and good end-game sequences of moves. There is a huge amount of accumulated knowledge on opening sequences and end games in chess. This can be stored in a computer in a form suitable for access by a chess-playing program. In openings and end games, rote memory can be used to play very high quality chess.

Human chess experts continue to analyze possible opening sequences and end games. As their results are added to a chess-playing computer's repertoire, the program is gaining in knowledge. That is, human knowledge of this sort is easily converted into a type of knowledge that a computer can use. Of course, human chess experts continue to study this gradually growing database of accumulated knowledge and to make use of it as they play chess.

From an education point of view, we need to think about rote memory for situations requiring immediate recall and use, and rote memory for situations not requiring immediate recall and use. Building and maintaining one's rote memory is time consuming. Thus, our educational system needs to make careful decisions as to what rote memoirs to foster. The emphasis should be on rote memories that the student will find frequently useful in situations requiring immediate recall.

When a chess player is participating in a chess tournament, he or she cannot refer to reference books or a computer in deciding on a move during a game. (An exception to this occurs when a game is adjourned, and then continued later, such as the next day.) Somewhat similarly, when a student is answering an essay test question, he or she is (typically) not allowed to make use of reference books or a dictionary. I say "somewhat similarly" because chess tournaments are governed by a careful set of rules—the rules and the tournament are the "real world" of chess competition. However, timed essay tests done without use of reference materials are relatively far removed from the real world of writing and making use of one's knowledge. Such tests violate the principles of situated learning for transfer of learning to non-school setting.

Advanced Placement High School Chemistry

Paul Allen, co-founder of Microsoft, has started a company named Vulcan. This company is doing research and implementation on developing knowledge-based systems. In 2004 they completed a pilot project on Advanced Placement Chemistry (Project Halo, n.d.). Quoting from their Website:

> Project Halo is an effort by Vulcan Inc. towards the development of a "Digital Aristotle"—a staged, long-term research and development initiative that aims to develop an application capable of answering novel questions and solving advanced problems in a broad range of scientific disciplines. The Digital Aristotle is being developed with a focus on two primary functions: as a tutor capable of instructing and assessing students in the sciences, and as a research assistant with broad, interdisciplinary skills to help scientists in their work.

The Website contains a number of articles describing the project and its results so far. Here is a brief quote that helps describe the rational for the project:

> Today, the knowledge available to humankind is so extensive that it is not possible for a single person to assimilate it all. This is forcing us to become much more specialized, further narrowing our worldview and making interdisciplinary collaboration increasingly difficult. Thus, researchers in one narrow field may be completely unaware of relevant progress being made in other neighboring disciplines. Even within a single discipline, researchers often find themselves drowning in new results. MEDLINE, for example, is an archive of 4,600 medical publications in thirty languages, containing over twelve million publications, with 2,000 added daily.

The pilot test was based on appropriately encoding (using knowledge engineering techniques, with chemists and knowledge engineers working together) 70 pages of a college-level chemistry text. When tested over the content, the computer system performed at about the same level as a high school student who would have gained advanced placement credit for such a performance. Here are two question the computer correctly answered and correctly explained the reasoning behind its answer.

A solution of nickel nitrate and sodium hydroxide are mixed together. Which of the following statements is true?

a. A precipitate will not form

b. A precipitate of sodium nitrate will be produced

c. Nickel hydroxide and sodium nitrate will be produced

d. Nickel hydroxide will precipitate

e. Hydrogen gas is produced from the sodium hydroxide

Sodium azide is used in air bags to rapidly produce gas to inflate the bag. The products of the decomposition reaction are:

a. Na and water

b. Ammonia and sodium metal

c. N_2 and O_2

d. Sodium and nitrogen gas

e. Sodium oxide and nitrogen gas

Note added 4/24/06: This is an interesting topic. However, my Web searches on 4/24/06 did not find mention of this project after 2004. I wonder what has become of it?

World Wide Web: A Global Library

You are familiar with the very large and rapidly growing database that we call the World Wide Web (the Web). It can be thought of as a global library designed so that millions of people can add to the contents of the library. It is a library designed for the use of people, by ICT systems, and by a combination of people and ICT systems.

The development of reading, writing, and arithmetic about 5,000 years ago was a major turning point in human history. Knowledge could be more readily accumulated, moved around the world, and passed on to future generations. Libraries (databases) of data, information, knowledge, and wisdom could be accumulated. Through appropriate education, people could learn to make use of libraries and their own collection of print materials.

Perhaps the single most important idea in problem solving is building upon the previous knowledge of yourself and others. Much of formal schooling is directed toward helping students learn some of the accumulated information and learn to effectively use both what they have learned and additional information stored in libraries and other sources.

It is clear that a library is an important component of both informal and formal education systems. The school library has long been an important part of a school. However, money, space, and staff considerably restrict the size of a school library. The Web brings a new dimension to the library. A microcomputer with Web connectivity, along with appropriate education, training, and experience, gives a person access to a library that is far larger than what any school can afford.

Some keys to using the Web include:

1. learning to make use of search engines
2. learning to make relatively rapid and informed decisions on which individual Websites to explore
3. learning to read (with understanding) interactive hypermedia documents

4. learning to separate the “wheat from the chaff.” The Web differs substantially from an ordinary hardcopy library in that little of no screening occurs for much of what is published on the Web. A refereed article in a high quality journal is apt to be a much more reliable source of information than is a personal Blog.

Search engines make use of both algorithms and heuristics. Lets start with a simple example. A hard copy (printed copy) set of encyclopedias is arranged in alphabetical order by topic. On the spine of each volume is the range of the alphabet covered in that volume. A typical user selects an appropriate volume and then uses some combination of algorithms and heuristics to find the desired topic, much in the same way that the user looks up a word in a dictionary.

Of course, an encyclopedia is not a dictionary. A topic may require a sequence of words to describe. Moreover, a topic may well be contained within an article about a completely different topic. Thus, a hardcopy set of encyclopedias contains an extensive index. Even then, a topic might be in the encyclopedia, but nearly impossible to find. It requires training, experience, and good thinking to develop a high level of expertise in making effective use of a hardcopy encyclopedia.

Now, consider what happens when one puts such an encyclopedia on a CD-ROM or on the Web. The user can no longer use the hardcopy search techniques. As a replacement, the encyclopedia is indexed using every content word in the encyclopedia. A computer program prepares the index. This program contains a list of non-content words such as a, all, and, be, but, …that are not used as index terms. An algorithm prepares the electronic index and links to the start of the article(s) and sections that contain the index term. The user merely keys in a word, such as “cat” and gets a listing of every encyclopedia article containing the word cat.

Unfortunately, there will be lots of articles that contain the word cat—far more articles than a person will want to read. Are you interested in house cats, show cats, wild cats, members of the cat family that one might find in a zoo, or what? Are you interested in the historical background of house cats, show cats, cats in North America, or what? Perhaps you are interested in a Broadway play named Cats?

An answer to this difficulty lies in adding some more capabilities to the search engine. The search engine can be provided with provisions to do Boolean searches. Thus, the user might ask for a search on “cats AND North America AND domesticated.” Even then, one is apt to get a lot of “hits”—that is, articles that contain all three of the search terms.

An alternative and/or addition is to allow the searcher to write a sentence or more describing their interests. “I want to know about cats that make very good house pets and that are common in North America.” This approach works well when one is seeking help from a human research librarian. That is because the sentence conveys information to the research librarian, who then processes and understands the information. This idea has been tried out in the development of a number of different search engines. The processing of a sentence or paragraph is done using heuristics. The current state of AI in this area is not very good, as such computer systems have little or no understanding of the input.

The various electronic searches done using search engines typically produce a large number of hits. (A few weeks ago, I specified what I thought was a relatively narrowly defined topic, and I got more than 6 million hits!) How does a search engine decide on which hits it finds are more likely to be of importance? The designers of a search engine develop a set of heuristics to order the hits. One of the features of a good search engine is that it is good at selecting hits that are apt to meet the searcher’s needs.

Google is my favorite search engine. I am still learning some of its capabilities and limitations. In 2003, when I was writing the first edition of this book, I tried the experiment of keying in the following search request:

> I want to know about cats that make very good house pets and that are common in North America

The result was:

1. A statement that the word "and" was ignored because Google automatically uses the Boolean operator AND on all words that are entered.
2. A statement that North and all subsequent words were ignored because Google uses only the first 10 words in a search request.
3. A statement that the common words (**I, to, about, that, are, in)** in the search entry were all ignored. These are examples of words that do not carry sufficient content information to make them worth including in a search.
4. The search resulted in 9,800 hits and used up .23 seconds of the time on the search engine's computer.

The 9,800 hits are listed in order of relevance as determined by the Google search engine heuristics. I am still left with a formidable task in finding the desired information. Moreover, a quick scan of the hits suggests that I did not find materials that I wanted to read.

A little bit of thought led me to doing the search over. This time I searched on:

> cats good house pets common North America

The Google search engine reports 8,790 hits that it found in .17 seconds. A quick scan of the titles of the first few hits suggests that this was a more useful search than my first search. The hits look like they may contain the information that I am seeking.

On 5/6/05, while doing some revision of this book, I again used the search sentence:

> I want to know about cats that make very good house pets and that are common in North America

This time Google told me that "and" is unnecessary and that it had found 474,000 hits in .36 seconds. (On 4/24/06 and I got more than 10 million hits and used up .75 seconds on the Google search computer system when I performed the same search.).

The number of Web pages searched by Google has increased substantially over the past couple of years, but that does not explain the huge increase in hits over this time.

I next expanded my search "sentence" to:

> I want to know about cats that make very good house pets and that are common in North America.
> I want to buy a pet cat for a grandchild.

This time (on 5/6/05) I got 9,040 hits in .31 seconds. The first of the hits contains some useful information on the topic. However, it is clear that is still room for huge improvements in both search engines and the searcher (me).

I performed the same search on 4/24/06 and got 67,600 hits. The book you are now reading was number nine in the first ten hits. None of the first ten hits was relevant to my interests; many were Blogs.

The important thing that is missing is that the search engine does not extract meaning or understanding form my search expression. Suppose that you are a person who knows a lot about pets, cats, children, and so on. I might say to you:

> I want to get a cat for my daughter's three children. The children are young, with two in elementary school and one still younger. They have a house with a large fenced in back yard. What do you recommend?

You would then carry on a conversation with me, providing me with some ideas and perhaps a recommendation. You would perhaps want to get more information from me, such as whether the grandchildren seem to be taking responsibility in caring for the dog, and whether their parents have experience in caring for cats. We might want to talk about whether a dog and a cat will have troubles adjusting to each other.

Contrast this with Google's response to using my short paragraph as the search expression:

> The search expression did not match any documents.
>
> Suggestions:
>
> - Make sure all words are spelled correctly.
> - Try different keywords.
> - Try more general keywords.
> - Try fewer keywords.

When I used the same search expression on 4/24/06, the only hit was this book.

The Web (the global library that we call the Web) is steadily growing in size. It is a huge repository of data, information, knowledge, and wisdom. The search engines that are designed for searching the Web are gradually gaining in algorithmic and heuristic intelligence. Through a combination of formal and informal education and experience, students are gaining in expertise in using search engines as an aid to using the Web. In some sense, one might argue that a student gains in intelligence by learning to make effective use of the Web, and that steady improvements in the Web content and search engines still further increases the intelligence of this student.

According to Tim Berners-Lee and a number of other researchers, the next really important progress in Web development will be the Semantic Web (n.d.). Quoting from Wikipedia:

> The Semantic Web is a project that intends to create a universal medium for information exchange by giving meaning (semantics), in a manner understandable by machines, to the content of documents on the Web. Currently under the direction of its creator, Tim Berners-Lee of the World Wide Web Consortium, the Semantic Web extends the ability of the World Wide Web through the use of standards, markup languages and related processing tools.

Expert Systems

Expert Systems are an area of AI that explores how to computerize the expertise of a human expert. For example, is it possible to computerize the knowledge of a medical diagnostician, a computer repair person, or a teacher?

We are used to the idea that a large amount of the knowledge of an expert can be put into a book. The book may be designed to help a human learn some of the knowledge of its author. It may contain detailed step-by-step procedures which, if carefully followed, will solve certain problems or accomplish certain tasks that here-to-fore were done by a human expert. If you are a parent who has raised children, it is likely that you have made use of *Dr. Spock's Baby and Child Care* by Benjamin Spock. It is a great help to diagnosing certain types of child medical problems and what to do based on the diagnoses.

Computerized versions of the same general ideas are called expert systems. An expert system typically consists of four major components:

1. Knowledge Base. This is the knowledge in the expert system, coded in a form that the expert system can use. It is developed by some combination of humans (for example, a knowledge engineer) and an automated learning system (for example, one that can learn through the analysis of good examples of an expert's performance).
2. Problem Solver. This is a combination of algorithms and heuristics designed to use the Knowledge Base in an attempt to solve problems in a particular field.
3. Communicator. This is designed to facilitate appropriate interaction both with the developers of the expert system and the users of the expert system.
4. Explanation and Help. This is designed to provide help to the user and to provide detailed explanations of the "what and why" of the expert systems activities as it works to solve a problem.

Mycin was one of the first expert systems. It was developed at Stanford in the 1970s. Its job was to diagnose and recommend treatment for certain blood infections.

One way to diagnose blood disorders is to grow cultures of the infecting organism. However, this takes approximately two days, and the patient may well die before then. Thus, it is important to make a relatively accurate preliminary diagnosis and to take actions based on the preliminary diagnosis. Some human doctors are very good at this, while many others are not.

Mycin represents its knowledge as a set of IF-THEN and "certainty" rules. Here is an example of one such rule (MYCIN):

IF the infection is pimary-bacteremia

AND the site of the culture is one of the sterile sites

AND the suspected portal of entry is the gastrointestinal tract

THEN there is suggestive evidence (0.7) that infection is bacteroid.

The 0.7 is roughly the certainty or probability that the conclusion based on the evidence will be correct.

Mycin was developed to help AI researchers learn to design and implement an expert system that could deal with a complex problem. The system was never actually used to diagnose patients. In research on the system, however, the system out performed staff members of the Stanford medical school. Work on Mycin has led to still better expert systems that are now used in a variety of areas of medicine and in many other fields.

It is very important to understand the narrow specialization of the typical expert system. An expert system designed to determine whether a person applying for a loan is a good loan risk cannot diagnose infectious diseases, and vice versa. An expert system designed to help a lawyer deal with case law cannot help a literature professor analyze poetry.

Researchers in AI often base their work on a careful study of how humans solve problems and on human intelligence. In the process of attempting to develop effective AI systems, they learn about human capabilities and limitations. One of the interesting things to come out of work on expert systems is that within an area of narrow specialization, a human expert may be using only a few hundred to a few thousand rules.

Another finding is that typically takes a human many years of study and practice to learn such a set of rules and to use them well. The set of rules is a procedure that involves both algorithmic and heuristic components. In certain cases the set of rules can be fully computerized or nearly fully computerized, and can produce results both very quickly and that may well be more accurate (on average) than highly qualified human experts.

Consider a medical diagnostic tool such as Mycin. It operates following a set of algorithmic and heuristic procedures. Of course, the computer system is not embodied in a robot that can draw blood samples and carry out medical tests. However, it might well be that a medical technician and the expert system working together can accomplish certain tasks better than a well trained medical doctor.

Moreover, it is very time consuming for a human doctor to memorize the steps of the procedures and to gain speed and accuracy in carrying them out. (The astute reader will notice a similarity between this discussion and earlier discussions of long division of decimal numbers or carrying out arithmetic using fractions.) The point being made is that an expert system can be thought of as a tool that embodies or contains knowledge. The issue of educating people to work with, or compete with, such tools then faces our educational system.

ICT-Generated Knowledge

There are a number of different approaches to using ICT systems to generate knowledge that can be used by people and ICT systems. Several examples are discussed in this section.

Most AI systems gain their knowledge by a combination of the learning ideas discussed in the previous section and the learning ideas discussed in this section. Expert systems provide a good example. Once an expert system gains its initial knowledge that has been developed by human experts and knowledge engineers, then the system can be "trained." That is, the system can learn through experience.

As an example, consider a Mycin-like system designed to diagnose various types of infections. At the same time the AI system is being used, cultures of the infections can be taken and cultivated. The data from the cultures, which might take a couple of days to obtain, can be fed into the expert system. The expert system can then adjust its knowledge base and heuristics to take this performance data into consideration.

Somewhat similar training can be done using data from cases in medical files. The expert system does a preliminary diagnosis based on the data that was gathered by the doctor before the cultures were grown. The expert system then compares the results with data produced from the cultures, and uses this information to learn to make more accurate preliminary diagnoses. The general idea being described here does not differ from how we educate humans. However, a computer system can explore and learn from a much large set of cases than a human has time to explore. Moreover, the computer system does not forget (over time) what it has learned.

Example from Checkers

Chess, checkers, and many other games require use of look-ahead and the evaluating board positions. The evaluation function typically is based on some weighted combination of numerical values from a number of different variables. It is possible to have a computer determine the weighting coefficients to use. This idea is illustrated in the following discussion of early checker playing work done by Arthur Samuel (Kendall, 2001).

> Arthur Samuel, in 1952 (Samuel, 1959), wrote the first checkers program. The original program was written for an IBM 701 computer. In 1954 he re-wrote the program for an IBM 704 and added a learning mechanism. What makes this program stand out in AI history is that the program was able to learn its own evaluation function. Taking into account the IBM 704 had only 10,000 words

> of main memory, magnetic tape for long-term storage and a cycle time of almost one-millisecond, this can be seen as a major achievement in the development of AI.
>
> Samuel made the program play against itself and after only a few days play, the program was able to beat its creator and compete on equal terms with strong human opponents.

I find it interesting to note that Samuel's work was done on a computer that was less than a millionth as fast as today's microcomputers. The key ideas demonstrated by Samuel are that the machine improved its performance by playing against itself, and that through such improvements the computer became a better checkers player than its creator. By the mid 1990s, a computer was the reigning world checker champion.

Data Mining

Imagine a grocery store that uses a bar code scanner to "ring up" a customer's grocery purchases. The customer makes use of a store-issued card in order to get some of the discounts that are available, and/or the customer pays using a credit or debit card. The store's computer ends up with data on the customer's name and address, the items purchased, the date and time of day, and so on.

This data can be processed to produce information about the customer. For example, after I have been grocery shopping a computer might conclude:

> This customer must have a lot of cats. The customer buys lots of cat food, kitty litter, and cat treats.
>
> This customer must be addicted to chocolate ice cream and candy.

Even before the customer completes the checkout process, the computer can print some special coupons good for discounts on items that might interest the customer. Moreover, the inventory of items on the store shelves is adjusted, as is the inventory of items in the store. When appropriate, a message is sent to the shelf-stocking employees and/or to the employees who place orders to restock the warehouse. Indeed, the computer might automatically place the orders for products needed to restock the warehouse.

But wait—there's more. The store has placed certain items in some of its special locations, such as at the checkout counter and at the ends of isles. Which items are selling best? The computer gathers data from a number of customers and produces a report. This report is used by the store manager to make decisions on how to best use these special locations.

All of this is now commonplace, and it is now just part of the story of what is happening. Data is gathered in the process of ringing up a customer's sales. This data can be "mined" to produce information and knowledge that is useful to for a variety of purposes in the retail grocery store business. For example, a grocery chain's data mining software might detect some interesting relationships between the demographics of the neighborhood around a particular store, the season of the year, the weather, and what sells well at the store. Data is processed into information. Information is processed into knowledge. Humans (and perhaps computers) use the knowledge to make decisions that will lead to better meeting the needs of the customer and will produce greater profits for the store.

Data mining is the process of finding new and potentially useful knowledge from data. In recent years, this has become an active area of research and implementation. For example, in 1998 the Association for Computing Machinery established the Special Interest Group on Knowledge Discovery in Data and Data Mining (SIGKDD).

> The primary focus of the SIGKDD is to provide the premier forum for advancement and adoption of the "science" of knowledge discovery and data mining. To do this, SIGKDD will encourage:

- basic research in KDD (through annual research conferences, newsletter and other related activities),
- adoption of "standards" in the market in terms of terminology, evaluation, methodology, and
- interdisciplinary education among KDD researchers, practitioners, and users. (ACM SIGKDD)

Earlier in this book, I talked about the computer program Deep Blue that won a six game match against Kasparov, the reigning human chess player in 1997. Deep Blue included a database of 700,000 chess games that had been played by Grandmasters. This database was analyzed by the computer (using data mining techniques specific to chess) to create a database of good moves to use in the first part of a game. This information is used in conjunction with a large database of opening moves that have been carefully analyzed by chess experts.

The machine learning from analysis of 700,000 Grandmaster games was quite effective. By accident, in a 1996 game played against Kasparov, the database of opening moves developed by chess experts was turned off. The computer depended only on the results of its analysis of the 700,000 games. Still, the computer played very well in the opening part of the game. This suggests that machine learning through data mining may work well in somewhat similar settings such as medical diagnosis and treatment, and stock market analysis and transactions.

(Intelligent) Computer-Assisted Learning

As an educator, you are probably familiar with the idea of an Individual Education Program or Individual Education Plan (IEP) that is developed for students in Special Education (deFur, 2000). From time to time people have considered the idea that every student should have an IEP and that much of a student’s instruction should be geared specifically to the current level of knowledge and skills of the student, the individual goals of the student, the individual abilities of the student, and so on. That is, it is suggested that individualized, constructivist-based education is important for all students, not just special education students.

Research by Benjamin Bloom and others suggests that with individual tutoring by a well qualified tutor, the typical “C” student can perform at the “A” level (Bloom, 1984). A number of researchers are focusing on how one might produce such learning gains through less expensive means such as Intelligent Computer-Assisted Learning (ICAL). (The Open Learning, 2003.)

A good (human) tutor has excellent knowledge of the learner, the materials to be learned, and the teaching & learning process. There is a large amount of researcher and practitioner literature on Computer-Assisted Learning (CAL) and on ICAL. Indeed. By 1994, there had been enough meta-studies on CAL so that it was feasible to conduct a meta-meta-study, a study of the meta-studies (Kulik, 1994). The research evidence is that on average, CAL helps students learn both faster and better, as compared with traditional classroom instruction.

An ICAL system gains its knowledge is several ways. Knowledge about the subject matter is programmed into the computer system. Knowledge about the student may be gained from a number of sources (such as school records) and directly from the student (such as by computer-administered and computer-scored tests). Knowledge about the student’s learning characteristics may be gained through analysis of the data produced as the student participates in ICAL. The ICAL system directly applies its knowledge in the individualized instruction of a student. It may well make minute-to-minute adjustments in the instruction it is providing.

Some CAL and ICAL systems can now out perform a good human tutor in limited areas of instruction. One of these areas is in the training of airplane pilots and spaceship pilots. Computer simulations can put the trainee into dangerous situations that would be life threatening if they were real, instead of simulations. The simulations are sufficiently good so that there is substantial transfer of learning from learning in the simulator to using the knowledge and skills in real-word environments.

Another area of excellent progress has been in working with children who are severely speech delayed because the phoneme processors in their brains process too slowly. An ICAL approach has produced results far better than what had previously been produced by individual instruction by professional speech therapists. The following quoted material provides some sense of how this is done through an ICAL system (Tallal, 2003).

> Two independent research studies report that language learning impaired (LLI) children improved by approximately two years after only four weeks of intensive exposure to speech and language listening exercises presented with an acoustically modified speech signal, together with a new form of adaptive computer training (Merzenich, 1996; Tallal, et al., 1996).
>
> …
>
> Computer games were developed using both nonverbal and verbal stimuli. The games were adaptive. By adaptive, we mean that the stimulus sets and series of trials were controlled by each subject's trial by trial performance. The adaptive computer games were developed with the aim of first establishing the precise acoustic parameters within stimulus sets required for each subject to maintain 80% correct performance on that stimulus set. Once that threshold point was determined for each subject, the subject's own performance determined the acoustic parameters of each subsequent trial. The goal of the training was to first determine the thresholds for specific acoustic variables and then, for subjects with elevated thresholds, attempt to drive them to process closer and closer to a more normal processing rate. The "games" were designed to be fun for the subject and to maintain ongoing attention.

In brief summary, an interactive computer-game-like environment is used to train a child’s brain so that it processes speech sounds faster and more accurately. This research and development has let to a product line called Fast ForWord produced by Scientific Learning Corporation. There is a growing body of research on the effectiveness of this type of ICAI. Quoting Trei (2003):

> For the first time, researchers have shown that the brains of dyslexic children can be rewired—after undergoing intensive remediation training—to function more like those found in normal readers.
>
> The training program, which is designed to help dyslexics understand rapidly changing sounds that are the building blocks of language, helped the participants become better readers after just eight weeks.

Artificial Neural Network (ANN)

An Artificial Neural Networks (ANN) is a computer model of certain aspects of the neural networks in a brain. One can think of the simple processors (units) as being somewhat akin to a biological neuron, and the network of connections being somewhat akin to biological axons and dendrites. An ANN is trained (learns) by adjusting the numerical values of the weights of the connections between the simple processors (units). An ANN learns from examples, much in the way that a child learns from examples, For example, a child learns to distinguish toy animals from live animals through seeing many examples and being provided appropriate feedback (Artificial Neural Network, n.d.).

Some really hard problems have been approached through the use of ANN. Examples include developing computer systems for recognition of human faces, recognition of abnormal or malignant cells, recognition of "enemy" troop concentrations and movements, voice input systems, voice output systems, and stock and bond price forecasting. This approach to machine learning is rooted in the checkers-playing work of Arthur Samuel done during the 1950s.

Brief Summary

Machine learning and applications of machine learning are very large and complex topics. We have touched on a few aspects of this field that is continuing to make significant progress on a year-to-year basis. This progress is resulting in the production of some AI-based systems that can out perform human experts. Many ICT systems that make use of a combination of algorithmic and heuristic intelligence are now in routine use. They function well enough to be cost effective and effective aids to helping solve a wide variety of problems that people want to solve.

Personal Growth Activities for Chapter 7

1. This chapter discusses a Fast ForWord ICAL program that out performs a highly qualified speech therapist providing one-on-one tutoring for one particular type of learning problem. Think and feel about your thoughts and feelings when you read this material. Then share and explore these thoughts and feelings with some fellow educators.

Activities for Chapter 7

1. A brief news item is quoted below. It discusses data mining to help locate possible terrorists. After reading this news item, give your insights and opinions on this potential use of data mining.

   O Big Brother, Where Art Thou? (Everywhere)

   In order to monitor the U.S. civilian population in its effort to detect terrorists, the government's Total Information Awareness program will rely almost completely on data collection systems that are already in place—e-mail, online shopping and travel booking, ATM systems, cell phone networks, electronic toll-collection systems and credit card payment terminals. Technologists say that what the government plans to do in data sifting and pattern matching in order to flag aberrant behavior is not very different from programs already in use by private companies. For instance, credit card companies use such systems to spot unusual spending activities that might signal a stolen card.

   …

   However, some computer scientists question whether such a system can really work. "This wouldn't have been possible without the modern Internet, and even now it's a daunting task," says cryptology expert Dorothy Denning, a professor in the Department of Defense Analysis at the Naval Postgraduate School. Part of the challenge, she says, is knowing what to look for. "Do we really know enough about the precursors to terrorist activity? I don't think we're there yet." (New York Times 23 Dec 2002) (NewsScan Daily, 23 December 2002)

2. Think about the various topics that you teach or are preparing to teach. Identify one in which you feel that student use of current CAL or ICAL may be more effective than your current whole class or small group teaching. Do some Web research to find whether such software exists. Write a report on your thoughts, feelings, and findings.

3. In what sense is a library more knowledgeable than a person, and vice versa? Select a specific discipline that you teach or are preparing to teach. Discuss the topic question in the context of this discipline. Be sure to include an analysis of curriculum, instruction, and assessment implications of your ideas.

4. Nowadays, commercial airline pilots are required to take periodic training in flight simulators as part of the process of monitoring their performance capabilities. There are a steadily increasing number of expert systems in medicine that can do diagnoses and medical tests. What are your thoughts about requiring doctors to be periodically tested in how well they perform relative to current AI medical systems?
5. Do a Google search using several search terms. Then rearrange the search terms into a different order, and do the search again. Then rearrange the search terms and do the search again. Discuss your findings and how they relate to heuristics that Google uses in its search engine.

Chapter 8: Summary and Conclusions

This chapter begins with a summary of the key ideas covered in previous chapters. It then forecasts the near term and long term future of AI in education. Finally, it discusses some educational implications and makes some recommendations.

The Pace of Change

Long before the beginnings of recorded history, people developed tools to help them solve problems and accomplish tasks. Tools embody some of the knowledge and skills of their developers. Thus, some of this knowledge and skill is passed on to later users and builders of the tools. This has a cumulative effect, leading to a steadily increasing pace of change.

When we look back 100,000 years ago, and more, the pace of change was slow. A higher quality stone ax, spear, bow and arrows, flint knife, or scraping tool was a useful development, but did not produce a profound change in life styles. Up until about 11,000 years ago, all people lived in hunter-gather societies, and the total human population on earth was perhaps 12 million. (The current population is well over 6 billion, more than 500 times as large.)

Then came the development of agriculture, with its raising of crops and animals. This created living environments that promoted a significant increase in the pace of development of new tools and in the pace of change of societies. Still, a person living on a farm would see little change over a lifetime.

Beginning a little over 5,000 years ago, reading, writing, and arithmetic were developed. Formal education (schooling) was established to help a few people develop a useful and functional level of knowledge and skill in using these mental tools. Information and knowledge could more readily be accumulated, distributed among large numbers of people, and passed on to future generations. These mental tools greatly increased the pace of change in societies. Still, the pace of change remained relatively slow. The typical farmer remained illiterate and saw few significant changes over a lifetime.

At the time of the American Revolution (circa 1776) fully 90% of the United States population lived on farms. Thomas Jefferson was a Virginian and one of the key leaders during this time. He tried to get the Virginia legislature to fund free public primary school education (grades 1-3) in his state. He argued that this was important in a democratic society. However, he was not able to gain acceptance of this "revolutionary" educational idea.

Now, less than 250 years later, many countries provide their citizens with free K-12 education. Significant numbers of people go on to higher education. Improvements in education, along with continued rapid progress in science and technology, have led to a much faster rate of change in the societies of our world. The totality of human knowledge is growing quite rapidly.

Each new tool changes the societies that widely adopt the tool. This may be a long, slow process. However, we all recognize that reading and writing, when combined with Gutenberg's moveable type printing press about 550 years ago, had a major impact on Europe and other parts of the world. Knowledge and skill in reading and writing, when combined with the mass production and distribution of books, empowers people. Religions, government, and industry were all significantly changed.

> Author's note added 5/7/05. When I first wrote the paragraph given above, I did not yet know that a movable type printing press had been developed in China about 500 years before Gutenberg. "During the Ch'ing-li period (1041-1048) the printing technique was further advanced through the

> invention of movable type. Block printing was a costly and time-consuming process, for each carved block could only be used for a specific page of a particular book. An alchemist named **Pi Sheng** appears to have conceived of movable type. Each piece of movable type had on it one Chinese character which was carved in relief on a small block of an amalgam of clay and glue. The portion that formed the character was as thin as the edge of a small coin. After the block had been hardened by fire, the type became durable (Movable Type, n.d.)."

Many people like to draw a parallel between the three R's and the printing press, and the past half century of progress and use of Information and Communication Technology. They suggest that ICT will have an impact comparable to the three R's and the printing press.

Of course, in some sense this is like comparing apples to oranges. What is particularly evident, however, is the pace of development and widespread adoption of ICT. It took nearly 5,000 years to move from the beginnings of the three R's to widespread adoption. ICT has grown to its current worldwide use during my lifetime.

Three examples will help to make this pace of change more concrete.

- It took well over a hundred years after Alexander Graham Bell's 1876 development of the telephone before a billion telephones were in use. Now, more than a billion cell telephones are being manufactured every three years! A number of these cell telephones include a built-in color digital camera with a viewing screen, and a Web browser.
- Although the Internet is now more than 30 years old, its widespread growth in use began with the development of the Web. Email and the Web became routinely used tools of large numbers of people throughout the world in just a dozen years!
- The "mass production" of computers began in 1951, with an initial production rate of less than a dozen machines per year. Now, worldwide production of microcomputers is about 130 million per year. Over 1 billion million "smart cards" (a credit-card type of device with built-in computer circuitry), are being manufactured per year. The compute power of many of these Smart Cards is about the same as the microcomputers of 1980. However, currently many of the newest Smart Cards contain a 32-bit microcomputer and memory with more compute power than the typical microcomputer of the early 1990s.
- Many of the newer cell telephones include more compute power than typical microcomputers of the late 1990s. In addition, many now include a built-in digital still or digital video camera.

Summary of Key Themes in This Book

We began by noting that "Artificial Intelligence" is a loaded expression, evoking strong negative emotions from many people. Throughout this book, we have stressed the differences between human intelligence and AI. Here are three additional comparisons that may contribute to your understanding of such differences. All three are based on comparing machines against biological creatures.

- A nuclear powered submarine or aircraft carrier is faster and larger than a whale. However, in no sense does it swim like a whale.
- A jet airliner is faster and larger than a bird. However, in no sense does it fly like a bird.
- A freight train is faster than an elephant, and it can carry a far heavier load. However, in no sense does a freight train run like an elephant.

Throughout this book, we have focused on use of ICT to enhance the capabilities of tools. Although we have talked about human intelligence and machine intelligence, our emphasis has been on the steadily growing capabilities of tools as aids to solving problems and accomplishing tasks. We have avoided getting embroiled in arguing whether computers have or will ever have consciousness and souls in the sense that people have these characteristics.

Instead we have stuck to the thesis that tools embody some of the knowledge and skills of their developers, and that this empowers users of the tools. AI can be viewed as an area of research and development that strives to increase the knowledge and skills that are embodied in tools. As such tools are widely distributed and used, they change the societies of our world.

Figure 8.1 is from chapter 1.We repeat it here as an aid to summarizing some key ideas presented in this book.

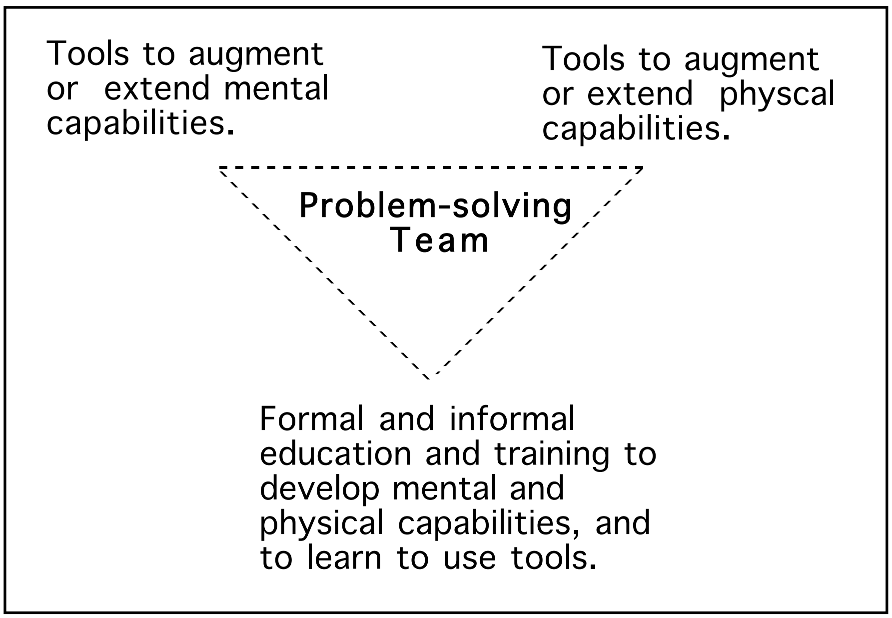

Figure 8.1. Aids to a problem-solving team.

In this book, we have examined a number of AI-related tools that augment or extend mental capabilities. In addition, we have come to understand that many of the tools that augment or extend physical capabilities now make use of AI and other aspects of ICT. That is, we are seeing a merger of the two general categories of tools.

Thus, people have available a steadily growing number of mental and physical tools that can "just do it" for them. That is, the mental and physical tools are sufficiently automated (have appropriate levels of AI) so that they can automatically solve or help substantially in solving an increasingly wide variety of problems. This idea is illustrated in figure 8.2.

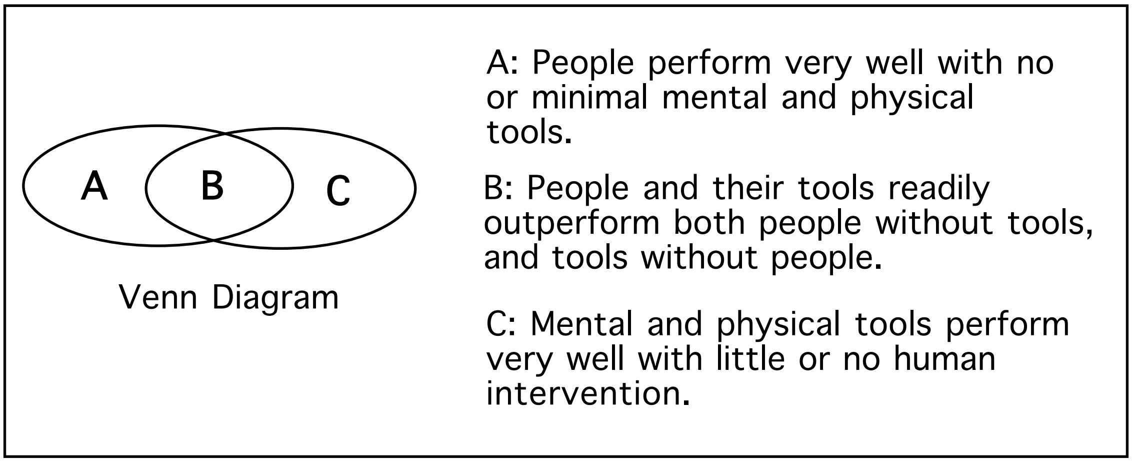

Figure 8.2. Venn diagram for discussing people and their tools.

Referring to the A component of figure 8.2, in my daily life I often walk around my place of work and carry on conversations with my colleagues and students. It is true that I make use of tools such as shoes and clothing, and I may well be inside a building. However, the actual conversations make use only of my own personal mental and physical capabilities. Indeed, people who have had no introduction to reading, writing, and arithmetic are quite capable of carrying on an intelligent and spirited conversation.

Referring to the C component of figure 8.2, you are probably aware of the fact that people have developed robotic equipment that can be sent to a place such as Mars and then automatically, with little or no human intervention, gather and process data, take actions based on the data that is being obtained, and radio reports back to earth. Also, of course, you know something about the autopilot system in commercial airplanes. It is quite capable of flying the plane over long distances.

Quite a bit of this book has focused on the B component of figure 8.2. Here we are looking at situations where people and their tools can outperform people without tools and tools without people. We are particularly interested in how formal and informal training and education fit into this approach to solving problems and accomplishing tasks. How should educators structure and implement curriculum, instruction, and assessment to help prepare their students to function well in a world where A, B, and C are changing?

The following is a brief summary of some of the other key ideas covered in this book.

1. AI-based tools can be built so that they learn not only from people, but also on their own.
2. Within the domain of a narrowly defined problem area (for example diagnosis of infectious disease, game playing) AI systems have been built that function at or above the level of human experts, and some Intelligent Computer-Assisted Learning systems outperform individual human tutors as aids to student learning.
3. People learn by gaining increased amounts of data, information, knowledge, and wisdom, and understanding of what it is they are learning. AI systems have been developed that contain, learn, and use data, information, knowledge, and (perhaps) wisdom. But at the current time, AI systems lack the types of understanding that is commonplace in humans.

4. AI problem-solving systems tend to be highly domain specific. That is, they are designed to deal with problems in very narrowly defined domains. An AI system can be produced that functions quite well in the diagnosis of infectious diseases, but so far people have not done very well in producing an AI system that can carry on a conversation that roams over a number of different domains (that is, that can pass the Turing test).

Brief Analysis of Educational Goals

It is sometimes said that what is hard for people is easy for machines, and vice versa. Obviously this is an over simplification of a very complex set of ideas. However, machines can certainly memorize far faster and better than people. At the current time, people are far better at transferring their knowledge and skills across disciplines and having a broad understanding of what they are doing. People understand what it is like to be a human being—they understand "the human condition." Figure 8.3 summaries these ideas; the left column is the goals of education developed by David Perkins and presented in chapter 2.

Education Goal	Human Strengths and Weaknesses	AI System Strengths and Weaknesses
Acquisition and retention of knowledge and skills.	Slow in acquisition, weak in retention without frequent relearning and/or use.	Once accomplished for one ICT system, distribution to other ICT systems tends to be easy.
Understanding of one's acquired knowledge and skills.	Comprehension and understanding are difficult to achieve, but tend to be retained over time. Education can be designed to help facilitate understanding, long-term retention, and transfer of learning. However, such education is a slow process.	There is a huge gap between human understanding and machine understanding. Currently, to the extent that machines have understanding, it is much different than human understanding and tends to be quite domain specific.
Ability to use one's knowledge, skills, and understanding to effectively deal with a wide range of problem-solving situations one encounters in the future. Active use of one's acquired knowledge and skills.	Success in these areas is measured on an expertise scale. Through appropriate formal and informal education and experience, one can move up such a scale relative to him or her self and relative to some sort of established standards.	Within many different narrowly specified domains, AI plays a major role in mind and body tools that have a high level of expertise—in some cases, a higher level of expertise than the best humans.

Figure 8.3. AI and human strengths and weaknesses..

Final Remarks: A Glimpse into a Small Part of the Future

The following diagram is suggestive of the future. Mind and body tools merge in this future. Knowledge and skills are built into the tools. Lifelong education and training are designed to help prepare the Problem/Task Team in making wise decisions as problems are posed and solved by a combination of people and their tools. In some sense, the three components of the diagram become partners as they work together to solve problems and accomplish tasks.

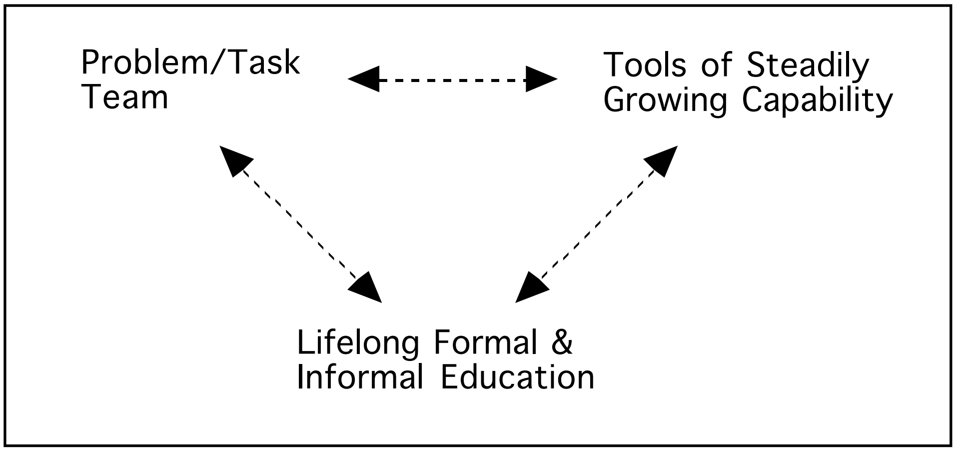

Figure 8.4. Merging of mind and body tools.

Now, here is a look at part of the future that is currently rapidly approaching. Consider an ICT **Communicator** tool that has the following characteristics:

- The Communicator weighs less than a pound, runs on long life batteries or a built-in fuel cell, and has a color display screen.
- It contains a global positioning system that determines its location on earth within a few meters and displays maps of its location.
- It contains a digital still and video color camera and an audio recorder.
- It contains a cell phone.
- It provides wireless connectivity to the Internet (for example, for email and for Web browsing).
- It provides wireless radio-based connectivity to other nearby Communicators.
- It has sufficient storage capacity to store a full-length movie or many thousands of still pictures, many hours of recorded audio, an address book, and lots of other data.
- It includes a clock that displays the time in the time zone you are in. This clock automatically adjusts as you move to a different time zone and is self-correcting so that it provides the time correct to the nearest .01 seconds.
- It uses voice input and voice output.
- It accurately processes handwritten input.
- It includes a built-in arithmetic, graphing, and equation-solving calculator.
- It uses a combination of fingerprint identification, voiceprint identification, and password protection to help guard against unauthorized use.
- It can be used as a “Smart Card” to store and spend electronic money and/or to make credit card and debit card purchases.

- It has a modest but useful level of capability to translate among a number of different languages, using its voice input and output.
- As an "add-on" feature, one can purchase a pair of eyeglasses that receive signals from the ICT Communicator and project images onto the user's retina, thus producing the equivalent of a large screen display.
- Another add-on feature is a hearing aid type of device that receives stereo broadcast radio signals from the ICT Communicator, and that can also act as a hearing aid if the user needs one.
- Another add-on feature is a scanner that can scan and process text and bar codes.

No new technological breakthroughs are needed to produce the Communicator described above. You can see progress toward this Communicator occurring in a number of currently available tools. For example, people now use cell phones to access the Web and take pictures. They use global positioning systems that include built-in maps. They use portable devices to carry and access music and video. They use credit cards, debit cards, and Smart Cards. They use portable scanners and portable language translators. They use voice input systems and voice output systems. They use eyeglasses that project video images onto their retinas.

Thus, it is merely a matter of time, refinement of current technology, consumer demand, and so on before such a tool enters mass production. The AI in such a tool is transparent. That is, the user expects the tool to do what the tool is designed to do and does not need much technological knowledge to use the tool. The user may have some insight into the limitations of the tool, such as its voice input and language translation systems not being perfect. However, the human-machine interface of this tool will be simple and natural to learn, so that relatively young children will easily learn to use the features that are age-appropriate to their developmental levels.

Now, think about the educational implications of the Communicator and continuing progress in AI. It is not difficult to imagine a time when every student has a Communicator, routine access to high quality interactive Intelligent Computer-Assisted Learning materials that cover all academic disciplines, and an interactive Intelligent Individual Education Plan. Every student has access to a Global Library that includes a steadily increasing number of AI-based systems that solve problems and accomplish tasks.

This is not science fiction. We live at a time in history where the Communicator, the Global Library, and the AI tools that can "just do it" are coming into existence. This is a continuing process, with significant change occurring on a year-to-year basis. A huge amount of change will occur over the time that a kindergartner progresses through elementary school, a secondary school student moves toward high school graduation, or a high school graduate moves through higher education and into the job market.

We need an education system that accommodates such change. At the current time, we do not have such an education system.

Personal Growth Activities for Chapter 8

1. You have probably heard the expression, "Viewing the world through rose-colored glasses." Try viewing the world through AI-colored glasses. Look at people, machines, organizations, and institutions in terms of their activities and goals. Think

about the idea that some people assert: What's easy for machines is hard for people, and vice versa. From your point of view, does this assertion seem to be correct?

2. What changes do you see over the past few years in the societies and education systems of our world that can be attributed to ICT? What will the world be like as machines continue to gain in machine intelligence? What will education be like as the Communicator becomes readily available to students? After a period of introspection, explore your insights with some of your colleagues and students. Think about whether humans have the knowledge and wisdom to appropriately guide the development of such a future.

Activities for Chapter 8

1. Summarize your current thoughts, feelings, and answers to the question: If a computer can solve or substantially aid in solving a type of problem that students are studying in school, what should students be learning about solving this type of problem? Develop your current answer for students at a particular grade level or in a particular course or sequence of courses. For example, you might explore this topic for third grade students, or for students taking a sequence of science courses in high school.

2 Are there topics that you feel should be eliminated from the curriculum or topics that should be added to the curriculum because of the capabilities of computers to solve problems and/or to assist in solving problems? As you discuss this question, pay particular attention to what you now know about the capabilities and limitations of AI. Be as specific as possible. You might increase your specificity by selecting a particular set of grade levels, such as upper elementary, or a particular subject area, such as social studies.

3. Summarize your current thoughts on allowing students to use a full range of ICT facilities as they take tests. Keep in mind that there are many forms of assessment. For example, suppose that students are doing an extensive project (leading to a product, presentation, and/or performance), and that they routinely make use of ICT facilities in this work. In this graded work, you might well grade a student down for not making appropriate use of the ICT facilities.

4. Select a subject area and/or a grade level in education that interests you. How will the gradual emergence of the Communicator affect curriculum, instruction, and assessment in this subject area and/or at this grade level?

5. Perhaps you have read some of Isaac Asimov's science fiction books in which he develops and explores three laws of robotics.

    1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
    2. A robot must obey orders given it by human beings except where such orders would conflict with the First Law.
    3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

    A number of Asimov books feature robots with "positronic" brains that are more capable than human brains, with the three laws wired into their brains. The robotic bodies are more capable than human bodies—and, parts can be replaced as they become worn or damaged.

What are your personal thoughts and feelings about the possibility that such robots will eventually be developed?

6. Suppose you have five minutes to tell the members of a school board what you think they should be doing as a consequence of continued rapid progress in AI and other aspects of ICT in education. What would you say?

Appendix: Project-Based Learning Activities

This appendix contains a number of Project-Based Learning activities. For the most part, they assume a middle school or higher level of cognitive maturity. All are suitable topics for teachers, and many are suitable topics for a Capstone Project or Master's Degree Project for preservice and inservice teachers. Each of the topics given below can be used as an extensive project that results in an oral report to the whole class and a written or multimedia report.

1. Our educational system places a great deal of emphasis on the linguistic and the logical/mathematics components of general intelligence (Gardner, 1993). Much less emphasis is placed on other aspects of general intelligence. Select one of the eight multiple intelligences listed by Howard Gardner, other than logical/mathematical and linguistic. Do a project that studies the types of problems that one addresses using the intelligence, the roles of AI in solving these types of problems, and the emphasis on this intelligence in our educational system.
2. Some researchers in AI work on developing machines with emotional intelligence. Researchers Cynthia Breazeal at MIT and Charles Guerin and Albert Mehrabian in Quebec have built Kismet and EMIR (Emotional Model for Intelligent Response), two systems that exhibit primitive feelings. Develop a project on the topic of emotional intelligence in people and machines. (Humanoid Robotics Group.)
3. The content taught in our schools is a balance between lower-order and higher-order knowledge and skills. Nowadays, some people argue that school should place more emphasis on lower-order skills (in a back to basics movement) while others argue that school should place increased emphasis on higher-order knowledge and skills. Indeed, some go so far as to suggest that the things that computers can do are essentially lower-order knowledge and skills, and that we should education students to work with computers rather than to compete with computers. Do a project that explores the current impact that ICT is having on the balance between the traditional lower-order and higher-order knowledge and skills in the curriculum.
4. Select a discipline (a subject area) that is in the standard school curriculum. Explore current uses of ICT (including AI) in solving problems and accomplishing tasks in this discipline. Do a project that explores these ICT and AI capabilities versus the actual integration of these topics into the current school curriculum.
5. Computer programs exist that can write stories. Do a project on the current state of the art of this application of AI. To help you get started, two references are given below.

   Innovative Art and Entertainment. Ray Kurzweil's Cybernetic Poet. Accessed 5/7/05: http://www.kurzweiltech.com. Download art generation and poetry generation software from http://www.kurzweilcyberart.com/.

   Regency Romance Generator: Computer-generated romance stories. Accessed 5/7/05: http://www-ssrl.slac.stanford.edu/~winston/baers/romriter.html.

6. Computer programs exist that "grade" written essays and other constructed responses to exam questions. Do a project on the current state of the art of this application of AI. To help you get started, two references are given below.

Rudner, Lawrence & Phill Gagne (2001). An overview of three approaches to scoring written essays by computer. *Practical Assessment, Research & Evaluation,* 7(26). Accessed 5/7/05: http://pareonline.net/getvn.asp?v=7&n=26.

Valenti, Salvatore et al (2003). An overview of current research on automated essay grading. *Journal of Information Technology Education.* Accessed 5/7/05: http://jite.org/documents/Vol2/v2p319-330-30.pdf.

7. There are many medical expert systems, but such systems have been slow to be adopted by the medical community. Both human doctors and medical expert systems can and do make mistakes, such as incorrect diagnoses and incorrect treatments. When a human doctor makes such mistakes, sometimes the patient or relatives of the patient think about suing the doctor. The use of medical expert systems creates a new legal problem. Who is responsible for an incorrect medical diagnosis and treatment that is based on the work of a heuristic-based AI system? The following two Websites provide useful starting points in exploring this topic.

Whyatt and Spiegelhalter. *Medical expert systems.* Accessed 5/7/05: http://www.computer.privateweb.at/judith/index.html

Ben-Avi. *Expert systems*. Accessed 5/7/05: http://www.ee.cooper.edu/courses/course_pages/past_courses/EE459/expert/. Quoting from this Website: "INTERNIST II …has been tested against experienced physicians in the field of internal medicine. It arrived at the correct diagnosis, first time, 83% of the time whereas experienced human physicians managed 82%. Supposing that M.D.s actually are human, the difference between a program and a human is statistically insignificant. (Incidentally, a shiny new M.D. manages about 35%, so don't get sick during September, October and so on, just after their graduation and before they have learned anything)."

8. Referring back to (7) above, think about the somewhat similar situation of teaching being done by a human teacher versus teaching being done by a Computer-Assisted Learning system or an Intelligent Computer-Assisted Learning system. One similarity is the fact that CAL and ICAL tend to meet resistance from human teachers. Another similarity is who or what should be held accountable if the student fails to learn at an expected level? Do a project based on instructional uses of AI.

9. Computer Adaptive Testing is growing in use. The following is quoted from Rudner (1998):

   > When an examinee is administered a test via the computer, the computer can update the estimate of the examinee's ability after each item and then that ability estimate can be used in the selection of subsequent items. With the right item bank and a high examinee ability variance, CAT can be much more efficient than a traditional paper-and-pencil test.
   >
   > …
   >
   > With computer adaptive tests, the examinee's ability level relative to a norm group can be iteratively estimated during the testing process and items can be selected based on the current ability estimate. Examinees can be given the items that maximize the information (within constraints) about their ability levels from the item responses. Thus, examinees will receive few items that are very easy or very hard for them. This tailored item selection can result in reduced standard errors and greater precision with only a handful of properly selected items.

   A Computer Adaptive Test incorporates some combination of algorithmic and heuristic AI to guide its selection and analysis of exam items from a database of exam questions and/or from a database of templates that it uses to generate exam questions. Do a project on the advantages, disadvantages, and current uses of Computer

Adaptive Testing. As you explore this topic, you may also want to explore computer-generated tests and computer-administered & graded tests.

10. A number of AI-based computer systems have been developed to solve or help solve math problems. These are usually called Computer Algebra Systems, although they deal with a far wider range of problems than just algebra. Do a project on the current and potential use of Computer Algebra Systems in precollege mathematics education. The following reference provides a useful starting point in exploring this topic:

    Computer algebra system. From Wikipedia, the free encyclopedia. Accessed 5/7/05 http://www.wikipedia.org/wiki/Computer_algebra_system. Quoting from this Website:

    A **computer algebra system (CAS)** is a software program that facilitates symbolic mathematics. The core functionality of a CAS is manipulation of mathematical expressions in symbolic form.

    …

    Computer algebra systems began to appear in the early 1970's, and evolved out of research into artificial intelligence (the fields are now regarded as largely separate). The first popular systems were Reduce, Derive and Macsyma which are still commercially available; a copyleft version of Macsyma called GNU Maxima is actively being maintained. The current market leaders are Maple and Mathematica; both are commonly used by research mathematicians. MuPAD is a commercial system which provides a free version (with slightly restricted user interface) for non-commercial research and educational usage.

11. One type of machine learning could be called memorize and regurgitate. For example, a dictionary can be stored in a computer. This might be combined with a document stored in a computer so that when a person reading the document double clicks on a word, a definition of the word is quickly retrieved and displayed. When people first began to think about the computer translation of foreign languages, they noted that it is easy to do translations of individual words. However, this is not the way that translation is done. A dictionary definition of a word is typically many words in length and includes a variety of meanings. A person doing a translation needs to understand the meaning of the sentence or passage to be translated. An automated dictionary approach does not suffice.

    The AI problem of translation of languages has a long history and a significant amount of progress. However, AI-produced translations still leave much to be desired. AI still has a long way to go in "understanding" the written or spoken word.

    Explore the current state of the art of computer translation of natural languages and the uses being made of such translators. (You should have little difficulty in finding Web sites that offer free computer-based translation services.) Discuss the educational implications of what you discover.

12. Do a project based on finding and analyzing examples of CAL and ICAL in which student learning outcomes are approximately equal to or are better than can be achieved by the student working with an individual tutor. In your analysis, look for patterns or characteristics of general tutoring situations in which a human tutor can far out perform current CAL and ICA, and vice versa.

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