A Faculty Member's Guide to Computers in Higher Education

Dave Moursund

University of Oregon

Eugene, Oregon

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About Dave Moursund

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

- Doctorate in mathematics (specializing in numerical analysis) from the University of Wisconsin-Madison
- Instructor, Department of Mathematics, University of Wisconsin-Madison
- Assistant Professor and then Associate Professor, Department of Mathematics and Computing Center (School of Engineering), Michigan State University
- Associate Professor, Department of Mathematics and Computing Center, University of Oregon
- Associate and then Full Professor, Department of Computer Science, University of Oregon
- Served six years as the first Head of the Computer Science Department at the University of Oregon, 1969-1975
- Full Professor in the College of Education at the University of Oregon for more than 20 years
- In 1974, started the publication that eventually became *Learning and Leading with Technology*, the flagship publication of the International Society for Technology in Education (ISTE)
- In 1979, founded the International Society for Technology in Education. Headed this organization for 19 years
- Author or coauthor of about 40 books and several hundred articles in the field of computers in education
- Presented about 200 workshops in the field of computers in education
- Served as a major professor for about 50 doctoral students (six in math, the rest in education). Served on the doctoral committees of about 25 other students
- Founding member of the Math Learning Center (MLC). Served on the MLC Board of Directors since its inception in 1976, and chaired the board for several years
- For more information about Dave Moursund and for free online access to 20 of his books and a number of articles, visit http://uoregon.edu/~moursund/dave/

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University of Oregon

Eugene, Oregon

Email: moursund@uoregon.edu

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

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Brief Summary

"Fortune favors the prepared mind." (Louis Pasteur)

The unifying goal of this book is to help improve college and university education. The primary audience is people who teach college and university courses. This includes guest lecturers, graduate assistants, adjuncts, tenure-track faculty, tenured faculty, researchers who teach an occasional course, and others. When I say "you" in this book, I mean a person interested in and involved in improving the education of college students.

Two major aspects of computers in education are discussed in this book. The primary focus is on Information and Communication Technology (ICT). Note that this is often called Information Technology (IT), but that term fails to capture the importance of the communication aspect of the computer technology field.

The secondary focus is on Computer and Information Science (CIS). CIS is a relatively new academic discipline, with its own collected body of knowledge and achievement. It also provides an important way of thinking, called computational thinking. This refers to human intelligence working together with computer capabilities (including artificial intelligence) to solve problems and accomplish tasks.

ICT can be thought of as the technological applications that come out of the theoretical foundations provided by CIS. ICT and CIS both contribute to the content of each academic discipline and to teaching and learning processes.

At the current time, our system of higher education is struggling to develop and integrate appropriate and effective uses of ICT and CIS. This is proving to be a challenge to every person involved in teaching or helping to teach college students. This book will help you to understand some of the problems and potentials of ICT and CIS. It suggests a number of things you can personally do to help to address these problems and achieve these potentials.

Contents

Introduction

> "Do not fear going forward slowly; fear only to stand still." (Chinese proverb)
>
> "Before you become too entranced with gorgeous gadgets and mesmerizing video displays, let me remind you that information is not knowledge, knowledge is not wisdom, and wisdom is not foresight. Each grows out of the other, and we need them all." (Arthur C. Clarke)

This book has one major goal: To help improve the quality of education that students in postsecondary education are receiving. The book focuses specifically on possible roles of computer technology and computer science in accomplishing this goal.

Essentially all faculty in higher education now have a significant amount of experience in using computer technology for email, searching the Web, and word processing. This is the prerequisite computer knowledge and experience assumed throughout the book.

Advancing the Story

I have written many academic books. When I am writing an academic book, I am telling a story. My stories are based on my life experiences, knowledge, and skills. However, they also draw heavily on the current research and practitioner literature. In addition, I talk to people in my intended audience, both to gain new ideas and to try out the ideas I am developing.

This book can be thought of as a story about current practices in higher education. The story line is both simple and quite complex. Educational researchers and practitioners know a great deal about curriculum development, teaching, learning, and assessment; but they are faced by the challenge of computers. The story line is an exploration of how computers affect curriculum content, teaching processes, learning and learning processes, and assessment.

The history of schools and formal education is more than 5,000 years long. The history of higher education is shorter, but higher education is still a very old, large discipline. Thus, in writing this book, I have had to restrict myself to a very modest number of topics, and I have had to treat each topic in a somewhat shallow manner.

As you read the book, from time to time you will likely wonder how a particular topic helps to advance the story. I think of the writing process as a combination of talking to myself and talking to potential readers. When I am talking or writing to myself, I interpret what I have written in terms of what I already know. When I am talking or writing to other people, I attempt to guess what they already know and thus to talk or write so that they will understand what I am saying. Sometimes a reader will say "right on." However, at other times the same reader will say "I don't understand what you are trying to say."

From my personal point of view, each topic in this book—and the treatment of the topic—follows the story line and advances the story. However, it is up to you, the reader, to construct knowledge and understanding from what I have written. When you come to parts of the story that seem to deviate from your understanding and point of view, do not despair. Do a mental rewrite of these parts to meet your needs, and move on. The overall story being presented does not depend on you and I agreeing on all of the fine details.

Humans and Machines

Each of us has become what we are through a combination of nature (genetics) and nurture (formal and informal education and experiences; damage from diseases, drugs, and accidents; and other factors). Our formal precollege and higher educational systems have a huge affect to our cognitive development and capabilities.

We have thousands of years of ongoing experience and research in effective methods for teaching and learning. Now we have computers, providing us both with a variety of new aids to the teaching and learning processes and with new topics to be learned. Here is a challenging question I like to ask people:

> In terms of helping to implement improvements in the teaching and learning process, what is it that computers and computerized machines can do better than human teachers? Here, the term *better* might mean better as measured by potential cost effectiveness, or it might mean better in an absolute sense.

The above question underlies much of the content of the book. Our formal educational systems create an ongoing problem of for us: How can we provide the best education with the resources that are available? The relevance of computer technology and its continuing rapid decrease in price-to-performance ratio creates an ongoing set of challenges and opportunities.

Changing Millions of People

At the current time in the United States, there are about 18 million students taking undergraduate and graduate courses in higher education. The intended audience for this book includes part-time and full-time faculty members, graduate teaching assistants, postdoctoral students, and others who are involved in teaching these 18 million students. This is a large audience—more than 2 million faculty members (NCES, n.d.).

Wow! How can one possibly make an appreciable change in the activities of 2 million full- and part-time faculty members and their 18 million full- and part-time students? All kinds of approaches have been tried in the past, such as increasing the academic requirements to teach in higher education, conducting research in teaching and learning, changing the curriculum and books, and using overhead projectors, slide projectors, movies, and television as aids to instructional delivery.

These approaches to improving higher education have brought us to where we are now—which does not represent a significant improvement over where we were a decade or two ago. Indeed, there are signs that the quality of education that students in the U.S. are receiving may be declining. Certainly the U.S. is no longer number one in the world in higher education, a position it held for many years.

Now we have the Internet and the Web, along with computers. We have distance education and computer-assisted learning. We have computer use integrated into the content of many different academic disciplines. Will these technologies make an appreciable contribution to improving higher education?

This book explores three important answers to this question:

1. Computers can aid in improving teaching and learning processes. They are a powerful aid to translating research in teaching and learning into practice.
2. Computers can aid in the design and representation of the content to be learned so that it is more compatible with human abilities to learn and make use of that learning. We can place more emphasis on students learning to work effectively with computer technology rather than learning to compete with computer technology.
3. Computers can aid in doing research on ways to improve education.

Interface Design

In this section, I will briefly explore some of the parallels between the design of manufactured products and the design of courses. There is a lot known about the effective design of user interfaces in manufactured products, and there is a lot known about the design of effective courses—their content, instruction, assessment, and learning outcomes. Computer technology is having a significant impact on user interfaces both in manufactured products and in courses.

Before proceeding, spend a little time thinking about the similarities and differences in manufactured products and courses. What would constitute an improvement in the interface between a course and students taking the course? We are used to reading annual reports of prizes being given for good quality in the design of manufactured products. We are also used to awards being given to faculty for their outstanding teaching. What would a prize-winning course look like in terms of its design characteristics and interface with students?

Is it possible that one can think of a prize-winning course independently of its teacher? In terms of manufactured products, the end user tends to use the product independently of the designer, manufacturer, or seller. A good product can be mass-produced and distributed to users throughout a nation or the world. Historically, a good human teacher has always been a major component of a good course. It is extremely difficult to mass-produce good teachers!

Manufactured Products

Here is a brief quote from the preface of Donald Norman's (1989) book, *The Design of Everyday Things:*

> We are surrounded by a large number of manufactured items, most intended to make our lives easier and more pleasant. In the office, we have computers, copying machines, telephone systems, voice mail, and fax machines. In the home, we have television sets, VCRs, automated kitchen appliances, answering machines, and home computers.
>
> All these wonderful devices are supposed to help us save time and produce faster, superior results. However, wait a minute—if these new devices are so wonderful, why do we have special dedicated staff members to make them work—"power users" or "key operators"? Why do we need manuals or special instructions to use the typical business telephone? Why do so many features go unused? And why do these devices add to the stresses of life rather than reduce them?

In his book, Norman helps us to understand and explore several questions:

- Why can't "they" design and build products that I can easily learn to use and use?
- Why is modern technology so frustrating and so user-unfriendly?

- Don't "they" know that I am going to forget some of the details if I don't use the products every day and that from time to time I am going to make mistakes?

In these questions, "they" are the companies and people who are designing, developing, manufacturing, selling, and servicing the manufactured products. If you are like the vast majority of people living in our society, you probably agree with the sentiments represented by these questions. Personally, I am often angry at and frustrated by the technology I routinely try to use.

In thinking about what Donald Norman has to say about manufactured products, it occurred to me to ask the same types of questions about courses. The next few subsections capture some of the ideas I considered when I thought about the parallels between manufactured products and courses.

Instructional Design

As faculty, we are quite comfortable designing courses or pieces of courses. We routinely design and implement "today's lecture" or "today's class." In some cases, a course or a class meeting is captured on video and made available for broad distribution. For the most part, however, a class meeting is a one-of-a-kind performance. Unless you are teaching multiple sections of the same course, it will likely be a term or several terms before you get the opportunity to refine the design and presentation.

Contrast this design and implementation activity with that for a manufactured product. There are two major differences:

1. In the product design process, a great deal of effort goes into designing, developing prototypes, testing, and redesigning. Much of this work is done by or led by people who are design experts.
2. Even after this substantial design effort, it typically takes a number of cycles of production, use, redesign, and production to "get it right." The literature I have read suggests that it takes five or six cycles.

The discipline of course design fully recognizes the difficulties in doing a good job in course design. As Mahnaz Moallem (2001) notes:

> Instructional design is the systematic development of instructional specifications using learning and instructional theory to ensure the quality of instruction. It is the entire process of analysis of learning needs and goals and the development of an instructional system that meets those needs. It includes development of instructional materials and activities, trial and evaluation of all instruction and learner activities. Instructional design process has the ambition to provide a link between learning theories (how humans learn) and the practice of building instructional systems (an arrangement of resources and procedures to promote learning).

Notice the emphasis on drawing upon learning and instructional theory. The science of teaching and learning is a large, complex, and growing discipline. It takes considerable effort over an extended period to develop a high level of expertise in this discipline.

Also, notice the mention of needs assessment. One of the difficulties in designing instructional systems is that the needs of individual students vary considerably. One of the characteristics of computer-assisted learning is that such materials often provide for a significant amount of individualization of instruction.

This brief discussion about instructional design is intended to make you feel a little bit uneasy. ICT makes it possible for the design and implementation of a course to be somewhat like the design and production of a manufactured product. The computerization of a course or pieces of a course makes it possible to repeatedly using the "test, revise" cycle and makes wide-scale distribution possible. Computer-assisted learning makes it possible to somewhat individualize a course of instruction.

Accumulated Knowledge of the Human Race

The accumulated knowledge of the human race is huge and is growing quite rapidly. If we look back far enough in history, there was a time when a scholar could be at the frontiers of many different disciplines. For example, Gottfried Wilhelm Leibniz (1646-1716) co-invented calculus (along with Isaac Newton) and made original contributions to many different areas of math, science, and philosophy. As stated in an NSF (1998) symposium report:

> Since Leibniz, there has perhaps been no man who has had a full command of all the intellectual activity of his day. Since that time, science has been increasingly the task of specialists, in fields which show a tendency to grow progressively narrower.

We now divide the accumulated knowledge of the human race into a large number of different disciplines. Our higher education system is divided into departments and programs of study. A faculty member in a department is required to have a high level of expertise in the discipline or disciplines of the department and its programs of study. It typically takes years of formal study and/or on-the-job experience to gain the prerequisite level of content knowledge and experience.

The division of accumulated knowledge into disciplines has served many faculty members and researchers quite well. However, one can argue that this is not the case in terms of serving many of our students. The typical real-world problem is interdisciplinary, and it does not occur in the rather pure, sterile setting of a discipline-specific or subdiscipline-specific course. Many students learn relatively little of lasting value through the courses they take. They are unable to transfer the college course-based education to the types of problems they encounter outside of the course setting. This may be especially true of students who are taking courses to meet requirements and have only modest interest in the content of specific courses or the disciplines that contain the courses.

A person learns to use a manufactured product to help solve some problem, accomplish some task, or fulfill some personal need. If appropriately designed, the product is relatively easy to learn how to use, relatively easy to use, and relatively easy to relearn how to use in the future.

I wonder to what extent these statements hold true for the courses I have taught. Think about this to the extent that it is applicable in your teaching.

The Web

The Web is a tool—a new type of library. This tool affects students and faculty in every discipline.

The Web is different from other tools we routinely use. One of the Web's characteristics is that many tens of millions of people are contributing to this library, so it is steadily growing. Much of the material being added to the Web is not refereed or screened by publishers.

Another characteristic is that significant portions of the contents of this library change over a short time. For example, consider the contents of an airline reservations system or a hotel reservation system. The availability and costs of flights and rooms are easily accessible via the Web. This information changes from second to second as reservations are made and cancelled.

Another characteristic of this virtual library is that it easily handles interactive multimedia. It facilitates the storage and use of nonlinear interactive documents containing text, audio, video, graphs, charts, drawings, pictures, color, and more.

A very important characteristic of the Web is that has the ability to automatically solve certain types of problems and accomplish certain types of tasks. One way to think about this is that, in essence, there is not much difference between running a piece of software that resides on your computer and running a piece of software that resides on a server. If the server and its software are accessible via the Internet, then use of the software can be built into a website. (Of course, there is the problem of who pays for the software and use of the software, but that is not the issue here. Lots of the free content is available on the Web, but many sites charge for using the content.)

This multimedia, nonlinear, interactive, problem-solving, task-accomplishing, constantly changing Web is slowly gaining in intelligence, and the user interfaces are being improved. The Web is a marvelous aid to teaching and learning and is a major challenge for both faculty members and students. We will return to this topic at other places in the book. However, as a teacher you might want to ask:

1. How do I work effectively with students who want to write and publish their homework as interactive, multimedia documents? How do I effectively read and grade such documents?
2. How do I design, develop, and make available aids for students taking my classes? Am I expected to develop multimedia, interactive "handouts" that communicate effectively? If I don't have all students reading the exact same book or articles, how can I tell if they are reading appropriate materials and learning appropriate things?
3. If the Web (or readily available software) can solve a problem or accomplish a task that I usually have my students learn to do by hand, how should I modify my curriculum content and assessment processes?
4. How do I compete with or participate in the trend toward making pieces of courses or entire courses available on the Web? Part of this movement includes making such materials available without charge (eSchool News, 2007). Will this free-courseware movement cause me to lose my job?

In brief, the Web is a technological tool, and it shares many characteristics with manufactured products. The interfaces between the Web and people using the Web are designed and implemented by people, much in the same manner that people design and implement interfaces with manufactured products. This creates threats and opportunities for individual faculty members, departments, and entire institutions of higher education.

Education and Training

We are used to the idea of having technical schools and technical courses that focus quite strongly on particular tools or groups of tools. Thus, for example, a student might take a course of study to learn to repair cars, to be a plumber, or to be a chef. Such programs of study can be thought of as the modern replacement for apprenticeships. These courses of study include both general education (for example, a focus on reading, writing, speaking, listening, and doing math) and specific training on the tools and problem solving within a specific trade.

ICT and its underlying CIS bring powerful tools into every academic discipline. Thus, all postsecondary programs of study are faced by the challenge of appropriate training and education in the use of these tools.

It turns out that this is a major challenge. An elementary school student can learn to use the Web. First, the child receives some training in the mechanics of using the Web. With a little practice, the child can then retrieve information by keying in a Web address the teacher supplies. With a little more training, the child can key one or more search terms into a search engine and perhaps get many thousands of hits.

It is here that one sees the difference between a novice who has had a little training and an expert who has had both a lot of training and a lot of related education, each of which was built upon a high level of cognitive development. Think about the Web-oriented information retrieval knowledge and skills of this child versus those of a well-prepared adult research librarian. The research librarian has much greater breadth and depth of training in the use of the Web as well as a broader general education and a higher level of cognitive development.

Now, translate this into one of the possible goals in any course that you might teach. Your students could be gaining an increased level of training and an increased level of education in being effective at using the Web and other libraries to retrieve information about the course and discipline you are teaching. From my point of view, all faculty members have a duty to help their students increase their course-specific and discipline-specific information retrieval knowledge and skills.

Summary of Interface Designs

This section on interfaces started with a discussion of interface design for manufactured products. It then expanded into a discussion of interface design for courses, drawing a parallel between manufactured products and courses. This led to a discussion of the rapidly growing totality of accumulated knowledge available on the Web, the world's largest library.

Every course makes use of and draws upon tools. Tools incorporate or embody knowledge. Tools that are partially or highly automated contain or embody knowledge in an "I, the tool, can do it for you" mode. While we are used to this idea when using some relatively complex tools such as an automobile, we tend to think less carefully about it in terms of computer tools that can solve some of the problems and accomplish some of the tasks that we have previously taught students how to do by hand.

Examples of this "knowledgeable" tool exist in every course, but certainly more so in some courses than others. Thus, for example, a statistics course can be taught in a math or statistics department and be highly theoretical. Alternatively, it might be taught in some other department and focus mainly on preparing students to use statistical software packages available on computers. The former course may include relatively little training, and the latter course may include considerable training in how to use the computer software. Both courses may include considerable emphasis on when various statistical processes are applicable, what types of problems they address, and how one understands and uses the results of applying the statistical processes.

The point is, computer technology provides tools that aid the human brain. Teachers in every discipline need to consider what they want their students to learn about use of these tools. What aspects of the content of a course lend themselves to the types of brain and mind aids that computer technology can provide? The design of the tools and the teaching accompanying the tools thus become important in each academic discipline. The computer field provides a steady stream of increasingly powerful brain tools.

The Spellings Report on Higher Education

The September 27, 2006, report of the U.S Secretary of Education's Commission on the Future of Higher Education contains considerable criticism of our current higher education system and includes a number of recommendations for improving this system (Spellings Report, 2006). The report suggests that higher education needs to do some thinking outside the box to seek out new paradigms and to act in a more entrepreneurial manner.

As a faculty member, you are aware that private, for-profit colleges and universities are beginning to attract a significant number of students. Perhaps you teach in such an institution. You are aware that many colleges and universities offer courses and programs of study via the Web and target many students similar to those served at your institution. You are aware that highly interactive, computer-assisted learning materials have been designed to compete with traditional methods of instruction.

The point being made is that computer technology is contributing to making education into a consumer industry. A unit of study, a course, a program of study, or a degree program can be thought of as a consumer product. That is part of what the Spellings Report acknowledges when it recommends that higher education be more entrepreneurial. Thus, whether or not you like it, you and your institution are engaged in a competitive business. Computer technology is helping make this an increasingly competitive business.

Teacher Roles in an Entrepreneurial Teaching Environment

The chances are that you have accepted some of this entrepreneurial thinking for a long time. For example, do your courses have reading requirements from books and other resources that your students must pay for? Developing and selling these materials is an entrepreneurial activity. You may have few qualms about requiring your students to base a significant part of the learning in your courses upon commercially produced books.

What other materials do your students use as they take a course from you? For example, do you have your students listen to television broadcasts, radio broadcasts, and Webcasts of various people, including other faculty from throughout the world? If so, you have accepted the idea that it is okay if other people actually present part of the content of your course.

Where does this line of questioning end? Suppose that you routinely have your students use computer-assisted learning materials available on the Web, distance learning modules, or courses available from other institutions of higher education or from various companies. Suppose that you use assessment materials available from textbook publishers or others. What is it that makes a course "your course"?

Cottage Industry

These types of questions help me to understand why the Spellings Report questions many of the current practices in higher education. Historically, higher education was a sort of cottage industry. Now, it is facing severe competition both from within traditional forms of higher education and from for-profit and not-for-profit organizations that are competing with traditional higher education. The local monopolies of cottage-industry types of traditional higher education institutions are facing severe challenges.

These challenges are exacerbated by steady progress in computer technology and computer science. The challenges reach into each institution of higher education and continue down into individual programs of study and into the courses you teach.

One chapter of this book discusses human intelligence and artificial intelligence. The challenge of artificial intelligence affects each student. Computers are getting "smarter." They perform or help perform many tasks that used to be done by a person—perhaps a person with quite a bit of training and education. Students want an education that gives them knowledge, skills, insights, and expertise that computers do not have. They do not want to prepare for a career that will likely disappear in the next decade or two due to progress in artificial intelligence.

You may feel the same way about your current job as a teacher. What can you do that a machine cannot do? What aspects of teaching will be greatly changed by continued progress in artificial intelligence and other aspects of ICT?

As a teacher, one way to think about this situation is to consider which components of your course can be put into an interactive, artificially intelligent, computer-assisted learning Website that is available for students to use at a time and place of their own choosing.

Let me give a specific example. It is clear that all students need to develop knowledge and skill in using the Web and other electronic resources to retrieve information. While students gain some of this knowledge and skill before entering college, information retrieval is a deep, complex discipline. I am envious of the knowledge and skills of a well-prepared research librarian. Many colleges and universities offer freshman-level and higher-level courses in library research knowledge and skills. Part of the content of such a course is likely to focus on the local resources of the institution, while the greater part probably focuses on information relevant to students at all institutions of higher education.

This is an ideal situation for an entrepreneurial approach. One institution of higher education or a company developing a superb computer-assisted learning unit of study might be sold or made available free throughout the country. Making a product available free might be a good way to advertise an institution or lead potential customers to other, related products that are not free. The Ohio State University Libraries has developed a set of materials that it makes available free on the Web (Ohio State University, n.d.). Perhaps eventually such a set of materials will become a part of a course you teach.

Final Remarks

This book explores some threats and opportunities that computer technology and computer science presents to teaching and learning. As you read this book and reflect about the content, you will come to understand how some of these threats and opportunities apply specifically to you. You might also consider what you might want to do about them.

I hope that in responding to these threats and opportunities you will make decisions that lead to your students getting a better education. This may well require you to make significant changes in the way you do things.

I believe that "no pain, no gain" is an appropriate description of feasible changes to our current educational system. It is not easy to make significant changes to the content of the courses one teaches, the methods one uses in teaching, and the assessments one uses to measure progress. It is not easy for students to adjust to changes in learning expectations, teaching processes, learning processes, and assessment processes. This book addresses these issues from the point of view of someone deeply interested in the use of computers in education.

Part 1: Education

"It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change." (Charles Darwin)

"Simple things should be simple. Complex things should be possible." Alan Kay

The Spellings Report (2006) mentioned in the introduction to this book contains considerable criticism of our current system of higher education and includes a number of recommendations for improving the system.

This book explores various aspects of teaching and learning at the postsecondary level. It emphasizes the potential of computer technology and computer science to improve education. Part 1 contains four chapters about several general aspects of education and educational change.

Chapter 1 introduces the idea of improving education through appropriate use of computers and other approaches. It explores the question of what it means to "improve" education. A substantial portion of the book looks at a wide range of research-based approaches to improving education and at the roles of computer technology in implementing research-based approaches.

Chapter 2 discusses limitations of our current precollege and lower-division college educational systems. Evidence suggests that if we keep doing what we have been doing and make only minor modifications to the current system, we will only produce the same results that we have been producing for the past few decades. If we want to improve education, we will need to implement substantial changes—we will need to identify and implement appropriate paradigm shifts.

Chapter 3 discusses technological change. The pace of technological change is becoming increasingly fast. The educational challenges of such change are immense.

Chapter 4 discusses threats and opportunities brought on by computer technology and computer science in postsecondary education.

Chapter 1
The Big Picture

"The mind is not a vessel to be filled but a fire to be kindled." (Plutarch)

"A great teacher makes hard things easy." (Ralph Waldo Emerson)

Our higher education system has considerable room for improvement. College and university faculty often argue that if our precollege education system were a lot better, then higher education would be a lot better. While that is undoubtedly correct, it does not relieve our higher education institutions from working to improve what they are doing.

This book is mainly aimed at people who teach in higher education. It specifically addresses some of the things they can do to make higher education better. Some of my other books address precollege education, which many teachers and educational administrators are also working to improve.

The general thesis in this book is that using computer technology appropriately and integrating it into the higher education curriculum will significantly improve postsecondary education.

In order to talk about improving education, we need to establish some agreed upon goals of education, and we need ways to measure how well those goals are being achieved. Of course, this simple observation could easily stop us in our tracks. People who think about education tend to come up with their own list of educational goals. They are apt to have their own ideas about how well the goals they feel are important are actually being met. Finally, these people are apt to have their own beliefs about how to improve education.

In this book, I am trying hard not to get us bogged down in this "definition of improvement" quagmire. Those who teach in higher education are in a position to work individually and collectively to improve the quality of education their students obtain.

There is a lot of data available on the Web about the current conditions of education at the precollege and college levels. Some of the collected data provides insights into what educators consider important aspects and goals of our educational system (IES, 2006).

Some General Goals of Education

Here is a short list of widely accepted general goals of education:

1. **Acquisition and retention of basic, important knowledge and skills.** There is considerable agreement that reading, writing, arithmetic, speaking, listening, information retrieval, and use of retrieved information are basic and important skills that all students should have.
2. **Understanding of one's acquired knowledge and skills.** *Understanding* tends to be difficult to define and measure. However, there is considerable

agreement nowadays that education must proceed far beyond rote memorization. The Web and other online information retrieval systems have strengthened this consensus, since they provide an alternative to memorization.

3. **Active use of one's acquired knowledge and skills.** This includes being able to transfer one's learning to new settings and being able to analyze and solve novel problems. We expect our educational system to:
    a. Provide challenging and rigorous programs of study designed to help each student become a literate, responsible, creative, and productive adult citizen.
    b. Help all students learn to learn, learn to take responsibility for their own learning, understand their capabilities and limitations as learners, and develop intrinsic (internal, self) motivation, drive, and habits that promote lifelong learning.
    c. Help all students learn to help others learn. In considering this, it is helpful to think of each student as a teacher. For example, children often help each other and their siblings to learn. A parent is a teacher to his or her children, and a worker is often a teacher to his or her coworkers. Of course, each person also teaches himself or herself.
    d. Help all students learn to cope with technological, social, and other forms of change that will occur during their lifetimes.

We want students to learn to use their education to solve problems, accomplish tasks, and deal with novel situations. We want students to have an education that helps them become responsible, productive adults. We want these adults to be lifelong learners who cope with change and who help others to learn. Computers are a powerful change agent in these areas and have already facilitated significant changes in the world of learning and education.

These general goals do not speak to values-based goals or goals such as preserving and passing on the culture of a family or community. Moreover, considerable detail is left out. For example, being a "responsible adult" might include understanding and supporting environmental sustainability. In summary, many specific and important goals of education are not included in the short list, but the goals in the list are nevertheless widely supported and provide a good starting point for discussing potential improvements in higher education.

Vocabulary: ICT, CIS, and Computational Thinking

As noted in the introduction, this book explores two aspects of computers in education:

- Information and Communication Technology (ICT). Many people use the shorter name Information Technology (IT) to represent this aspect of the computer field.
- Computer and Information Science (CIS). Many people use the shorter name Computer Science (CS) to represent this discipline.

ICT focuses on the technology-related consumer products and services that have come from progress in computer science. Prominent products include cell telephones, global positioning systems, computer games, CD and DVD digital storage media, digital still and video cameras, portable music and video storage and playback devices, magnetic disk and flash drive storage technology, substantial improvements in connectivity, the Internet, and the Web. Nowadays it is common to combine a number of these pieces of technology into one device, such as a cell telephone that includes built-in games, a digital video camera, audio and video storage and playback capabilities, and so on.

Operating these widely used ICT devices tends to require relatively little formal schooling. A typical user gains considerable value and satisfaction from such devices through self-instruction, informal instruction from acquaintances, and (usually as a last resort) reading the manual.

This approach to learning has significant educational implications. The global positioning system (GPS) provides an excellent example. Think about what constitutes a good education for a surveyor, geographer, or navigator now compared to the education needed before computers, electronic map databases, and GPSs were available.

CIS is the study of the underlying theory (science and engineering) from which many ICT products and services have sprung. According to Wikipedia, CIS is:

> the study of the theoretical foundations of information and computation and their implementation and application in computer systems. Computer science has many sub-fields; some emphasize the computation of specific results (such as computer graphics), while others (such as computational complexity theory) relate to properties of computational problems. Still others focus on the challenges in implementing computations. For example, programming language theory studies approaches to describing computations, while computer programming applies specific programming languages to solve specific computational problems.

In other words, CIS is far more than just computer programming, but computer programming remains an important aspect of the discipline.

Because computer programming was such an important component of CIS as the discipline was first developing, the ideas of procedures and procedural thinking arose as key components of study in the discipline. Computer scientists are interested in procedures that can be carried out by a computer system. Such procedures may be algorithmic, heuristic, or a combination of the two.

- An algorithmic procedure is a finite set of instructions that has be proven to solve a specified type of problem or accomplish a specified task in a finite number of steps.
- A heuristic procedure is a finite set of instructions that is designed to solve or help solve to solve a specified type of problem or accomplish a specified task, but is not proven to always accomplish its aim.
- More recently, the expression *computational thinking* has come into widespread use as a broadening of procedural thinking. The term computational thinking is now being used to describe people and computers working together to solve problems and accomplish tasks. As Jeannette Wing (2006), a highly respected computer scientist, says:

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

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

Teachers and their students need to pay particular attention to the two questions:

- What can humans do better than computers?
- What can computers do better than humans?

Answers to these two questions vary from discipline to discipline and from course to course.

Here is a quote from Ian Foster (2006), director of the Computation Institute at the University of Chicago and Argonne National Laboratory, supporting the importance of computational thinking and CIS:

> A more sophisticated narrative says that science is increasingly about information: its collection, organization and transformation. And if we view computer science as "the systematic study of algorithmic processes that describe and transform information," then computing underpins science in a far more fundamental way. One can argue, as has George Djorgovski, that *"applied computer science is now playing the role which mathematics did from the seventeenth through the twentieth centuries: providing an orderly, formal framework and exploratory apparatus for other sciences."* [Italics added for emphasis]

The italicized statement by George Djorgovski suggests that we might be at the beginning of a profound change in math education. The change involves moving from having a lot of educational time and effort placed on math and math thinking to having some or a lot of this time spent on CIS and computational thinking. I believe that we are seeing signs of this in higher education, but there is not much evidence of this occurring in precollege education.

Computational thinking is applicable in every discipline of study. Computational thinking involves people and computers working together to solve problems and accomplish tasks. Computational thinking includes the design and implementation of models and simulations that take advantage of the power of computer systems. The specific problem being studied might be weather forecasting, global warming, protein folding, or an investigation of how to help students learn better and faster.

Studying the problem of how to help students learn better includes the development of models of student knowledge structures, teaching processes, learning processes, assessment processes, and so on. Faculty have been doing this without the use of computers for thousands of years. As in all academic disciplines, computers are providing new tools and new insights that help solve the problems and accomplish the tasks of the discipline.

The definition of computational thinking stresses that both human and machine intelligence are being used, each contributing what it can to solve a specific type of problem or accomplish a specific type of task. Chapter 8 explores human and machine intelligence.

Academic Disciplines

The totality of human knowledge is huge and steadily growing. No person can begin to master the many disciplines of study available in a comprehensive college or university. Thus, colleges and universities are divided into departments, and professional schools and colleges. Faculty members with doctorates or the equivalent level of formal education and experience are usually narrow specialists within a specific area. This might be within one discipline or it might be in an intersection of two of more disciplines. The latter situation is illustrated by faculty members with specializations in areas such as physical chemistry or molecular biology.

Each academic discipline can be defined by a combination of several general things:

- The types of problems, tasks, and activities it addresses.
- Its accumulated accomplishments, such as its results, achievements, products, performances, scope, power, uses, impact on the societies of the world, and so on.
- Its history, culture, and language (including notation and special vocabulary).
- Its methods of teaching, learning, assessment, and thinking, and what it does to preserve and sustain its work and pass it on to future generations.
- Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, and recording and sharing accumulated results.
- The knowledge and skills that separate and distinguish among (a) a novice, (b) a person who has a personally useful level of competence, (c) a reasonably competent person, (d) an expert, and (e) a world-class expert. Each discipline has its own ideas as to what constitutes a high level of expertise within the discipline and its subdisciplines.

The disciplines that one studies at a college or university tend to be well established, with considerable breadth and depth of accumulated accomplishments. Students taking a course in a particular discipline can be learning various aspects of the discipline. For example, students can learn what the overall discipline is about, some of its major achievements, what distinguishes the discipline from other disciplines, some of the modes of thought in the discipline, some of the current challenging areas and unsolved problems in the discipline, and so forth. Students can witness the passion of the teacher for the discipline, and they can begin to build their own interest and passion for the discipline.

Figure 1-1 provides a useful way for a teacher to think about the last item in the bulleted list above: expertise.

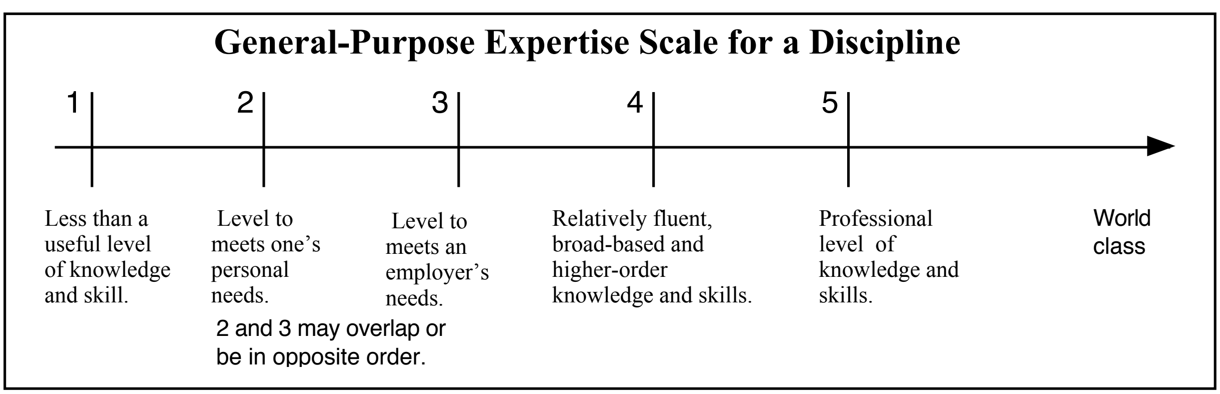

Figure 1-1. Expertise scale in a specific topic or area.

The top end of an expertise scale is open ended, with the potential that one may be "world class" or "best in the world" in a particular discipline or narrow part of a discipline.

Each discipline has multiple aspects or areas in which one can gain a very high level of expertise. When you are teaching a course, you are helping your students increase their levels of expertise in various aspects of one or more disciplines. Your own levels of expertise in various aspects of a discipline will influence the content of the courses you teach. Suppose, for example, that you are teaching an introductory course in art. If you have a high level of interest and knowledge in art history, you are apt to include quite a bit of art history in your course, regardless of the overall stated goals of the course.

Here is an important idea to think about. Suppose that you are teaching a beginning course in a department that is based on discipline X. For example, X might be math, history, or sociology. At the beginning of the course, what kinds of answers do you think you would get if you asked your students: "What is X, and what does it mean to know some X?" What kinds of answers might you get at the end of the course?

I have talked to a lot of students and faculty about this type of question. My feeling is that students often have little understanding of the overall discipline they are studying or the methods of knowing the discipline. They have some general knowledge about how to study, but they do not have in-depth knowledge about how to study and learn a specific discipline. They know how to read, but they are not skilled in reading in the various content areas. They know how to retrieve information from the Web, but they are not skilled in retrieving information in the deeper aspects of specific disciplines.

The point is that there are many different aspects to a discipline. The specific content of a course often represents a quite limited view of a discipline that underlies the course. Moreover, the content of even a first college course in a discipline may vary considerably from teacher to teacher.

Pedagogical Content Knowledge

Each discipline develops methods of teaching, learning, and assessment that are specific to the needs of the discipline. In a formal education setting, each discipline faces the challenge of developing course content for the curriculum, preparing faculty, and carrying out the other activities that help preserve and pass on the discipline from one generation to the next.

The faculty members within a specific discipline tend to teach in the same manner that they were taught. Since most faculty members were quite successful in learning the content of their discipline in their postsecondary education, they have a propensity to teach in a manner that worked well for them in their learning.

There are some obvious difficulties with this. For example, I was a very good math student, and I quickly got into math courses being taught by highly successful research mathematicians. They had a passion for math and for math research. They role-modeled being research mathematicians. In some sense, they viewed students such as me as part of the future of the discipline, and they prepared me to carry on the high-level research work of the discipline.

What happens when a person such as me is then asked to teach freshman courses populated mainly by students who are taking the courses because they are required to and who do not intend to take courses beyond the minimal requirements? These students tend to have difficulties with me as I teach the way I was taught. I have difficulties with them because they tend to not have the math interests, previous preparation, and math giftedness that I had. In retrospect, as I was learning to teach math I undoubtedly contributed to the "I hate math" and the "I can't do math" syndromes that so many students develop.

Postsecondary teachers in each discipline face this teaching challenge. Some have a high level of giftedness in being a teacher. Through study and practice, they learn to become good teachers for whatever level of students they are teaching. Notice the "study and practice" in the previous sentence. Over the years, there has been a considerable accumulation of research on good teaching, both in general and within each specific discipline.

There are, of course, teaching methods and learning methods that cut across all disciplines. However, there are huge differences among the various disciplines on how to teach effectively and how to learn effectively. Pedagogical content knowledge (PCK) is a very important and fairly recent idea deriving from Lee Shulman's work published in 1987 (Enfield, n.d.). In brief, PCK is defined as knowledge on how to teach a specific discipline effectively. Figure 1-2 illustrates that PCK lies between the content knowledge of a specific discipline and general pedagogy that cuts across many or all disinclines.

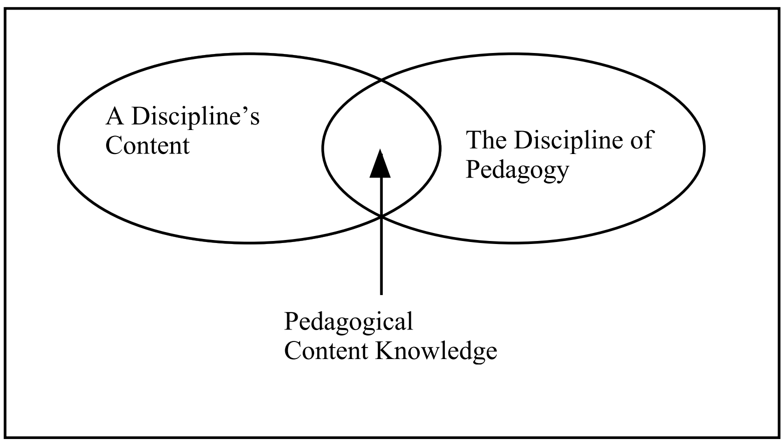

Figure 1-2. Pedagogical content knowledge.

Thus, as we talk about potential roles of CIS and ICT in teaching and learning, there are general ideas and there are ideas that are quite specific to each discipline. This poses three major problems for college faculty:

1. CIS, ICT, and computational thinking affect the content of each discipline. Thus, each college teacher faces the problem of learning how CIS, ICT, and computational thinking affect the content of his or her discipline and how appropriate changes in teaching the content can be developed and implemented.
2. CIS and ICT provide a variety of aids to teaching, learning, and assessment. Therefore, all faculty members face the problem of understanding the potential of CIS and ICT as an aid to teaching, learning, and assessment, and then implementing appropriate changes in their teaching. To do so, they must gain appropriate computer-related PCK within the areas they teach.

3. College students, politicians, corporate executives, and others who are not faculty members are a driving force for CIS- and ICT-related changes in both the content and the processes of education. They have expectations that may or may not be consistent with items 1 and 2 above. College faculty must be appropriately responsive to these expectations. For example, many college students have had experience in developing multimedia presentations and multimedia Websites. When asked to do a term project, term paper, or presentation in a course, some of these students want to do a multimedia project and/or presentation, and this presents a challenge to many faculty members. Eric Mankin (2004) has written an excellent short paper on this topic.

Higher-Order Cognitive Processes

Benjamin Bloom is well known for Bloom's Taxonomy of Educational Objectives. In the early 1950s, he examined the curriculum and assessment at the University of Chicago. He found that testing placed a high emphasis on rote memory and other lower-order knowledge and skills. These observations eventually led to a multi-author book that discusses a six-level taxonomy of educational objectives. The taxonomy moves from lower-order knowledge and skills to higher-order knowledge and skills. The taxonomy is described on a University of Washington Website (Bloom's Taxonomy, n.d.):

Categories in the Cognitive Domain: (with Outcome-Illustrating Verbs)

1. **Knowledge** of terminology; specific facts; ways and means of dealing with specifics (conventions, trends and sequences, classifications and categories, criteria, methodology); universals and abstractions in a field (principles and generalizations, theories and structures): Knowledge is (here) defined as the remembering (recalling) of appropriate, previously learned information.

   defines; describes; enumerates; identifies; labels; lists; matches; names; reads; records; reproduces; selects; states; views.

2. **Comprehension:** Grasping (understanding) the meaning of informational materials.

   classifies; cites; converts; describes; discusses; estimates; explains; generalizes; gives examples; makes sense out of; paraphrases; restates (in own words); summarizes; traces; understands.

3. **Application:** The use of previously learned information in new and concrete situations to solve problems that have single or best answers.

   acts; administers; articulates; assesses; charts; collects; computes; constructs; contributes; controls; determines; develops; discovers; establishes; extends; implements; includes; informs; instructs; operationalizes; participates; predicts; prepares; preserves; produces; projects; provides; relates; reports; shows; solves; teaches; transfers; uses; utilizes.

4. **Analysis:** The breaking down of informational materials into their component parts, examining (and trying to understand the organizational structure of) such information to develop divergent conclusions by identifying motives or causes, making inferences, and/or finding evidence to support generalizations.

   breaks down; correlates; diagrams; differentiates; discriminates; distinguishes; focuses; illustrates; infers; limits; outlines; points out; prioritizes; recognizes; separates; subdivides.

5. **Synthesis:** Creatively or divergently applying prior knowledge and skills to produce a new or original whole.

adapts; anticipates; categorizes; collaborates; combines; communicates; compares; compiles; composes; contrasts; creates; designs; devises; expresses; facilitates; formulates; generates; incorporates; individualizes; initiates; integrates; intervenes; models; modifies; negotiates; plans; progresses; rearranges; reconstructs; reinforces.

6. **Evaluation:** Judging the value of material based on personal values/opinions, resulting in an end product, with a given purpose, without real right or wrong answers.

   appraises; compares & contrasts; concludes; criticizes; critiques; decides; defends; interprets; judges; justifies; reframes; supports.

Bloom's Taxonomy has had a major impact on education. Take a careful look at the lowest-order level in the taxonomy, and think about how much emphasis you place on this in your teaching. Rote memorization is useful. However, rote memorization without higher-order thinking and understanding turns out to be a relatively poor approach to education. This is becoming even more evident as the Web becomes more available. Rather than have students memorize a lot of details that will soon be forgotten, we want them to learn how to retrieve information and use it within a framework of understanding and higher-order cognitive processes. That is, we want students to learn to make effective use of a computer's ability to memorize the exact contents of millions of books and other documents. Computers are far better than humans at rote memorization.

We spend a lot of time teaching students algorithmic and heuristic procedures, and helping them develop skill in carrying out these procedures. Many of these procedures are ones that can be stored as computer programs and carried out on computers. I find it interesting and provocative to think about such procedure-oriented learning as being lower order. Surely, students have better things to do with their learning time than learning to compete with computers in areas where computers are particularly capable!

Memorizing Facts and Learning to Think Using the Facts

The following example illustrates the importance of being able to draw upon rote memory as one does higher-order thinking and problem solving.

Working essentially in a stimulus/response modality, one can learn (memorize) a specific response to a specific stimulus. Thus, the stimulus 3 + 7 = may cause your brain to retrieve from memory a response of 10.

However, think about how your brain handles the stimulus III + VII = ?

Probably rote memory doesn't immediately provide you with X as an answer. Maybe your thinking goes something like mine:

> Hmmm. Those looks like Roman numerals. Aha! III is 3. What is VII? I know from my long-term rote memory that V is 5. I suppose that VII might possibly mean V take away II. But, that would be III. Unless this is a trick question, VII must mean V plus II. That is sort of what I remember, anyway. Thus, VII is 7. (Although I know from rote memory that 5 + 2 = 7, in this situation I quickly did a mental count starting at 5 and saying 6, 7 to get the answer of 7.)
>
> I have now succeeded in translating the Roman numeral addition problem into the Hindu-Arabic numeral system I am much more familiar with. I know that 3 + 7 = 10 (or, if I forget, I can quickly count up from 7, going 8, 9, and then 10.) Thus, I know the answer is 10 in the Hindu-Arabic numeral system. However, I need to give the answer in Roman numerals. I am relatively sure that X stands for 10. Thus, unless my old memories about Roman numerals have failed me, the answer is X.

> I wonder if VV would also be a correct answer. After all, the original problem can be restated as VII + III, since I know that this will give the same answer. (Hmmm. I wonder how I know that? The expression *commutative law* pops into my conscious memory.) VII + III is the same as VIIIII. Why not write this as VV, and thus claim that VV is the answer?
>
> Well, let me think about that. In VV, the first V is to the left of the second, and that would mean taking 5 off from the second V. At the same time, the second V is to the right of the first V, and that would mean adding 5 to the first V. Thus, I have worked myself into a corner of deciding that VV could be either zero or 10. My conclusion is that VV is not a correct way to represent the answer, because the Roman numeral system must be designed to avoid such ambiguities.

I find it interesting to think about what my brain needed to do in the above problem-solving and reflective analysis. I certainly had to draw upon some rote memory. At certain stages of the process, if my rote memory failed me, I would have been stuck. At other stages, I could use either rote memory of a fact (such as 7 + 3 = 10) or I could recall a "counting on" procedure to mentally count to do an addition. I could also have counted on my fingers. Thus, memorization of the idea of mentally counting on or the idea of counting on my fingers gives me a general approach to solving a variety of addition problems.

At some stage of the problem-solving process, my mind became playful and curious, and it generated a new problem. I had fun playing with the new problem. The overall problem-solving process strengthened some of the neural connections among various aspects of my math knowledge, my Roman numeral knowledge, and so on.

The overall process also illustrated my interest in math—I have a doctorate in math. Even though I have not taught math for many years, I find it fun to pose and explore math problems. In some sense, this is no different than a person liking to do crossword puzzles, read the Bridge column in a newspaper, or play Sudoku.

Final Remarks

As you read this book, keep in mind the goal of helping your students get a better education.

Although there are some generally accepted goals for education, each teacher interprets these goals in his or her own way, Each teacher integrates in some of his or her own insights on appropriate goals of education and how to achieve them.

In higher education, departments, professional schools, and programs of study tend to be organized along the lines of specific disciplines or combinations of disciplines. Thus, the courses you teach tend to be quite specific to a particular discipline or combination of disciplines. Once outside of formal schooling, the great majority of students use their education in an interdisciplinary manner. That is, the discipline-specific nature of higher education and the discipline-independent or multidisciplinary nature of using one's higher education seem somewhat inconsistent. This line of thinking has led some institutions to develop and implement many multidisciplinary courses and entire programs of study.

Keep in mind that a discipline has considerable breadth and depth. Thus, a student taking a course within a specific discipline may be much more interested in some aspects of the discipline than in others. Moreover, the great majority of students taking lower division courses in a discipline intend to major in some other discipline.

In building an increasing level of expertise within a discipline, a student gains in both lower-order and higher-order knowledge and skills. The full range of levels in Bloom's Taxonomy comes into play in any well-taught college course.

As you teach, keep in mind the importance of teaching for transfer of knowledge and skills to other courses and to other situations students will encounter in the future, You want your students to gain knowledge and skills that will last beyond the confines of your specific course.

Chapter 2
Limitations

"Try to learn something about everything and everything about something." (Thomas H. Huxley)

In the United States, more than 70 percent of students graduating from high school go on to some form of higher education within two years of their graduation. More than 50 percent of these students entering college take remedial courses, many in areas such as math, writing, and reading (Stanford University, n.d.).

This need for remedial courses is occurring even in high-quality colleges and universities. The cognitive developmental level and content area preparation of many students entering college is not adequate for the challenges presented by "solid" freshman-level courses.

Students' lack of knowledge and skills in CIS and ICT are also a major problem. Even though many states have adopted K-12 standards in this area, there are huge variations in what students actually learn. Moreover, the level of CIS and ICT instruction that many students receive before they enter college is not rigorous or cognitively challenging.

This chapter explores some aspects of the precollege education and cognitive development of students, with a particular emphasis on instruction in CIS and ICT.

Physical and Mental Limitations

There is a lot of data available on the physical capabilities and limitations of human beings. Some of this data is relatively easy to gather, and normative data is available. For example, we use the expression 20/20 to indicate that a person's vision at 20 feet meets the norm of what can be expected for a person with normal vision at 20 feet. For most of my adult life, I wore thick eyeglasses. They corrected my 20/500 (or worse) vision to approximately 20/25. Now, after cataract lens implants, my relatively thin eyeglasses correct my vision to 20/20.

My hearing, strength, blood pressure, heart rate, and other functions can all be measured and compared to norms for healthy people my age. Deviations from desirable levels can be addressed by diet, exercise, medication, and so on. Many people use a hearing aid or have replacement joints, pace makers, and other aids to help overcome physical limitations of their bodies. In addition, science and technology have provided us with telescopes, microscopes, cars, trains, and airplanes that help us to far surpass the physical capabilities of an unaided human body.

It is interesting to think about mental (cognitive) capabilities and limitations. For more than a hundred years, we have had ways to measure intelligence. *Intelligence quotient* IQ) is a term that is now widely used. An IQ test produces a number or numbers that are estimates of some sort of capability relative to a norm. For example, a college student might score 115 on an IQ-type measure of verbal ability and 100 on an IQ-type measure of math ability. IQ tests are typically normed to a mean of 100 and a standard deviation of 15 or 16. On a test with a standard deviation of 15, a score of 115 means a person is one standard deviation above the mean. On such a test, about 16 percent of people have an IQ above 115.

Chapter 8 of this book focuses on human and computer intelligence, but in advance of that chapter I want to introduce three important ideas about human intelligence:

1. People vary considerably in their cognitive abilities.
2. Cognitive abilities can be improved through mental and physical exercise, formal and informal education, diet, medication, and so on.
3. There are many aids to one's cognitive abilities. For example, reading and writing are a powerful aid to memory. Paper-and-pencil arithmetic algorithms and calculators are powerful aids to arithmetic computation. Computers are a powerful cognitive aid over a wide range of cognitive tasks in a wide range of academic disciplines.

We have accepted the idea that it is all right for people to make use of eyeglasses, cataract lens replacements, hearing aids, heart pacemakers, and hip and knee joint replacements to aid them physically. We readily accept the use of telescopes, microscopes, and other technologies to greatly extend our visual capabilities.

We have also accepted the idea that students can use reading, writing, and paper-and-pencil arithmetic to supplement and extend their mental capabilities. We have even accepted the use of handheld calculators on state and national tests. *However, we have a long way to go before we accept that students should be able to use general-purpose computers connected to the Internet as an aid when taking a test.*

Upper Limit Theory

A highly talented and highly trained male athlete can run 100 meters in less than 10 seconds. Do you think that an "unaugmented" human will ever be able to run 100 meters in under 8 seconds? The point is that there are limits to physical performance.

My 11-year-old car and I can easily outperform the world's best athletes in the 100-meter dash and in the marathon run. The limits to human physical performance are easily overcome through use of technological aids.

Now, consider the same idea for human cognitive abilities. It is obvious that some people learn faster and better than others. This observation leads to the question: What are the learning capabilities of average people, or average college students, or average college students who are majoring in a specific discipline, and so on? It turns out that such questions are difficult to answer because performance in any specific course is dependent on all of one's previous formal and informal education as well as on factors such as intrinsic and extrinsic motivation, perseverance, available time, quality of instruction, and the quality and availability of books and other aids to learning.

Chapter 1 discussed Benjamin Bloom and Bloom's Taxonomy. Bloom also did seminal research on tutoring. Working with precollege students, he found that with individual tutoring an average student (a "C" student) performs at an "A" level (Bloom, 1984). This gives us added insight into a number of different educational problems. For example, children raised in poverty often have far less individual informal instruction from their parent, parents, or caregivers than do children raised in more affluent settings.

Research on individual tutoring helps explain the success of computer-assisted learning (CAL). In most cases, CAL is not (yet) as effective as a human tutor, but it does provide some of the individualization and immediate feedback provided by human tutors.

Robert Branson (n.d.) has done longitudinal studies of the performance of precollege students on a variety of national tests. As Branson notes:

> In a previous paper, I offered a technical explanation for the current level of school performance and why traditional fixes of the kind offered by national commissions and legislatures cannot lead to improvement. *I argue that the current model and organization of schools cannot improve because its performance approaches the upper limit of its capability (Branson, 1987).*
>
> This technical obsolescence cannot be blamed on teachers, administrators, school boards, school districts, or departments of education. There is no villain and no scapegoat that can bear the burden of blame. Figure 1 plots my views of the developmental history of contemporary school operations. *We have already achieved 95 to 98 percent of total performance using that model.* [Italics added for emphasis.]

Branson is not arguing that students are not capable of much more and better learning. Rather, he is arguing that if our precollege educational system does not make major changes (a successful paradigm shift), it will continue to get the results it has gotten over the past few decades. The research of Bloom and others on individual and small-group tutoring provides convincing evidence that the inherent intellectual capabilities of children are not the limiting factor.

Figure 2-1 illustrates the general idea of an upper limit theory. A new paradigm is developed and applied to some task. Over the years, incremental improvements lead to better performance. Eventually the performance improvements from these incremental improvements begin to slow.

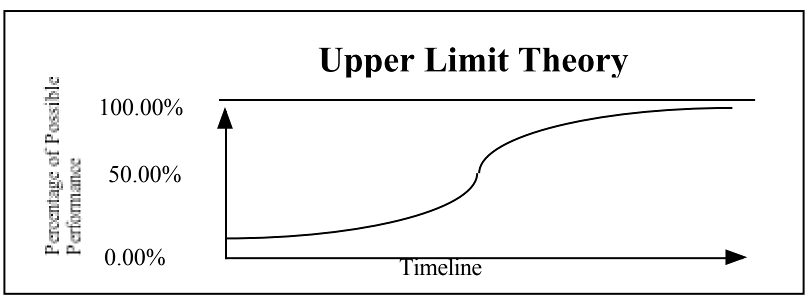

Figure 2-1. Upper limit theory, showing percentage of the potential that has been achieved.

In his papers, Branson argues that only a paradigm shift will lead to significant performance improvements in precollege education. He believes that computer technology—especially CAL—will provide such a paradigm shift. Figure 2-2 illustrates a typical situation when a paradigm shift leads to a significant increase in potential performance.

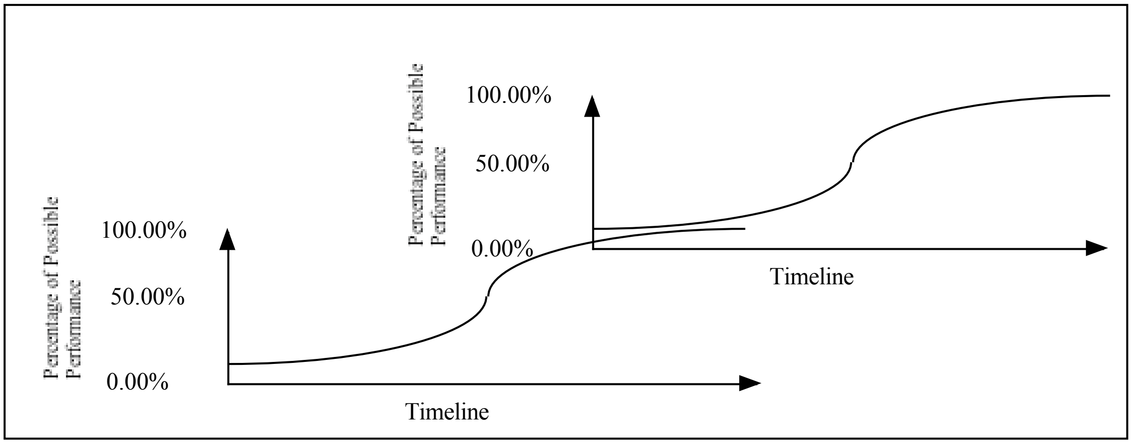

Figure 2-2. Paradigm shift jump to a "higher" level, allowing for more incremental change.

Suppose that Branson is right, and that colleges and universities cannot expect that the future will bring them better and better students unless precollege education undergoes a major paradigm shift. We all know that precollege education has been very slow to change. Thus, colleges and universities should not expect a sudden improvement in incoming students. For example, here is recent data provided by Mitchell Landsberg (2007):

> U.S. high school students are taking tougher classes, receiving better grades and, apparently, learning less than their counterparts of 15 years ago.
>
> Those were the discouraging implications of two reports issued Thursday by the federal Department of Education, assessing the performance of students in both public and private schools. Together, the reports raised sobering questions about the past two decades of educational reform, including whether the movement to raise school standards has amounted to much more than window dressing.

Upper limit theory can also be applied to students in colleges and universities. If we look at students taking traditional freshman courses, do we have evidence that they are performing significantly better than 10 or 20 years ago? Interestingly, it is hard to find good data to help answer this question. The recent publication of the U.S. Secretary of Education's report (Spellings Commission, 2006) provides some insight as to what has been happening in higher education:

> Among high school graduates who do make it on to postsecondary education, a troubling number waste time—and taxpayer dollars—mastering English and math skills that they should have learned in high school. And some never complete their degrees at all, at least in part because most colleges and universities don't accept responsibility for making sure that those they admit actually succeed.
>
> As if this weren't bad enough, there are also disturbing signs that many students who do earn degrees have not actually mastered the reading, writing, and thinking skills we expect of college graduates. *Over the past decade, literacy among college graduates has actually declined.* Unacceptable numbers of college graduates enter the workforce without the skills employers say they need in an economy where, as the truism holds correctly, knowledge matters more than ever. (p. 7) [Italics added for emphasis.]

Figure 2-3 (Spellings Commission, 2006, p. 23) provides some evidence that literacy of college graduates has decreased over an 11-year span from 1992 to 2003.

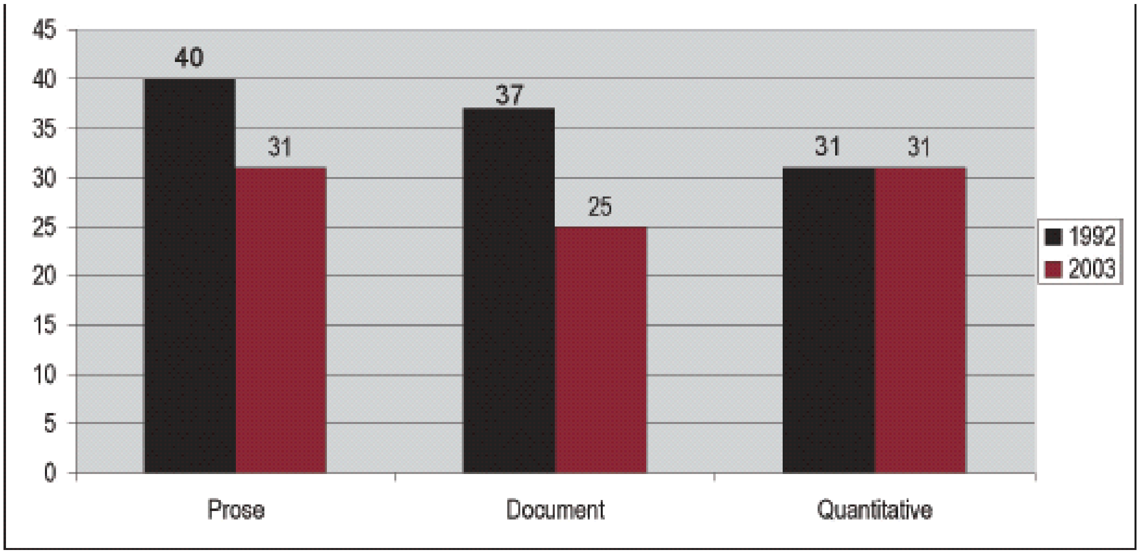

Figure 2-3. Percentage of students receiving a bachelor's degree who were proficient in prose, document, and qualitative literacy, 1992 and 2003.

Adult Literacy and Numeracy

The National Center for Educational Statistics (NCES) (IES, 2005) provides some additional information about adult literacy:

> The Adult Literacy and Lifeskills Survey (ALL) is an international comparative study conducted in 2003 to provide participating countries with information about the skills of their adult populations. ALL measured the literacy and numeracy skills of a nationally representative sample of 16- to 65-year- olds from six participating countries (Bermuda, Canada, Italy, Norway, Switzerland, and the United States). Literacy is defined as the knowledge and skills needed to understand and use information from text and other written formats. Numeracy applies to the knowledge and skills required to manage mathematical demands of diverse situations. A second phase of ALL, in which additional countries are collecting data, is currently under way. This will allow for a greater number of country comparisons.

One might expect the U.S., with its heavy emphasis on higher education, to lead the world in adult literacy and numeracy. Table 2-4, also from the NCES report, shows that this is not the case.

Literacy		Numeracy	
Country	Score	Country	Score
Norway	293	Switzerland	290
Bermuda	285	Norway	285
Switzerland	274	Bermuda	270
Canada	281	Canada	272
United States	**269**	**United States**	**261**
Italy	228	Italy	233

Score is significantly higher than the U.S. average
Score is not significantly different from the U.S. average
Score is significantly lower than the U.S. average
NOTE: Participants were scored on a 500-point scale.
SOURCE: Statistics Canada and Organization for Economic Cooperation and Development (OECD), Adult Literacy and Lifeskills Survey (ALL), 2003.

Figure 2-4. Comparison of six countries in 2003 in adult literacy and adult numeracy.

My personal observation, backed up by conversations with many faculty members, is that on average we may well be seeing a decline in performance of freshman students. I am particularly interested in math education, and the evidence I have found suggests that we have reached an upper performance limit in the college algebra course that is widely required of students throughout the country. Thus, small modifications in how we teach this course will not produce significant gains in student learning. A successful paradigm shift in precollege math education or a successful paradigm shift in remedial college math and the college algebra course are needed to improve performance significantly.

Cognitive Developmental Theory

We know that the human brain changes quite rapidly during early years of life, and it continues to change at a significant rate until we are in our mid 20s. Thus, the brains of many of our younger college students have not yet reached their full maturity.

It has long been assumed that as people age some of their neurons die and are not replaced. Recent research indicates that some new neurons are grown throughout one's lifetime. In addition, the dendrite connections among neurons are changing all the time, with new ones growing and the older ones strengthening and weakening as a result of the amount they are used. Through appropriate informal and formal education and the use of one's education, one's brain can continue to increase in overall cognitive ability for many decades after it achieves physical maturity. Chapter 8, on human and machine intelligence, covers this in more detail.

Jean Piaget's (1896–1980) work on cognitive developmental theory has contributed greatly to our understanding of the stages of human development. (Huitt & Hummel, 2003). Piaget developed a theory of four-stage cognitive development that is still widely used. Figure 2-5 outlines the stages and developments Piaget proposed.

Approximate Age	Stage	Major Developments

Birth to 2 years	Sensorimotor	Infants use sensory and motor capabilities to explore and gain increasing understanding of their environments. If the environment (nurturing, food and vitamins, shelter, freedom from lead and other poisons, healthcare) is adequate beyond some modest threshold, then developmental progress is strongly dependent on genetic/biological factors.
2 to 7 years	Preoperational	Children begin to use symbols, such as speech. They respond to objects and events according to how they appear to be. Children make rapid progress in receptive and generative oral language. There are large advantages of growing up in a "rich" cultural and socioeconomic environment.
7 to 11 or 12 years	Concrete operations	Children begin to think logically. In this stage (characterized by seven types of conservation: number, length, liquid, mass, weight, area, and volume), intelligence is demonstrated through logical and systematic manipulation of symbols related to concrete objects. Operational thinking—including mental actions that are reversible mental testing of ideas—begins to develop. Schools and schooling play a significant role in helping to shape a child's development during this stage.
11 or 12 years and beyond	Formal operations	Thought begins to be systematic and abstract. Reasoning takes place deductively and theoretically, from hypothetical situations to the concrete. Understanding the concept of probability occurs. In this stage, intelligence is demonstrated through the logical use of symbols related to abstract concepts.

Figure 2-5. Piaget's cognitive development scale.

A child's rate of progress through the Piagetian developmental stages is dependent on both nature and nurture. A good home, neighborhood, community, and school environment make a huge difference.

Formal operations is a broad concept. Each discipline is apt to make up its own definition of what constitutes the achievement of formal operations within its own discipline. It takes education and experience to learn the vocabulary, notation, symbols, and methods of reasoning used in a specific discipline.

Research in the past couple of decades indicates that movement into formal operations is not automatic. As Huitt and Hummel (2003) note:

> Data from similar cross-sectional studies of adolescents do not support the assertion that all individuals will automatically move to the next cognitive stage as they biologically mature. Data from adult populations provides essentially the same result: Between 30 to 35% of adults attain the cognitive development stage of formal operations (Kuhn, Langer, Kohlberg & Haan, 1977). *For formal operations, it appears that maturation establishes the basis, but a special environment is required for most adolescents and adults to attain this stage.* [Italics added for emphasis]

The correctness of the assertion that 30 percent to 35 percent of adults attain the cognitive development stage of formal operations certainly depends on how one defines and measures formal operations. Thus, one can find peer-reviewed papers assert that only about half of college students are at the level of formal operations, while other papers that assert that a much higher percentage of college students are at formal operations level. Moreover, a person may be at a formal operations level in one discipline area but not in another.

Thus, for example, a significant percentage of students taking a college algebra course have not yet achieved a level of formal operations in mathematics, even though they may have achieved that level in other components of cognitive development. When such students face the highly symbolic, logical, and abstract aspects of college algebra, their main recourse is rote memorization. This helps explain why so many students do not succeed in this course. The rote memorization approach does not help much in moving students toward achieving a formal operations cognitive level in mathematics.

From a faculty member's point of view, the various interpretations about formal operations suggest two things:

1. In lower-division courses where a cross section of students is enrolled, many of the enrollees will not be at a formal operations level in the disciplinary area of the course.
2. Faculty members should give careful thought to how their courses help increase both discipline-specific and discipline-independent cognitive development, paying particular attention to helping their students move toward higher levels of achievement of formal operations.

The ICT Preparation of Students

The International Society for Technology in Education (ISTE) first published National Educational Technology Standards for K-12 students in 1998. You can access the ISTE standards at ISTE NETS•S (n.d.). Now, almost every state in the U.S. has ICT goals, objectives, and standards for K-12 students, and most states have drawn heavily on the ISTE model.

The wide adoption of the ISTE NETS•S suggests that more and more students will be entering college with a solid background in the use of computers. Unfortunately, many schools and school districts are doing a very poor job in preparing their students in ICT. This means that there are huge differences in the ICT preparation of students now entering college.

This presents a significant challenge to college faculty members who want to have their students make use of ICT in their courses. It is not appropriate for faculty members to have to spend class time teaching the rudiments of ICT. On the other hand, it is quite appropriate for college teachers to teach about more advanced, discipline-specific ICT that is relevant to their course content.

A partial solution to the uneven ICT preparation of college students is to give a placement test in this area and offer or require remedial coursework for students who are not adequately prepared. Some colleges and universities do this, but it has not yet become a common practice.

ISTE NETS-Students

Here is an example of the ISTE standards for students completing the 5th-grade (NETS, n.d.).

Prior to completion of Grade 5, students will:

1. Use keyboards and other common input and output devices (including adaptive devices when necessary) efficiently and effectively.
2. Discuss common uses of technology in daily life and the advantages and disadvantages those uses provide.
3. Discuss basic issues related to responsible use of technology and information and describe personal consequences of inappropriate use.
4. Use general-purpose productivity tools and peripherals to support personal productivity, remediate skill deficits, and facilitate learning throughout the curriculum.

5. Use technology tools (e.g., multimedia authoring, presentation, Web tools, digital cameras, scanners) for individual and collaborative writing, communication, and publishing activities to create knowledge products for audiences inside and outside the classroom.
6. Use telecommunications efficiently to access remote information, communicate with others in support of direct and independent learning, and pursue personal interests.
7. Use telecommunications and online resources (e.g., e-mail, online discussions, Web environments) to participate in collaborative problem-solving activities for the purpose of developing solutions or products for audiences inside and outside the classroom.
8. Use technology resources (e.g., calculators, data collection probes, videos, educational software) for problem solving, self-directed learning, and extended learning activities.
9. Determine which technology is useful and select the appropriate tool(s) and technology resources to address a variety of tasks and problems.
10. Evaluate the accuracy, relevance, appropriateness, comprehensiveness, and bias of electronic information sources.

Think about whether the typical undergraduate student you currently teach meets these 5th -grade standards. For current students not meeting these standards, what do you think you, your department, or your institution should do about it? Finally, think about why I used 5th -grade standards in my discussion. Why didn't I use the 12th -grade standards? What would it do to college enrollments if the 12th -grade ISTE standards were a requirement for admission or a prerequisite to a variety of freshman courses?

Overall Academic Preparation of Precollege Students

Many faculty members in higher education have only modest insight into how well our precollege educational system is doing and its efforts to improve these learning outcomes. This section discusses some of these efforts.

Fifty years ago, approximately 20 percent of high school graduates in the U.S. went on to college. Now, the figure is about 70 percent. This marked change has drawn considerable attention to how well high school graduates are prepared for college-level coursework.

Studies and reports over the past couple of decades suggest than many high school graduates do not have a particularly good education and many are not prepared for college.

A Nation at Risk

The U.S. Department of Education's National Commission on Excellence in Education published the report *A Nation At Risk* in 1983. This document is often cited as the origin of current reform efforts. The report stated its conclusions in brief but dramatic terms:

> If an unfriendly power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves. We have even squandered the gains in achievement made in the wake of the Sputnik challenge. Moreover, we have dismantled essential support systems which helped make those gains possible. We have, in effect, been committing an act of unthinking, unilateral educational disarmament. (Nation at Risk, 1983, p. 5)

The Commission advanced the following recommendations:

- Graduation requirements should be strengthened so that all students establish a foundation in five *new* basics: English, mathematics, science, social studies, and *computer science*. [Italics added for emphasis.]

- Schools and colleges should adopt higher and measurable standards for academic performance.
- The amount of time students spend engaged in learning should be significantly increased.
- The teaching profession should be strengthened through higher standards for preparation and professional growth.

Documents such as *A Nation at Risk* receive a lot of attention. However, over the long run they tend to have only a modest impact on our educational system. Here is a quote from *A Nation Still at Risk* published 15 years later:

> Yet the state of our children's education is still far, very far, from what it ought to be. Unfortunately, the economic boom times have made many Americans indifferent to poor educational achievement. Too many express indifference, apathy, a shrug of the shoulders. Despite continuing indicators of inadequacy, and the risk that this poses to our future well being, much of the public shrugs and says, "Whatever."
>
> The data are compelling. We learned just last month that American 12th graders scored near the bottom on the recent Third International Math and Science Study (TIMSS): U.S. students placed 19th out of 21 nations in math and 16th out of 21 in science. Our advanced students did even worse, scoring dead last in physics. This evidence suggests that, compared to the rest of the industrialized world, our students lag seriously in critical subjects vital to our future. That's a national shame. (Center for Education Reform, 1998)

Goals 2000: Educate America Act of 1994

The Educate America Act of 1994 was signed into law by President Clinton on March 31, 1994. It declared that by the year 2000 (Goals 2000, 1994):

1. All children in America will start school ready to learn.
2. The high school graduation rate will increase to at least 90 percent.
3. All students will leave grades 4, 8, and 12 having demonstrated competency over challenging subject matter including English, mathematics, science, foreign languages, civics and government, economics, the arts, history, and geography, and every school in America will ensure that all students learn to use their minds well, so they may be prepared for responsible citizenship, further learning, and productive employment in our nation's modern economy.
4. United States students will be first in the world in mathematics and science achievement.
5. Every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship.
6. Every school in the United States will be free of drugs, violence, and the unauthorized presence of firearms and alcohol and will offer a disciplined environment conducive to learning.
7. The nation's teaching force will have access to programs for the continued improvement of their professional skills and the opportunity to acquire the knowledge and skills needed to instruct and prepare all American students for the next century.
8. Every school will promote partnerships that will increase parental involvement and participation in promoting the social, emotional, and academic growth of children.

Seven years after the target year of 2000 and more than a decade after the law was enacted, little progress toward these goals has occurred. Indeed, there is little evidence that these goals will be attained in the foreseeable future.

No Child Left Behind Act of 2001

On January 8, 2002, President Bush signed into law the No Child Left Behind (NCLB) Act of 2001. This was a reauthorization of the Elementary and Secondary Education Act that has had substantial funding in the past. Thus, the NCLB Act represents a more concerted effort to improve education than some of the past efforts. Quoting from the NCLB's (2002) executive summary:

> Three days after taking office in January 2001 as the 43rd President of the United States, George W. Bush announced No Child Left Behind, his framework for bipartisan education reform that he described as "the cornerstone of my Administration." President Bush emphasized his deep belief in our public schools, but an even greater concern that "too many of our neediest children are being left behind," despite the nearly $200 billion in Federal spending since the passage of the Elementary and Secondary Education Act of 1965 (ESEA).
>
> …
>
> The NCLB Act will strengthen Title I accountability by requiring States to implement statewide accountability systems covering all public schools and students. *These systems must be based on challenging State standards in reading and mathematics, annual testing for all students in grades 3-8, and annual statewide progress objectives ensuring that all groups of students reach proficiency within 12 years.* Assessment results and State progress objectives must be broken out by poverty, race, ethnicity, disability, and limited English proficiency to ensure that no group is left behind. School districts and schools that fail to make adequate yearly progress (AYP) toward statewide proficiency goals will, over time, be subject to improvement, corrective action, and restructuring measures aimed at getting them back on course to meet State standards. Schools that meet or exceed AYP objectives or close achievement gaps will be eligible for State Academic Achievement Awards. [Italics added for emphasis]

The NCLB Act places increased emphasis on accountability. One aspect of accountability is having agreed upon definitions and measures of accountability. What has emerged in the past few years is that state and national tests in areas such as reading and math are being used to measure progress toward achieving accountability standards.

There has been a significant increase in the amount of testing. In addition, there has been a significant increase in time and effort spent preparing for the tests and teaching specifically to the tests. Subject areas not covered in the tests are receiving less school time.

The emerging evidence is that NCLB will fail to achieve its goals. As David Armor (2006) notes:

> The most widespread criticism is the program's lack of funding to accomplish these goals**.** *But that is not the crucial problem; rather, it is the lack of knowledge about how to attain proficiency for all children.*
>
> Achievement gaps between ethnic groups are not caused by schools. They are caused by powerful family characteristics that impact children long before they start school and continue to operate throughout their school years. It is possible that school programs can overcome family influences to close achievement gaps, but we have yet to discover how. A school staff cannot simply go to a shelf and find a set of classroom practices that are tested and proven. [Italics added for emphasis]

In his article, Armor uses examples from middle school math to illustrate some of the points being made. Data is provided on the scarcity of research-based methods for improving math education at that level.

The point is that within any particular discipline at the precollege level we would like to be increasing student achievement. However, in many cases we lack the research and resources to do so. However, I suggest that you continue reading this book before you give up in despair!

Final Remarks

It is easy to talk about improving education, and lawmakers find it relatively easy to legislate improvements in education. However, neither the talk nor the legislation is any guarantee of success. In a 300-page study of precollege school reform, Vernez et al. (2006) remark:

> In recent years, pressure for improving student achievement has been steadily increasing, culminating in the No Child Left Behind Act of 2001. This legislation requires that schools reach 100 percent proficiency in reading and mathematics for all students by 2014. Responding to this pressure, an increasing number of schools have undertaken comprehensive school reform. Hundreds of different reform models have been developed over the years. Thousands of schools have adopted one of these models, most often using federal funds provided by Comprehensive Schools Reform Demonstration and/or Title I. However, the effect of comprehensive school reform models on student achievement remains debatable. Research results have been mixed. Most studies show only a modest effect—or sometimes no effect—on student achievement.

As the Vernez et al. study points out, most efforts at school reform do a poor job of translating the research theory into actual practice. The report argues that a major cause of the failures is that the fidelity of their implementations is seriously flawed.

However, there is another way of thinking about this. Most of the reforms themselves are not very robust. Small deviations from the reform model lead to large deviations in the results. A reform model that has such characteristics is almost surely going to fail in large-scale implementation efforts because it is not possible to get large numbers of people (students, teachers, school administrators, parents, and politicians) to all adhere to the detailed requirements of a reform plan.

This beginning of this chapter included a brief introduction to upper limit theory as it applies to education. It is conjectured that perhaps we are reaching an upper limit of what we can expect from our current educational system, both at the precollege level and on into the first year or two of higher education. This conjecture is accompanied by the idea that it may take substantial paradigm shifts to produce a significant breakthrough in current levels of achievement.

Chapter 3
Technological Change

> "In times of change, the learner will inherit the earth while the learned are beautifully equipped for a world that no longer exists." (Eric Hoffer)

Educational systems tend to be conservative and well rooted in the past. They help to preserve and pass on the knowledge, history, and culture of past generations. Such an approach to education has served us well for thousands of years. However, the pace of technological change began to quicken with the start of the Industrial Age more than 200 years ago.

We are now living at a time of when technological change is occurring at a very high rate and seems to be increasing. Thus, our educational system is faced by the problem of how to educate and prepare students for living in a rapidly changing world.

The focus in this chapter is on possible changes in education that will come about mainly because of changes in technology. The chapter contains a number of forecasts. While these forecasts are speculative, they may be good enough to help guide your participation in and contributions to—or opposition to—the forecasted changes.

On Being a Futurist

A number of people make their living being futurists. Some teach this discipline, and there are doctorate programs in this area of study.

I am not a very good futurist. However, I like to read books written by futurists, and I have written a couple of books about possible futures of ICT in education. I have also presented a number of workshops and talks on this topic. My most recent book on possible futures of ICT in education is available free on the Web (Moursund, 2005). In addition to such scholarly accomplishments, I have read a lot of science fiction. I especially enjoy various authors' attempts to make plausible forecasts of the future.

ICT and other technologies are massive change agents. We can study past change agents and the changes they produced. These give us some insights into how to view current change agents.

Electronic Digital Computers

This section discusses the speed of change in various aspects of ICT systems. These speeds have been increasing at an exponential rate, and are likely to continue at this pace of change for many years into the future. Forecasts about the future of ICT in education are usually rooted in assumptions that the capabilities and availability of ICT will continue at the same pace of rapid growth that has occurred during the past several decades.

A Little History About Aids to Computation

The Sumerians developed writing and began to educate a few people in the mysteries of reading, writing, and arithmetic about 5,200 years ago. For nearly 5,000 years before that time, simple record keeping was aided by clay tokens. Thus, a token with a (symbolic) picture of a sheep was used as a record-keeping device to represent one sheep. These tokens were a precursor to the development of writing.

The abacus proved to be a remarkably useful invention and is still in use. It was developed long after the development of written language. As described in Wikipedia:

> The origins of the abacus are disputed, as many different cultures have been known to have used similar tools. It is known to have existed in Babylonia and in China, with invention to have taken place between 1000 BCE and 500 BCE. The first abacus was almost certainly based on a flat stone covered with sand or dust. Lines were drawn in the sand and pebbles used to aid calculations. From this, a variety of abaci were developed; the most popular were based on the bi-quinary system, using a combination of two bases (base-2 and base-5) to represent decimal numbers.

Other important historical but more recent developments include tables of logarithms, mechanical calculators, slide rulers, analog computers, and electromechanical calculators and computing devices. Various forms of the electronic digital computer were developed during World War II in England, Germany, and the United States.

The developmental work on computers in the United States led to the commercial production of UNIVAC computers, which first became available in 1951. Since then, the price-to-performance ratio of computers has improved by a factor of approximately **10 billion**.

It is hard to comprehend such change in a commercially available product. If we look at just the past two decades, we see that today's medium-priced desktop microcomputer has about the same capabilities as the world's fastest multimillion-dollar super computer of 20 years ago.

Gordon Moore and Moore's Law

Gordon Moore was one of the people who helped start Intel Corporation. As Intel began to produce faster and faster central processing units, Gordon Moore made an empirical observation about the rate of change from one generation of computer chips to the next. Quoting from (Moore, 1965):

> The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. … Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000. I believe that such a large circuit can be built on a single wafer.

There have been several modifications to this forecast over the years. Roughly speaking, what has happened over the past 40 years is that the performance capabilities of a single-chip central processing unit has been doubling about every two years. This observation has come to be called Moore's Law. This high rate of technological progress has made possible desktop, laptop, and palmtop microcomputers, cell telephones, and a wide variety of electronic toys.

There has been a steady stream of literature discussing how long Moore's Law will prove to be a reasonably accurate forecast of the future. What seems most likely is that the capabilities of microcomputers will continue to grow at a rapid pace for many years to come. It would not be too surprising if the speed of a desktop microcomputer 20 to 30 years from now were to be faster than today's top-of-the-line $15 million supercomputers.

Such progress in chip technology has also driven rapid improvements in the capacity and speed of the primary memory in computers. When microcomputers first began to be mass-produced about 30 years ago, they typically had about 16K bytes to 64K bytes of primary memory. (A byte is eight bits—eight binary digits—the amount of storage space needed to store an alphabetic or numeric character. Scientists use K to mean 1,000. However, in computereze, it means 2 to the 10th power, or 1,024.)

Nowadays a desktop or laptop microcomputer often contains a gigabyte of primary storage. A gigabyte is 2 to the 30th power, or somewhat more than a billion bytes. A 350-page novel contains about 1 million bytes of text. Thus, a gigabyte is enough storage to hold about a thousand novels.

Disk Storage and Connectivity

There have been two other areas of very rapid change in ICT. First, disk storage price-to-performance has improved at an exponential rate. About 25 years ago, disk storage for a microcomputer cost about a thousand dollars per megabyte (2 to the 20th bytes, or about 1 million bytes). Now the cost is less than 50 cents per gigabyte. Taking inflation into consideration, during the past 25 years the cost of disk storage has gone down by a factor of more than 5 million.

The development of fiber optics and substantial improvements in the design and use of wireless transmissions have been increasing connectivity speeds at an exponential rate. When I first began using computer connectivity from home about 25 years ago, I used a telephone connection with a speed of about 30 characters per second. Currently I have a telephone-based broadband connection at home that runs about 2,000 times this fast. Of course, my on-campus connectivity is about 20 times as fast as my home connectivity.

There have been other spectacular changes. When I first went to work for the University of Oregon in 1967, it had just purchased a new computer. The computer had about 250 megabytes of disk storage that cost about $250,000 and was housed in about 100 cubic feet of cabinetry. Now, a 4-gigabyte flash drive that is much smaller than my thumb costs about $50.

Ray Kurzweil

Ray Kurzweil is one of the world's most prominent computer-oriented futurists. He did his doctoral work in Artificial Intelligence (AI) under the supervision of Marvin Minsky at MIT, who is one of the pioneers of this field. He was awarded the National Medal of Technology by President Clinton and has received a number of other high-level awards. He is an entrepreneur who has started a number of high-tech companies.

Kurzweil's book *The Singularity Is Near: When Humans Transcend Biology* was published in 2005. This book contains a number of forecasts, with a special emphasis on genetics, nanotechnology, and robotics. A number of the ideas in this book are summarized in a 24-minute talk given by Kurzweil and available on the Web (Kurzweil, 2005).

The *singularity* referred to in the title of his book is a time when computer intelligence exceeds human intelligence. As Kurzweil describes it:

> I set the date for the Singularity—representing a profound and disruptive transformation in human capability—as 2045. *The nonbiological intelligence created in that year will be one billion times more powerful than all human intelligence today.* (p. 136) [Italics added for emphasis]

Kurzweil's book contains carefully argued analyses of the possibilities of continued exponential growth (indeed, an acceleration in the current exponential growth) of computer capabilities discussed in the previous section. He provides considerable detail as well as a large annotated bibliography.

The analysis and forecasting sections of Kurzweil's book also contain considerable data on historical trends as well as examples of recent progress in various ICT-related and ICT-facilitated technologies.

People vary in how they react to Kurzweil's writings. Some dismiss such forecasts out of hand. Others tend to sort out the parts that they want to believe and dismiss the rest. Still others point to Kurzweil's credentials and the accuracy of forecasts he has made in the past and say, "Watch out! Very big changes are coming!" If you are interested in the future of ICT-related technology, I highly recommend Kurzweil's book.

Kurzweil gives over quite a few pages of his book to analyzing the human genome project and how rapidly its pace of progress increased during the initial 13 years of the project (HGP, n.d.). The U.S. federal government invested nearly $3 billion in the project, which began in 1990 and ended in 2003. Current costs of sequencing a person's genome are estimated to be perhaps $10 million to $15 million, but some people believe that the cost may eventually be as low as $1,000 (Wade, 2006).

Kurzweil and others have attempted to determine the information-processing capabilities of a human brain and compare it to the information-processing power of current and future computers. Thus, there are a variety of forecasts—in the range of 2016 to 2021—of when the information-processing power of a supercomputer will reach and then exceed that of the human bran. Keep in mind, however, that there is a substantial difference between information processing and intelligence. In certain areas, computer systems are already far more capable than people. However, the most "intelligent" artificially intelligent computer systems still do not have the general intelligence capabilities of a five-year-old child.

An Example: Biology

An article by Rick Stevens in the August 2006 issue of *CTWatch Quarterly* was entitled "Trends and Tools in Bioinformatics and Computational Biology." You don't need to be a biologist to understand that ICT is drastically changing the field of biology and accelerating its rate of progress. According to Stevens (2006):

> Probably the most important trend in modern biology is the increasing availability of high-throughput (HT) data. The earliest forms of HT were genome sequences, and to a lesser degree, protein sequences; however, now many forms of biological data are available via automated or semi-automated experimental systems. This data includes gene expression data, protein expression, metabolomics, mass spec data, imaging of all sorts, protein structures and the results of mutagenesis and screening experiments conducted in parallel.
>
> …
>
> The second trend is the general acceleration of the pace of asking those questions that can be answered by computation and by HT experiments. *Using the computer, a researcher can be 10 or 100 times more efficient than by using wet lab experiments alone.* Bioinformatics can identify the critical experiments necessary to address a specific question of interest.
>
> …

> *The third trend is the beginnings of simulation and modeling technologies that will eventually lead to predictive biological theory.* Today, simulation and modeling applied at the whole cell level is suggestive of what is to come, the ability to predict an organism's phenotype computationally from just a genome and environmental conditions. [Italics added for emphasis]

The article differentiates between areas of biological research that lend themselves to extensive use of computers and those that don't. It suggests that the growing power of ICT in aiding certain aspects of biological research will tend to drive research in those directions.

The U.S. National Science Foundation (NSF) has funded a variety of other discipline-wide projects in other sciences. The general idea is that computers are now such a sufficiently powerful aid to information storage and retrieval that it pays to invest heavily in codifying the collected research knowledge in various areas of science.

The educational implications of these trends are interesting. It means that students at all levels can gain access to a huge amount of the research-based results in various fields of science. I believe that this approach to codifying the accumulated research in a field should be discussed and illustrated in beginning college courses in the disciplines where such practices have taken place.

Example from Genetics

Researchers are now working on problems that overwhelm all but the fastest supercomputers. For example, biologists have increasing insight into how a gene is "expressed" and makes a protein. The "folding" of the protein molecule helps to determine its characteristics. IBM currently leads the world in producing supercomputers with the highest capabilities, and protein folding is one of the key problems being addressed by such computers.

As the Website Folding@home (n.d.) describes the process:

> It's amazing that not only do proteins self-assemble—fold—but they do so amazingly quickly: some as fast as a millionth of a second. While this time is very fast on a person's timescale, it's remarkably long for computers to simulate.
>
> In fact, it takes about a day to simulate a nanosecond (1/1,000,000,000 of a second). Unfortunately, proteins fold on the tens of microsecond timescale (10,000 nanoseconds). Thus, it would take 10,000 CPU days to simulate folding—i.e. it would take 30 CPU years! That's a long time to wait for one result!

The computer industry is working to produce faster and faster computers because there is a substantial market for them. Many problems in protein folding, long-range weather forecasting, and global environment issues are beyond the capabilities of the world's fastest computers.

As you probably know, one way to build a faster computer is to build a machine that uses many thousands of microprocessor chips. Another way is to harness the potential of many millions of computers that are being used for only part of the day. This can be done through the Internet. Both of these approaches are being used and will prove to be valuable for many years to come.

An Example: Nanotechnology

A nanometer is a billionth of a meter. Nanotechnology is currently one of the "hottest" areas of research and development. Here is the first part of an article (Bullis, 2006) relating nanotechnology to the future of both medicine and computers:

> One of the leading candidates for a technology that could make computers smaller and more powerful is based on transistors made from semiconducting nanowires. But until now, circuits made with such transistors have been impractical because they were too power hungry and too difficult to manufacture. Now researchers at Caltech have built efficient nanowire-based circuits using a process they believe could be reliable enough for mass production.
>
> The first applications, which could be *available commercially in five years,* will probably be in ultra sensitive, inexpensive sensors that could detect and measure hundreds of different cancer markers or pathogens in a small sample, such as a single drop of blood. Eventually, the nanowire-based electronics could be used in processors for computing. [Italics added for emphasis]

Nanotechnology is now a high priority research topic in many different countries. The U.S. government has invested heavily in this area, and the research is beginning to produce significant results. Businesses have also invested heavily in nanotechnology, and a number of products are now commercially available. The Website of the National Nanotechnology Initiative (NNI, n.d.) describes its activities this way:

> The National Nanotechnology Initiative (NNI) is a federal R&D program established to coordinate the multiagency efforts in nanoscale science, engineering, and technology.
>
> The goals of the NNI are to:
>
> - Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology;
> - Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit;
> - Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and,
> - Support responsible development of nanotechnology
>
> Twenty-five federal agencies participate in the Initiative, 13 of which have an R&D budget for nanotechnology. Other Federal organizations contribute with studies, applications of the results from those agencies performing R&D, and other collaborations.

Global Changes

ICT is changing the business world. If this topic interests you, I recommend that you read Thomas Friedman's (2005) book *The World is Flat: A Brief History of the Twenty-First Century.* An alternative is to view a video of a recent talk by Friedman or read a recent interview with him (Chanda, 2005). Here is part of what Friedman has to say:

> I would argue that there have been three great eras of globalization. One I would call, for shorthand, Globalization 1.0. That was from about 1492 till 1800 when we saw the beginning of global arbitrage. … Columbus discovers America, so basically that era shrunk the world from a size large to a size medium. The dynamic element in globalization in that era was countries globalizing, for imperial reasons, for resources.
>
> The second great era was 1800 till the year 2000—it just ended. And that era shrunk the world from a size medium to a size small. And that era was really spearheaded by companies globalizing for markets and for labor.
>
> …
>
> Now, what I discovered by visiting India in 2004 was that we'd actually entered a whole new era of globalization. And *Lexus* [one of Friedman's earlier books] was wonderful for what it was, but it was out of date! It couldn't tell the whole story anymore, it couldn't explain the world, because

> what I really found in going to India was that we'd entered Globalization 3.0. And it's shrinking the world from size small to size tiny, and flattening the global economic playing field at the same time. And so this book builds on the shoulders of *Lexus*, in that sense, but it's really about the next stage.

The changes that Friedman describes (and forecasts more of in the future) have been going on for quite a while. An early part of this change occurred when people in the United States first began to buy large quantities of goods produced in countries that were devastated during World War II. Labor costs were low enough in some of these countries that even after one added in shipping costs, the goods were much cheaper than competing goods produced in the U.S. Over the years, the quality of many of these goods became higher than those of competing goods produced in the U.S.

Steady improvements in transportation (container ships, jet cargo airplanes), ICT, and other world-flattening technologies and education systems have had a major impact on the U.S. and many other countries. The U.S. balance of payments (imports over exports) is now in the range of $60 billion to $70 billion a month! One can view such large number in various ways:

- Wow! An awful lot of customers in the U.S. find that they get a good deal by buying foreign-made goods and services.
- Wow! That represents a lot of jobs that could perhaps be done by workers in the U.S. but instead are being done in other countries.
- Wow! Worldwide competition for jobs. That certainly is a change in the job market. I wonder how this is affecting our educational system?

Educational Implications of Technological Change

Worldwide, a huge amount of resources are being invested in technology research and its underlying science. Such research tends to be cumulative, as researchers build on their own previous work as well as on the previous work of others. The development of tools to better aid researchers has greatly advanced some of this research. Computers are making a huge contribution to this research and development.

It is easy to see the pace of technological change in computer technology and the large number of products that use this technology. Ray Kurzweil provides us with evidence suggesting that the pace of change in many areas of technology is increasing.

Many people find that the pace of change is somewhat "mind boggling." For example, I frequently read about and talk to adults who say things such as, "My sixth-grade children know far more about computer technology (toys, recording and playback devices, games, computers) than I do."

Now, think about a young child who will be growing physically and cognitively for many years to come. The everyday life of a child involves learning to cope with things that he or she has never seen before and has not yet learned how to use. The child is learning a culture and how to communicate orally and through use of gestures. If the educational environment is right, the child may be developing oral fluency in two or three languages and may be developing cultural fluency in two or more cultures. Such learning comes easy to children.

Formal schooling adds to the types of changes a child faces. For example, you probably know something about the Pythagorean theorem, which relates the lengths of the sides of a right triangle. If you were in school 3,000 years ago, you would not have learned about the Pythagorean theorem or studied Euclidean geometry. Neither Pythagoras nor Euclid had been born by then. The steady accumulation of mathematical knowledge over the past 5,000 years places a significant burden on today's students.

From an educational point of view, it seems to me that our precollege and higher education systems face a variety of challenges related to change. Examples include the following:

1. Deciding what is important for students to learn. The totality of human knowledge is huge and growing steadily. The amount a person can learn in 12, 16, 20, or more years of schooling is minuscule relative to the totality of human knowledge. Thus, each discipline needs to make choices of what a student can be expected to learn about the discipline given the amount of time our educational system and the student has to dedicate to the task. It is easy for me, as author of this book, to propose that each discipline take responsibility for helping students learn the roles of CIS and ICT in each discipline. Notice, however, that I am not making specific suggestions as to what current content should be left out as new content is added and taught in various disciplines. Curriculum designers in each program of study need to work regularly on the task of pruning curriculum content as the available content in their discipline continues its rapid growth.
2. How to help students cope with the physical and cognitive development changes they face as they grow toward physical and cognitive maturity. In some sense, each day a young student faces the world using a body and mind that has changed since the previous day. These changes include growth in potential as well as declines in knowledge and skills due to forgetting, lack of use of certain muscles, and so on. The "forgetting" issue does not receive as much attention as it should. As faculty, we tend to focus on what students are learning in our particular courses and how they demonstrate their learning during the course and at the end of the course. Many of us give little thought to teaching in a manner that will help them retain (or regain) their knowledge and skills many years into the future.
3. How to prepare students to deal appropriately with the types of changes they will encounter as adults attempting to cope with life in a very complex and rapidly changing world. Think about this as education for change. How do you educate students so they are prepared to deal with novel situations they have not previously encountered? One obvious answer is that we want students to learn to learn and to have the knowledge and skills to undertake new learning tasks. We want part of the assignments and part of the assessment in a course to include a focus on each student becoming better at being an independent, self-sufficient, self-regulated, lifelong learner.

Final Remarks

CIS and ICT are powerful change agents. Their emergence and rapid growth during the past 60 years have been a major challenge to our educational system.

The pace of technological change throughout the world is quite rapid and is increasing. This creates a continuing challenge to our educational systems. In postsecondary education, much of the challenge has been met in three ways.

1. College and university CIS departments and programs of study have been developed. For some students, instruction in CIS begins in high school through an Advance Placement course. However, the great majority of precollege and college students receive little or no formal instruction in CIS.
2. Many non-CIS departments have developed CIS and ICT courses and programs of study designed specifically to meet the needs of students in their disciplines. Thus, there are programs of study in digital arts, digital journalism, digital law, digital music, and so on. For many years, I ran a master's degree program and a doctorate program in the field of computers in education. This was done through a College of Education.
3. Many institutions of higher education provide extensive consulting, help services, and short tutorials on various aspects of ICT. These are available to both students and faculty members. In addition, higher education has moved reasonably rapidly toward providing wireless networks on campus, hardwired and/or wireless networking in every classroom, projection equipment in classrooms, computer labs for students, wireless laptops that faculty can bring to their classrooms, and other technologies.

Chapter 4
ICT Threats and Opportunities

> "The illiterate of the 21st century will not be the one who can not read and write, but the one who can not learn, unlearn, and relearn." (Alvin Toffler)
>
> "The most dangerous experiment we can conduct with our children is to keep schooling the same at a time when every other aspect of our society is dramatically changing." (Chris Dede, written statement to the PCAST panel, 1997)

Computer technology is a powerful change agent. A technological change offers advantages and opportunities to many people and nations. However, it may disadvantage and threaten other people and nations.

As an example, I find that email is a very useful aid to communication. However, have you ever done the following:

- Sent email to everybody on a list when you really just want to send a personal response to one person on the list?
- Sent an email message and then immediately have second thoughts, wishing you had not sent the message?
- Wasted a large amount of time dealing with spam email?

It is easy to see how email is both an opportunity and a threat!

This chapter lists a few of the threats and opportunities that ICT and CIS pose for higher education faculty members and their institutions.

Computers Are Here to Stay

I spend a lot of time talking to educators. I don't know how many times I have heard an educator make the statement "computers are here to stay." This immediately raises my hackles, since what follows next is often a statement that reveals why the educator is not using computer technology effectively in his or her job as a teacher or education administrator.

More than 50 years ago, in the early 1950s, it was not too clear that computers were here to stay. They were expensive, bulky, unreliable, and difficult to use.

The United States was the third country (after Great Britain and Germany) to begin the commercial production of electronic digital computers. The first commercially produced computer in the United States was the UNIVAC I, delivered in March, 1951. Priced in the range of $1.25 million to $1.5 million, the UNIVAC I machines had about 5,200 vacuum tubes, weighed 29,000 pounds, and could perform 1,905 operations per second. Only 46 of these machines were built over a period of about six years.

Even at that speed and cost, the early computers were cost effective on some jobs. In certain types of repetitious calculations—such as payroll— one computer could do the work of many hundreds of people who were using electric calculators.

Computer technology has changed a lot since 1951. Much of this change has been made possible by the invention of the transistor. At the time the UNIVAC I was being produced, a vacuum tube cost about seventy-five cents. The transistor had been invented only a few years earlier and initially cost far more than a vacuum tube. However, in many electronic circuits, a transistor could replace a vacuum tube, be much more reliable, and use much less power. Moreover, progress in transistor technology soon decreased their price.

Adjusting for inflation, in today's dollars the cost of a UNIVAC I was in the range of $8 million to $10 million. Contrast this with today's $1,000 laptop or desktop microcomputer that can do two billion operations per second. A rough calculation indicates that the cost per calculation has gone down by a factor of 10 billion since the early 1950s.

Here is an interesting tidbit of information for people who like large numbers (Turley, 2003):

> In 2001, there were about 60 million transistors built for every man, woman, and child on earth. By 2010, the number should be close to 1 billion transistors per person.

If a transistor was worth as much as a vacuum tube of the early 1950s, then a worldwide equal distribution of the transistor wealth would make every person on earth a multimillionaire.

Here is another tidbit of information that provides some insight into how ubiquitous computers have become. Today's new cell telephone contains more computer power than the leading-edge microcomputers of 10 years ago, making it possible for a cell telephone to provide telephone service, take pictures, play music and videos, and play games. Yearly worldwide sales of cell telephones are now about one per seven people on earth (Nelson, 2006).

Okay! Computers are here to stay. That doesn't mean that we all have to like computers. Indeed, for each of us, computers present both threats and opportunities.

An Example of Threats and Opportunities

As a young child, I learned to use the library in my school, the public library in my town, and the library at the university where my parents taught. Over the years, I have accumulated a good-sized personal library of books, journals, and magazines. I still spend quite a bit of money in this endeavor.

Nowadays, however, I depend more and more on the Web. The Web is now the world's largest library, and it continues to grow quite rapidly. Let's think for a minute about how the Web poses both threats and opportunities to faculty members and their institutions.

Historically, one of the hallmarks of a good college or university has been its large and up-to-date library. Now, each physical library faces competition from the Web. As the Web continues to grow, it will meet more and more of the information retrieval needs of students and faculty. This means that a large physical library's collective holdings will gradually be less of a competitive advantage to a college or university. Moreover, it means that each physical library is faced by the challenge of remaining economically viable and cost effective.

Now, I want you to think about the threats and opportunities the Web presents from the point of view of your college or university, and also from a personal point of view. Can you identify both threats and opportunities?

Here is an example that is probably important to your institution. The Web may be of considerable value to you and the students at your institution, but it also serves as a library for online colleges and universities that compete with your institution. Distance learning courses offered by competing colleges and universities may eventually attract significant student enrollment that lowers enrollment in the courses that you teach.

Here is another example. Your students may use the Web to do most of their literature searches for their class papers and projects. You know that the Web is still quite limited in the scholarly resources it makes available. You know your students are not very skilled in delving deeply into the Web resources that are available. Maybe you should be teaching them how to become better at using the Web. You also know it is easier to plagiarize from the electronic content available on the Web than it is from the hard copy materials in a physical library. As a teacher, you must deal with your students not making adequate use of the full range of research resources available, as well as with the possibility that they are plagiarizing (even to the extent of purchasing complete papers from online businesses that sell student papers).

By now, you get the idea. Consider any aspect of CIS or ICT that might directly affect you or your institution or department and its programs of study. With only a minimal amount of thought, you should be able to identify both threats and opportunities.

Some Direct Personal Threats

It is easy to become quite dependent on resources such as email and the Web. I depend very heavily on these resources, and I feel "lost" when they are not readily available and working correctly. It is not that I am addicted to the email and the Web (or is it?).

Electronic spam is a threat to all people who use email and various other types of Internet-facilitated communication. As Wikipedia describes it:

> Spamming is the abuse of electronic messaging systems to send unsolicited, bulk messages. While the most widely recognized form of spam is e-mail spam, the term is applied to similar abuses in other media: instant messaging spam, Usenet newsgroup spam, Web search engine spam, spam in blogs, and mobile phone messaging spam.

The spam messages may contain viruses, attempt to sell you products and services you are not interested in, and expose you to pornographic language and materials. Spam is a huge and growing problem. Quoting from NewScientist.com (December 11, 2006):

> A study released in November 2006 by email filtering firm Postini, based in California, U.S., found that spam now accounts for 91% of all email and that over the past 12 months the daily volume of spam has risen by 120%.
>
> A separate report, from IronPort Systems, also in California, concludes that worldwide spam volumes increased from 31 billion messages daily in October 2005 to 61 billion messages daily in October 2006.

Many people use the Internet and other ICT capabilities for predatory, unethical, and illegal activities. Many different activities fall into these categories. Some receive much more attention than others. For example, it seems as if it is becoming increasingly common for thieves to steal computer files (sometimes by stealing complete computers) containing personal information about a lot of people. This information can be quite useful in identity theft.

The social networking Websites, chat rooms, and other two-way Internet-based communication systems have become a vehicle for predators. Many students foolishly post information about themselves that may be useful to a predator or may later reflect negatively upon them if retrieved by a potential employer.

The spam email I receive frequently includes a bogus message from a bank or credit union telling me that my account is under attack or something has gone wrong with it and that I can correct the matter by providing them with various pieces of information. These are blatant attempts to gain information needed for identity theft.

A somewhat different Web threat is that the information I retrieve will possibly be incorrect. Schools, libraries, and parents have long played a significant role in screening the print materials made available to children and others. Research journals follow relatively rigorous peer review procedures to help ensure that the materials they publish meet high-quality content standards.

Now, however, it is very easy to be a publisher. At the current time, there are more than 100 million distinct Websites (Netcraft, 2006). I personally maintain two Websites. One contains thousands of pages of books, articles, and other material. The book you are currently reading is self-published and available free on one of my Websites. It has not been peer reviewed.

The point is that each user of email and the Web is faced by threats of spam, viruses, and poor or incorrect content. This means that each user of these ICT services needs to learn:

1. How to guard against spam, viruses, identity theft, and other criminal activities.
2. How to distinguish high-quality, reliable information from poor-quality, unreliable information.

Determining the quality of information falls within the teaching responsibilities of each faculty member. Part of your job is to help your students learn to use the Web and other libraries effectively to retrieve information relevant to the courses you teach.

Threats of Lost Files

Over the years, I have become more and more dependent on using a word processor with a spell checker and a grammar checker. While I occasionally scribble hand-written notes, essentially all of my writing is done on a computer. Word processing has been a valuable tool for me for more than 25 years.

However, three major threats result from my use of a word processor. First, there is the previously mentioned threat that a virus might destroy my files. Second, there is the threat that my hard drive might crash (perhaps making the contents of my hard drive permanently inaccessible). Third, there is the threat that other types of computer damage or failure may cause the loss of a file or parts of a file. For example, from time to time I worry that a fire might destroy my computer system.

In my many years of working with students who frequently use a word processor, I have stressed to them the need to routinely back up their files and to keep backup copies at an off-site location. From early on, I learned to do this for my own files. Even so, I have occasionally lost some files and parts of files that required a significant amount of effort to recover or rewrite.

There is another very scary way in which files can be lost. The storage media deteriorate over time, and the file structures and the media become so out dated that they are no longer readable on the computer systems available to most people. A document printed on acid free, good quality paper will be readable hundreds of years form now. What about the files stored on the various sizes and formats of floppy disks used over the past 20 years?

Over the years, I have attempted to "migrate" my files as newer storage media, files structures, and computer systems have become available. This is an ongoing struggle. What about my books, such as this one? While a few copies were printed for a recent symposium, there has been no widespread distribution of hardcopy of this book. A variety of ongoing efforts are made to archive the web, or important parts of the web. However, it is not at all clear that anybody will be able to access a copy of this book a hundred years from now. (Of course, you might wonder who would want to access a copy a hundred years form now. However, that is a different story.)

Many computer users do a very poor job of dealing with the threat of lost or damaged files. Most express little concern with the possibility that important files (such as family photographs and video) may not be retrievable one or two generations from now. Currently our educational system does a poor job in helping students learn to deal with these types of threats.

Threats of Entertainment

A number of colleges and universities now offer programs of study in the development of computer games. My book, *Introduction to Using Games in Education: A Guide for Teachers and Parents,* is available free on my Website (Moursund, 2006). The book stresses how the study and use of games can be used to teach general ideas of problem solving.

The book also discusses how people become addicted to games and gaming. This is certainly a threat to students of all ages. A good friend of mine failed in his graduate studies because playing solitaire games with an ordinary deck of playing cards became a lot more fun for him than studying.

An item in CNET News (2006) describes the situation this way:

> According to a study released this week, *Americans aged 13 to 18 spend more than 72 hours a week using electronic media*—defined as the Internet, cell phones, television, music, and video games. Because teens are known for multitasking, their usage of devices can overlap. [Italics added for emphasis]

Nowadays, on average, school-age children spend more time playing computer games than they spend watching television. On average, the total time they spend playing computer games and watching television during weeks that school is in session far exceeds the time spent in school. Many students carry these entertainment habits along with them as they go on to college.

Electronic games can be thought of as an extension of television. Think of interactive television in which you, the viewer, play an active role. You may be interacting with characters generated by the computer game or with characters that are created and run by people from throughout the world. There may be a simple plot line, or there may be a complex plot line that continues over a long period. The latter situation is much like the soaps and other long-running TV series.

Computer games get better year after year, as computers become more powerful and large amounts of money are spent on developing games that are increasingly attention grabbing and attention holding. The steadily increasing computer power makes it possible to develop more realistic and interactive games. Young adults are a significant portion of the market for such games.

Many college students find computer games to be quite entertaining, and some find them to be addictive. Many of these students have grown up with computer games. These games compete with the many other demands on college students' time. They also compete with higher education in another way. Much of the instruction students receive in class is "dullsville" compared to the fast-paced and exciting game environments.

Threats of Telecommuting, Offshoring. and Outsourcing

ICT makes it possible for people to work from home. Many people who want to work from home consider this to be a great opportunity.

However, the concept of telecommuting has been extended to include people who serve customers located thousands of miles away, even in different countries. Thus, workers in India can provide technical help and make sales via computer and telephone connectivity to customers in the United States. Accountants in China can prepare income tax returns for U.S. citizens. This practice is sometimes called *offshoring*.

Online learning provides an excellent example of a massive change being facilitated by computer technology. The Sloan Consortium (2006) gives the following figures:

> **Background:** For the past several years, online enrollments have been growing substantially faster than the overall higher education student body. …
>
> **The evidence:** There has been no leveling of the growth rate of online enrollments; institutions of higher education report record online enrollment growth on both a numeric and a percentage basis.
>
> - Nearly 3.2 million students were taking at least one online course during the fall 2005 term, a substantial increase over the 2.3 million reported the previous year.
> - The more than 800,000 additional online students is more than twice the number added in any previous year.

Online learning is increasing rapidly at the precollege level, with an estimated 500,000 student enrollments at the K-12 level in the United States in the year 2005-2006 (Powell & Patrick, 2006).

The rapid increase in online learning is a worldwide phenomenon. It provides great opportunities for students but is a major threat to traditional schools, colleges, and universities.

Online tutoring services are another aspect of online learning. One-on-one tutoring can be a highly effective aid to learning. However, such tutoring is quite expensive and beyond the means of many precollege and college students. The Internet—including telephone and picture phone features running on the Internet—have made it possible for educated people to compete for tutoring jobs located throughout the world. For example, consider a college student studying a foreign language. This student might be able to hire a well-educated, native-language speaker for three or four dollars an hour. A freshman in an engineering program of study might be able to have an English-speaking tutor who is a graduate of India's Institute of Technology, one of the top programs in the world.

A combination of global transportation systems and communication systems makes it possible for physical goods to be manufactured in countries throughout the world where low wages are paid. These products are then sold to customers throughout the world. This process is often called *outsourcing*. Customers gain the advantage of lower costs, but manufacturing workers in areas where higher wages are paid face the threat of losing their jobs. Many students are now concerned about whether they are getting an education that will lead to getting a good job.

Threats of an Inadequate Education

We need to be aware, however, that there are other very serious threats from CIS and ICT that receive much less media attention. ICT provides general-purpose aids to problem solving and communication. In that regard, ICT is somewhat similar to reading, writing, arithmetic, speaking, and listening. That is, ICT can be thought of as a powerful extension of the basics that schools have stressed for hundreds of years. Today's precollege and college students face the threat that they will receive a totally inadequate education in CIS and ICT. Sure, they will learn some things about computers on their own, but they may not necessarily get a good education in these areas.

Here is an offhand question that you can ignore if you like. How many adults living today learned to program a VCR on their own? The point of the question is that many people find it difficult to learn complex aspects of computers on their own.

CIS and ICT are broad and deep fields, They affect every academic discipline. Most students are getting only a superficial understanding of roles of ICT in representing and solving the types of problems they study in school. They are not learning how ICT is dramatically changing the jobs of the future and the worldwide competition for gainful employment.

You should not be mislead by your students' ability to learn to play computer games, to do instant messaging on a cell phone or computer, to download music, and so on. It is wonderful that students easily learn such things from each other. However, this level of ICT knowledge and skill is a far cry from the level of knowledge needed to routinely and confidently use CIS or ICT to help solve the types of problems and accomplish the types of tasks that make up the core focus in our educational system.

Final Remarks

Computer technology is a both very empowering and a very disruptive change agent. This change agent is itself changing quite rapidly.

Improvements in ICT and transportation help to create worldwide competition for certain types of jobs. The chances are that the future will bring more of this type of competition. Today's college students face the challenge of competing for jobs in a worldwide market. Today's faculty members face the challenge of educating their students for such a future. Furthermore, today's faculty members and their institutions face the challenge of online learning.

Part 2: Teaching and Learning

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

"An intellectual is someone whose mind watches itself." (Albert Camus; French novelist, essayist, and playwright, who received the 1957 Nobel Prize for literature.)

Over the past century, there has been substantial research on teaching and learning. During the second half of these hundred years, computers have become increasingly available both as an aid to research and as an aid to implementing the research. In the past 25 years, progress in brain science has begun to contribute to teaching and learning processes.

The four chapters in Part 2 examine some important aspects of our current knowledge of teaching and learning. The discussion has a CIS and ICT focus.

Chapter 5 provides an introduction to the science of teaching and learning. Research in this area provides the foundation for improvements in curriculum content, instructional processes, assessment, and student learning.

Chapter 6 discusses computer-assisted learning and distance learning. These two approaches to education are gradually merging, since computer-assisted learning materials are often delivered online.

Chapter 7 explores expertise within a discipline. Solving problems and accomplishing tasks are an important aspect of such expertise. Computers are playing a steadily increasing role in solving problems, accomplishing tasks, and enabling other uses of one's expertise in a discipline.

Chapter 8 provides an introduction to human intelligence and machine intelligence (artificial intelligence). The chapter discusses human and machine cognitive capabilities and limitations as well as the educational implications of the relative strengths and weaknesses of these two types of intelligence.

Chapter 5
Science of Teaching and Learning

"They know enough who know how to learn." (Henry Brooks Adams)

A newborn child's brain is designed to learn and to make use of what it learns. A physically and mentally fit newborn child has the ability to learn to communicate orally and to handle the types of learning required in a hunter-gatherer society. Evolution supporting such activities occurred long before the invention of reading, writing, and writing-based arithmetic and math.

The development of reading, writing, arithmetic, and a steady stream of new technology challenges human learning capabilities. I have always been somewhat amazed that an average child is able to learn reading, writing, arithmetic, and higher math, and to deal with the complexities of life in our current world. Put another way, it does not surprise me that so many children are challenged by such learning tasks. Wide-scale teaching of reading, writing, and arithmetic has only been going on for a couple of hundred years. This is not enough time for the "survival of the fittest" principle to select for strengths in these areas.

Many researchers and practitioners have studied teaching and learning, and how to make teaching and learning more effective. This chapter explores a few key ideas about the Science of Teaching and Learning (SoTL).

SoTL is also used to refer to the Scholarship of Teaching and Learning (Carnegie Institute, 2002). Scholarship of Teaching and Learning is a broader discipline that includes the Science of Teaching and Learning.

Constructivism

Constructivism is a widely accepted theory of learning; thus, it is part of the SoTL knowledge base. Constructivism is (E-School, n.d.):

> An approach to teaching and learning based on the premise that cognition (learning) is the result of "mental construction." In other words, students learn by fitting new information together with what they already know. Constructivists believe that learning is affected by the context in which an idea is taught as well as by students' beliefs and attitudes.

Constructivism focuses on the idea that each learner is different. We know this is true at the level of the neural patterns and strengths of connections among the neural patterns that represent a person's knowledge. There are substantial differences between the brains of identical twins raised together.

In her article "Constructivist Pedagogy," Virginia Richardson (2003) provides a nice overview of constructivist teaching:

> Constructivism as a learning theory goes back a number of decades (see Phillips, 2000). Constructivist teaching as a theory or practice, however, has only received attention for approximately one decade. Current interest and writing in constructivist teaching leave many issues unresolved. These issues relate, in part, to the difficulty in translating a theory of learning into a theory or practice of teaching, a conversion that has always been difficult and less than

> satisfactory. However, the nature of constructivism as an individual or group meaning-making process renders this conversion remarkably demanding. But there are additional aspects of constructivist pedagogy, some that are relatively pragmatic, such as those related to our expectations for teacher knowledge, that have lead to issues that are as yet unexamined or certainly not solved.

It is obvious that a group of students can all read the same chapter in a book, listen to the same lectures, and do the same homework—and end up with a considerably different knowledge and understanding of the material. Each student starts with different knowledge and understanding, and each student constructs unique new knowledge and understanding.

Faculty members vary considerably in how they deal with constructivism. There are many different books on constructivism and on constructivist ways of teaching. Some faculty put a lot of effort into helping individualize at least parts of the teaching and learning process and into developing assessment that accommodates the different learning that occurs. Others adhere more closely to a model in which all students learn the same things and exhibit their learning in the same manner. This is often referred to as a "factory model" of education.

Metacognition

Metacognition is part of the knowledge base of SoTL. As described in Wikipedia:

> Metacognition refers to thinking about cognition (memory, perception, calculation, association, etc.) itself or to thinking/reasoning about one's own thinking.

There has been substantial research supporting the importance of metacognition in learning.

Even kindergarten-age children can begin to learn about metacognition and to think about their own thinking. As students progress through school, they can learn about three important ideas described by Edward Vockell (n.d.):

> **Metamemory.** This refers to the learners' awareness of and knowledge about their own memory systems and strategies for using their memories effectively. Metamemory includes (a) awareness of different memory strategies, (b) knowledge of which strategy to use for a particular memory task, and (c) knowledge of how to use a given memory strategy most effectively.
>
> **Metacomprehension.** This term refers to the learners' ability to monitor the degree to which they understand information being communicated to them, to recognize failures to comprehend, and to employ repair strategies when failures are identified.
>
> **Self-Regulation.** This term refers to the learners' ability to make adjustments in their own learning processes in response to their perception of feedback regarding their current status of learning.

It may well be that some of these terms are new to you. Spend a couple of minutes doing metacognition on what you know about these three ideas, how the ideas are reflected in your own teaching, and how the ideas are reflected in how you learn new aspects of your academic discipline.

The following is representative of some of my metacognition about metamemory, metacomprehension, and self-regulation.

Metamemory

> Metamemory reminds me of conversations I have had with a number of students who have a variety of learning disabilities. What is it like to be ADHD, dyslexic, or to have dysgraphia? What is it like to be manic-depressive?

It was only recently that I read a magazine article about prosopagnosia (Face Blindness) and learned that my brain has this disorder.

All of the students I have talked with agree that it is important for people who have such challenges to learn about them as soon as possible and then to have professional help in learning to cope.

Thinking about this leads me to thinking about Piagetian cognitive development and the fact that many college students have not yet moved to the level of formal operations in some of the discipline areas. For example, I wonder what it is like to be faced by a math course that is being taught at a formal operations level, when one's brain is still firmly entrenched at the math concrete operations level. If I were teaching such a course, what could I do to identify such students and to help them? Is this part of my responsibility as a teacher?

What is it like to be dyslexic and have a brain that does not learn to read in the way most people learn to read? I have a grandchild who is dyslexic. I now know that one-on-one tutoring for an hour a day over a period of several years makes a huge difference for such students! However, I also know that there is computer-assisted learning software that is very useful in addressing this problem.

Metacomprehension

I have thought a lot about how to help students better monitor their own learning. All students are able to learn to monitor their own learning. However, our schools tend to do little to help them gain in their self-assessment metacognitive abilities. Sure, some help is available. A math teacher indicates that you can often check the answer you have produced by doing the problem over again in a different way. Also, you can check addition by subtraction, division by multiplication, and so on. You can also check many different types of math manipulations by using a calculator or computer. Hmmm. A calculator or computer can solve such problems. Why should a student be learning by-hand methods that compete with a calculator or computer? Might it be better to learn to understand the problem well enough so that one can "sense" when an answer that has been produced is obviously incorrect and learn to do mental estimates to aid in this sensing process?

Self-Regulation

I have read a variety of books and articles about learning and learning to learn. I wonder why our schools don't do a better job of helping students learn to learn and to self-regulate their own learning. I know that learning math is a lot different than learning history or music. So I believe that each teacher has a responsibility of helping students in their courses learn to learn within the discipline of the courses. I wonder if there is research on the effectiveness of this.

I have read a lot of articles and books about problem solving and teaching problem solving. Over the years, I have written several books on this topic. Each time I write such a book, I say to myself: "Now I think I really understand problem solving and how to help students get better at problem solving in the disciplines they are studying." Why is it that many students have so much trouble in learning to do problem solving, critical thinking, and other higher-order cognitive activities within the various disciplines they study? Does this reflect fundamental flaws in the way we teach, fundamental limitations in people's brains, or some combination of the two? (Aha! Another example of nature and nurture.) I am convinced that many faculty members could learn to do much better in helping their students to develop their problem solving and other higher-order cognitive potentials.

As college faculty, we all want our students to learn the specific content we are teaching. However, we also want them to learn how to learn this type of content. We know, of course, that precollege education of students varies widely in how well students learn to do metacognition, learn metacomprehension, and learn self-regulation. Thus, we are faced both by this unevenness of background in metacognition and by the need to help students become more skilled in metacognition within the disciplines we teach.

The Logo computer programming language for children and adults has proven to be an excellent research tool for studying metacognition and problem solving in a computer environment. As noted in Wikipedia:

> Logo was created in 1967 at BBN [Bolt, Beranek and Newman], a Cambridge, Massachusetts research firm, by Wally Feurzeig and Seymour Papert. Its intellectual roots are in artificial intelligence, mathematical logic, and developmental psychology. The first four years of Logo research, development, and teaching work was done at BBN.

In this vein, Douglas Clements and Bonnie Nastasi (1999) have described some their work on metacognition in a computer environment:

> As a result of our research on metacognition and educational computer environments, we propose a model of metacognitive processing and development that addresses individual and environmental factors and their interaction. The model has several assumptions:
>
> 1. An individual's metacognition and its development are influenced by interaction with environmental influences.
> 2. Metacognition functions at both conscious and unconscious levels. It occurs on both global (general executive processes) and local (task-specific instantiations of these executive processes inextricably connected to domain-specific knowledge) levels.
> 3. Certain environmental influences serve to mediate the relationship between external stimuli and metacognitive processing within the individual.
> 4. Mediators can be both social (e.g., teacher or peer) and physical (e.g., educational computer environment).
> 5. Changes in metacognitive processing as a result of experiences in educational computer environments can be explained by interactions with the computer, the teacher, and (in the case of collaborative work) peers.

There is a lot of information packed into these brief statements. Notice the idea of metacognition occurring at both a conscious and an unconscious level. There is considerable research in problem solving that stresses the importance of getting a problem into one's head and then letting the subconscious work on it over time. Notice also the idea of having an environment in which computers, the teacher, and one's peers are all working together to facilitate learning.

One of the important aspects of the graphics-oriented computer environment of the Logo programming language is that students can get a lot of useful and immediate feedback by using their brains to gain an understanding of what they are trying to accomplish. For example, if a student has in mind drawing a rocket ship that will take off and rise to the top of the computer display, then the student can look at the rocket ship that his or her program draws and see whether it looks like a rocket ship. The student can look at the performance of the rocket and see if it moves at a desired speed to the top of the display screen. This is an excellent environment for self-regulated learning and for learning to learn.

When working in such an environment a student can make plans on how to tell a computer to accomplish a certain task, learn to detect errors in the plan, and learn to correct errors in the plan. This type of debugging (error detection, error correction) lies at the heart of the admonition "revise, revise, revise" that is critical in writing, composing, and other project-oriented activities.

Here is an excellent summary from Wikipedia of some of the ideas associated with self-regulation in teaching and learning:

> Most researchers agree that the term "self-regulated" can be used to describe learning that is guided by metacognition (awareness of one's knowledge and beliefs), strategic action (planning, monitoring, and evaluating personal progress against a standard), and motivation to learn (Butler & Winne, 1995; Winne & Perry, 2000; Perry, Phillips, & Hutchinson, 2006; Zimmerman, 1990). In particular, self-regulated learners are cognizant of their academic strengths and weaknesses, and they have a repertoire of strategies they appropriately apply to tackle the day-to-day challenges of academic tasks. These learners hold incremental beliefs about intelligence (as opposed to fixed views of intelligence) and attribute their successes or failures to factors (e.g., effort expended on a task, effective use of strategies) within their control (Dweck & Leggett, 1988; Dweck, 2002). Finally, students who are self-regulated learners believe that opportunities to take on challenging tasks, practice their learning, develop a deep understanding of subject matter, and exert effort will give rise to academic success (Perry et al., 2006). In part, these characteristics may help to explain why self-regulated learners usually exhibit a high sense of self-efficacy (Pintrich & Schunk, 2002). In the educational psychology literature, researchers have linked these characteristics to success in and beyond school (Pintrich, 2000; Winne & Perry, 2000).

My conversations with many different college and university faculty members leads me to believe that, on average, students are getting worse at self-regulation of their learning. More and more, they want to be "spoon fed" and told exactly what to do. I strongly believe that this trend needs to be reversed!

Situated Learning Theory

Learning is highly dependent on the situation (the environment) in which the learning is occurring. Brown, Collins, and Duguid (1989), in a seminal article on situated learning, discuss the connections between learning and the learning environment.

> Recent investigations of learning, however, challenge this separating of what is learned from how it is learned and used. The activity in which knowledge is developed and deployed, it is now argued, is not separable from or ancillary to learning and cognition. Nor is it neutral. Rather, it is an integral part of what is learned. *Situations might be said to co-produce knowledge through activity. Learning and cognition, it is now possible to argue, are fundamentally situated.* [Italics added for emphasis]

For example, suppose you are walking down a jungle path and you hear a particular sound that your brain or mind does not immediately recognize. You "freeze," carefully look around, and see a large snake. The faint sound you heard was the snake slithering through the bushes.

Your brain or mind recalls that a friend of yours was seriously injured by a snake and the description your friend gave you seems to fit this snake. You immediately learn that the sound you have heard in this jungle trail environment is associated with a dangerous snake. Likely, this learning will last a lifetime. Moreover, the learning occurs very quickly—this is apt to be an example of one-trial learning. In the future when you walk along a jungle trail, your ears and mind will be tuned to hear a slithering sound.

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

Apprenticeships

Situated learning theory helps to explain the value of apprenticeship types of education and training. In apprenticeship situations, the learner is engaged in hands-on activities that are closely related to the desired learning outcomes. For example, an apprentice carpenter gets to carry, measure, and saw wood. The apprentice gets to help put pieces of wood together to help form objects such as a building or cabinet.

In summary, apprenticeships provide good illustrations of effective application of situated learning theory. An apprentice is provided with small-group or one-on-one instruction that is quite specific to the desired learning outcomes. The instruction and the assessment are authentic. In many apprenticeship settings, the apprentice does sufficient work to cover or more than cover the cost of providing the individualized help.

Apprenticeship Versus Formal Schooling

My father was a math professor, and woodworking was one of his hobbies. I learned to measure and saw boards and to pound nails by watching and imitating my father. Thus, I received an informal apprenticeship in the hobby of woodworking. In addition to that, I took a yearlong woodworking shop class while I was in junior high school. The informal apprenticeship was in a one-on-one environment, while the formal course constituted a class of 20 to 25 students. Each contributed to my learning of woodworking. Indeed, in the shop class I learned to use a lathe. This learning led my father and me to buy a lathe together, and he learned to use it under my tutelage.

My early childhood included an at-home apprenticeship in math. Both my father and mother had taught math at the precollege level, and they both taught math at the University of Oregon. Thus, to some extent I grew up in a math culture that included talking about math, having friends who were "into" math, and using math to help solve the problems one encounters in everyday life.

This home culture was strongly oriented to doing well in school, going to college, and perhaps going to graduate school. In the ninth grade, I was in a course that included a major term project involving the study of a vocation. I studied the vocation of being a math professor. By the ninth grade, my initial career path was clear in my mind, even though I really had no idea what college or graduate school math was or what math professors actually did.

There are three points I'm making here:

1. A child's home environment provides him or her with immersion in a variety of cultures.
2. One's home environment provides a variety of informal apprenticeships. These apprenticeships may tie in with a variety of hobbies, jobs, careers, and interests that may last a lifetime.
3. Some formal educational settings provide an environment that builds on the strengths of apprenticeships and on the value of immersing students in a specific culture.

The third point above is particularly relevant to uses of computers in education. Think of the analogy between a set of carpenter's tools and a set of computer-based tools. One can learn a lot about the use of computer-based tools by being immersed in an environment (situated learning) in which the tools are routinely used and in which specific instruction about the tools and their uses routinely occurs.

Thus, every faculty member has an opportunity to serve as a role model as he or she routinely demonstrates effective use of computer tools and, in the environment or context of a college course, provides informal and formal instruction in their use.

A strength of an apprenticeship system is that it combines learning by doing (in which feedback is provided both by the apprentice and the master) with the student simultaneously being immersed in a culture that embraces the discipline area of the master. This combination promotes learning, learning to learn, and lifelong learning.

Transfer of Learning

One of the most important ideas in learning involves learning in a manner that facilitates retaining and using one's learning in the future, as well as building future learning upon it. There are various theories about how to teach and how to learn in a manner that facilitates such transfer of learning. Here is a description of transfer of learning from David Perkins and Gavriel Salomon (1992), who provide an excellent, short overview of the field:

> Transfer of learning occurs when learning in one context or with one set of materials impacts on performance in another context or with other related materials. For example, learning to drive a car helps a person later to learn more quickly to drive a truck, learning mathematics prepares students to study physics, learning to get along with one's siblings may prepare one for getting along better with others, and experience playing chess might even make one a better strategic thinker in politics or business. *Transfer is a key concept in education and learning theory because most formal education aspires to transfer.* Usually the context of learning (classrooms, exercise books, tests, simple streamlined tasks) differs markedly from the ultimate contexts of application (in the home, on the job, within complex tasks). *Consequently, the ends of education are not achieved unless transfer occurs.* Transfer is all the more important in that it cannot be taken for granted. *Abundant evidence shows that very often the hoped-for transfer from learning experiences does not occur.* Thus, the prospects and conditions of transfer are crucial educational issues. [Italics added for emphasis]

Some faculty members seem to have an inherent, well-developed sense of how to teach and assess for transfer of learning. Others seem to have little insight into the importance of teaching for transfer. Perhaps they think that if they adequately and appropriately "cover" the material in a course, students will automatically learn in a manner that facilitates transfer. For the majority of students, that is a mistaken belief.

Near and Far Transfer

For many years, the prevailing theory of transfer of learning was quite simple. The actual transfer was called either *near transfer* or *far transfer*. In near transfer, one applied his or her learning to contexts and situations that were closely related to (near) the context and situation of the learning. In far transfer, the application was to contexts and situations that were rather different (far from) the learning context and situation. It was also common to first define near transfer and then define any learning that did not readily transfer as far transfer.

Perkins and Solomon (1992) describe this process further:

> Near transfer refers to transfer between very similar contexts, as for instance when students taking an exam face a mix of problems of the same kinds that they have practiced separately in their

> homework, or when a garage mechanic repairs an engine in a new model of car, but with a design much the same as in prior models. Far transfer refers to transfer between contexts that, on appearance, seem remote and alien to one another. For instance, a chess player might apply basic strategic principles such as "take control of the center"' to investment practices, politics, or military campaigns. *It should be noted that "near" and "far" are intuitive notions that resist precise codification. They are useful in broadly characterizing some aspects of transfer but do not imply any strictly defined metric of "closeness.*" [Italics added for emphasis]

Low-Road/High-Road Theory of Transfer of Learning

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

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

Rote memory is useful in problem solving, but it has severe limitations. The range of problems one encounters in everyday life is far too large to be handled just by rote memorization. Rote memorization is a slow process, and forgetting occurs unless the memorized facts and procedures are routinely used.

High-road transfer is based on learning some general-purpose strategies and applying them in a reflective manner. It focuses on critical thinking and understanding. Here is an example. When faced by a complex problem, try the strategy of breaking the complex problem into a number of smaller, less complex problems. This is called the divide-and-conquer strategy. If the resulting problems are simple enough, you may well be able to solve each of them by drawing upon your repertoire of memorized facts and procedures.

Here is a strategy for such teaching for high-road transfer of learning. When you are teaching a new strategy within a course:

1. Identify the generalizable strategy that is being illustrated and used in a particular problem-solving or higher-order thinking situation.
2. Give the strategy a name that is both descriptive and easily remembered.
3. Working with your students, identify a number of different examples in other disciplines and situations in which this named strategy is applicable.
4. Have students practice using the strategy in a variety of areas in which it is useful and where students already have appropriate general and domain-specific knowledge.
5. Take advantage of situations in your everyday teaching in which a particular problem-solving or higher-order thinking strategy is applicable. You have

probably already helped your students gain some initial expertise in using the strategy. Clearly name the strategy (or ask your students to name it) and work with your students to refresh their memories by using it in a variety of situations.

There are dozens of problem-solving and higher-order thinking strategies that are applicable over a wide range of disciplines. Research into student learning of problem solving indicates that most students have a relatively small repertoire of general-purpose problem-solving and higher-order thinking strategies. Most students are not being taught in a manner that facilitates high-road transfer of learning.

Roles of Computers in Transfer of Learning

Low-road transfer of learning focuses on rote learning at a stimulus-response, subconscious level. This type of learning is essential for situations that require very rapid response to problems and task situations. Learning for this quick automaticity response takes quite a bit of time. Once learned, however, quite a bit of the learning lasts for a long time.

A good example is provided by touch typing, or touch keyboarding. Students who progress to a speed of perhaps 10 to 15 words per minute will lose most of this skill over a summer of disuse. However, students who progress to a speed of about 25 words per minute will maintain most of this speed over a summer of disuse. It tends to take a fourth- or fifth-grade student about 40–50 hours of study and practice over a period of about 10 weeks to gain a level of automaticity that will have a long life.

Note that computer-assisted learning (CAL) (sometimes called computer-assisted instruction) can provide the equivalent of one-on-one tutoring for a student learning touch keyboarding. Indeed, sophisticated CAL keyboarding software can keep track of the speed and error levels for each finger and can adjust its training to take this data into consideration. Nowadays, it has become common for students to learn keyboarding via CAL.

All of us face the issue of what to learn to gain a high level of proficiency that will promote long-term, low-road transfer of learning. Schools attempt to make some of these decisions for students. For example, schools tend to insist that students learn to spell many thousands of different words and to master a collection of number facts. Even with tutorial CAL software, there are severe limits to how much one can memorize for use in low-road transfer of learning.

Information retrieval provides an alternative to rote stimulus-response type of learning. Computerized information retrieval adds some new dimensions to the static storage of information in a book. Think about a global positioning system (GPS). A GPS can quickly retrieve data being broadcast from a collection of orbiting satellites and use the data to calculate the GPS's location on earth. In conjunction with maps stored in the GPS and a voice output system, the GPS can show its user a map of the territory and give oral directions on how to get to a specified place.

Such a GPS might also be tied into the Web and respond to requests about nearby places of interest to tourists, history of the region, and entertainment at the nearby theaters and sports arenas. Through these Web connections, a person can make a dinner reservation, buy theater tickets, and summon a taxi.

The point is that we are living at a time when our educational system must learn to effectively deal with computerized information retrieval systems that are both aids to and partial replacements for rote memorization. These systems can also solve or help solve a wide range of problems. The commercial values of such computerized information retrieval and problem-solving aids are so high that such systems are becoming ubiquitous, independently of the interests our educational system. That is, our educational system is lagging far behind in terms of deciding upon and implementing appropriate uses of computerized information retrieval and problem-solving technology.

Study Skills and Learning to Learn

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

There has been quite a bit of research on how to help students learn faster and better. All of this work is part of the growing science of teaching and learning. It is somewhat surprising to me that our educational system has not done a good job of translating SoTL theory into practice. Our precollege schools place only a modest emphasis on learning to learn and developing good study skills. That may help to explain why I got about a million hits when I recently did a Google search on the expression *"study skills" college OR university.* This seems like an exceptionally large number, considering that beginning college students have already had 12 years of formal schooling during which they could have (should have) been learning study skills.

Think about this in terms of when you were in school. For example, what are good ways to learn math and social studies? Is there a difference in how one goes about learning these two different disciplines? Do the same learning techniques work equally well for all students? More generally, how can students tell if their learning processes are efficient and effective? Did your teachers help you to be good at self-assessment of your learning efficiency and effectiveness?

Study skills and learning to learn are closely related topics. There is a lot that one might learn about study skills. Kizlik (2006) provides short summaries of many effective study skills. For example, here is a description of one of them:

> **Question**—ask questions for learning. The important things to learn are usually answers to questions. Questions should lead to emphasis on the what, why, how, when, who and where of study content. Ask yourself questions as you read or study. As you answer them, you will help to make sense of the material and remember it more easily because the process will make an impression on you. Those things that make impressions are more meaningful, and therefore more easily remembered. Don't be afraid to write your questions in the margins of textbooks, on lecture notes, or wherever it makes sense.

There has been considerable research on environments that help or hinder in studying and learning. Such research provides insight into how one's brain can automatically, without conscious thought, filter out information that is not particularly relevant to what it thinks is important.

We understand why one needs to study in an environment that does not add significant additional challenges to one's filtering systems. Cognitive interference derives from thinking and mental processing that interferes with the learning task. Interference arises from multitasking and when negative or positive feelings and attitudes hamper the acquisition of new knowledge. For example, cognitive interference occurs when a student is reading a math book and attempting to solve a math problem while talking to a friend about going on a date.

Learning Styles

Learning styles are approaches to learning or ways of learning. Through some combination of nature and nurture, students develop some ways of learning that they find more useful than other ways of learning. These ways of learning may differ with the instructional design and presentation of material to be learned. Thus, it behooves a student to learn how they best learn various disciplines or components of disciplines and how to deal with the various instructional designs and methods of various faculty members. On the other hand, research in this area suggests the importance of good instructional design and good teaching, with the teaching helping to accommodate the needs of differing students. A good summary of these issues is given by M. David Merrill (1999).

My recent Google search of the quoted expression "learning style" produced over a million hits. The search identified many different Websites where students can take free tests to help determine their preferred learning style or styles.

Visual, Auditory, and Tactile/Kinesthetic Learning

One of the simplest approaches to learning styles consists of just three components: visual, auditory, and tactile/kinesthetic. LdPride.net (n.d.) describes these types of learners this way:

- Visual learners learn through seeing.

  > These learners need to see the teacher's body language and facial expression to fully understand the content of a lesson. They tend to prefer sitting at the front of the classroom to avoid visual obstructions (e.g. people's heads). They may think in pictures and learn best from visual displays including: diagrams, illustrated textbooks, overhead transparencies, videos, flipcharts and handouts. During a lecture or classroom discussion, visual learners often prefer to take detailed notes to absorb the information.

- Auditory learners learn through listening.

  > They learn best through verbal lectures, discussions, talking things through, and listening to what others have to say. Auditory learners interpret the underlying meanings of speech through listening to tone of voice, pitch, speed, and other nuances. Written information may have little meaning until it is heard. These learners often benefit from reading text aloud and using a tape recorder.

- Tactile/kinesthetic learners learn through moving, doing, and touching.

  > Tactile/kinesthetic persons learn best through a hands-on approach, actively exploring the physical world around them. They may find it hard to sit still for long periods and may become distracted by their need for activity and exploration.

Howard Gardner's Theory of Multiple Intelligences

Howard Gardner published his first book on the idea of *multiple intelligences* in 1983. Since then, he has become well known for his work supporting the idea that the human brain has specific regions that can be linked to specific types of intelligence. The multiple intelligences Gardner (2003) has identified are:

- Visual/Spatial Intelligence
- Verbal/Linguistic Intelligence
- Logical/Mathematical Intelligence

- Bodily/Kinesthetic Intelligence
- Musical/Rhythmic Intelligence
- Interpersonal Intelligence
- Intrapersonal Intelligence
- Naturalistic Intelligence

A number of Websites that discuss learning styles also discuss Howard Gardner's work on multiple intelligences. At LdPride.net (n.d.) you can take free self-assessment tests to determine your learning style as well as your dominant multiple intelligence.

Robert Sternberg's Theory of Multiple Intelligences

Robert Sternberg is a professor of Psychology and Education at Yale University, a prolific author, and a world-class expert in the field of intelligence. His three-part theory of intelligence is often stated simply as street smarts, school smarts, and creativity. More technically, he calls these the practical, analytic, and creative components of intelligence. Quoting from Sternberg (n.d.).

> [Successful intelligence is] the use of your intelligence to achieve success in your life. So I define it as your skill in achieving whatever it is you want to attain in your life within your sociocultural context—meaning that people have different goals for themselves, and for some it's to get very good grades in school and to do well on tests, and for others it might be to become a very good basketball player or actress or musician. So, it's your skill in obtaining what you want in life within your sociocultural context…
>
> Being successfully intelligent means knowing when you're in the wrong place at the wrong time-—the wrong job, the wrong relationship, the wrong place to live—through a combination of *analytical, creative and practical abilities. You need creative skills to come up with ideas; you need analytical abilities to know whether they're good ideas-to evaluate the ideas-and you need practical abilities to make your ideas work and to persuade other people that your ideas are worth listening to*. [Italics added for emphasis]
>
> Sternberg, Robert (n.d.). Interview with Dr. Sternberg: Transcript and video. Retrieved 5/10/07: http://www.indiana.edu/~intell/sternberg_interview.shtml.

A Broader View of Learning Styles

As indicated earlier in this chapter, there is an immense amount of literature on learning styles. Frank Coffield et al. (2004) offer a free report that analyzes 13 different learning styles from a teaching-and-learning point of view. The focus in this report is on students in "post-16" education in England, that is, students in educational programs designed for students over 16 years of age.

One of the 13 learning styles highlighted in the report is the Dunn and Dunn learning style instrument, which is described by Thompson and Mascazine (2003):

> The model of learning styles created by Dunn, Dunn & Price (1979, 1980, 1990) comprises five major categories called stimuli. Within these five major categories are 21 different elements that influence our learning. Following are the five types of stimuli and the elements they comprise:
>
> * Environmental includes: light, sound, temperature, and room design.
> * Emotional includes: structured planning, persistence, motivation, and responsibility.

* Sociological includes: pairs, peers, adults, self, group, and varied.
* Physical includes: perceptual strengths, mobility, intake, and time of day.
* Psychological includes: global/analytic, impulsive/ reflective, and right- or left-brain dominance.

Next, consider the following quote, again from Thompson and Mascazine (2003):

> *But perhaps the greatest benefit from attending to learning styles in mathematics or science education is that of placing more responsibility for learning on the students themselves.* Students who discover and understand their personal learning styles can and often do apply such information with great success and enthusiasm. (Griggs, 1991) Thus, attending to learning styles can be an ongoing consideration and aid in attacking new or difficult learning situations and the processing of information.
>
> As we learn more about the physiological and neurological functioning of the human brain, attending to learning styles becomes more credible and accepted. Mathematics and science educators can utilize such findings in small but significant ways. And while many elements of individual learning styles may be obvious to educators, students may not be aware or appreciative of them. *Thus it is important for educators to help individual students discover, utilize, and appreciate their own unique learning styles.* [Italics added for emphasis]

Notice the focus on individual students learning more about themselves as learners and taking increased responsibility for their own learning. All students can and should do this, and their teachers need to encourage such activity.

Here is an important point faculty members should consider from Coffield et al. (2004):

> The more sophisticated learning style models appreciate that different disciplines require different teaching, learning and assessment methods. Entwistle, McCune and Walker (2001, 108), for example, are clear on this point: "The processes involved in a deep approach have to be refined within each discipline or professional area to ensure they include the learning processes necessary for conceptual understanding in that area of study." *Alexander (2000, 561) knew he was adopting an unfashionable standpoint when he argued that it was a fact that different ways of knowing and understanding demand different ways of learning and teaching.* Mathematical, linguistic, literary, historical, scientific, artistic, technological, economic, religious and civic understanding are not all the same. Some demand much more than others by way of a grounding in skill and propositional knowledge, and all advance the faster on the basis of engagement with existing knowledge, understanding and insight. (pp. 66-67) [Italics added for emphasis]

Authentic Assessment

After many years of teaching in mathematics departments and then in a computer science department, I began teaching in a college of education. I can still remember my surprise and amusement when I heard people talking about the ideas of *authentic assessment* being put forth by Grant Wiggins (1990, 2002). What? My tests are not authentic?

Wiggins ideas are simple enough. Suppose I want students to become skilled at doing relatively complex Web searches using a search engine. Then I should test them in a hands-on environment in which they are expected to do rather complex Web searches using a search engine. As Wiggins (2002) notes:

> Authentic assessment, to me, is not meant to be the charged phrase, or jargony phrase that it has come to be for a lot of people. When we first started using it, 15 years ago, we merely meant to signify authentic work that big people actually do as opposed to fill in the blanks, paper and pencil, multiple choice, short answer quiz, school-based assessment. So it's authentic in the sense [that] it's real. It's realistic. If you go into the work place, they don't give you [a] multiple choice test to see if you're doing your job. They have some performance, some performance assessment, as they say in business.

The ideas of authentic assessment and authentic content are closely aligned. In simple terms, teach and role model what you want your students to be learning and then assess them on their learning in a manner consistent with how you expect them to use this learning. If you want to assess my skills as a writer, do not make me write a short essay by hand in a time-limited classroom environment. Have me write using a word processor with spell checker (a connection to the Web and a cup of coffee would also be appreciated) on a topic that interests me and that I know something about.

Some forms of instruction, such as project-based learning, essentially force authentic assessment. For example, suppose that you divide a class into teams and have each team work on a term-length project. Each team does a different project. Part of the requirement is that each team produce a written document that will be useful to members of other teams and that each team do an in-class presentation of their project using a computer projection system and appropriate multimedia.

You will provide students with relatively detailed rubrics that clearly specify assessment criteria. Indeed, class time will likely be spent discussing the rubrics. Some teachers use this time to allow students to participate in writing or modifying the rubrics.

Assessment will be based on the quality of the written document and the quality of the in-class presentation. Specific details of the assignment might include having each member of a team take responsibility for a specific piece of the content of their document, clearly indicating what they have done. This is not a whole lot different from a book being written by multiple authors, with each author writing a chapter. The authors have to cooperate so that the pieces tie together. In addition, each member of a team is responsible for doing a piece of the presentation. Since one goal of the project is to help team members get better at working together, evaluation of both the written materials and the presentations will take this goal into consideration.

Brain Science

Progress in brain science is contributing significantly to SoTL. During the past two decades, study of the human brain has been greatly aided by progress in the development of computerized brain-scanning systems. Progress in brain science is beginning to produce results that are useful to educators.

Here is an excellent example of success. A few years ago, two cognitive scientists compared notes on children who had severe speech delays. Perhaps two percent of children have great difficulty in learning to speak even though they have normal hearing.

It turns out that for many of these children, the phoneme processors in their heads run too slowly. Thus, when a string of phonemes comes into their hearing system, it cannot process them fast enough to actually process out the spoken words. According to Turner and Person (1999):

> Children acquire the basic sound units of language through normal development. English has 44 of the units, called phonemes, that occur in different transitions—some fast, some slow. The brain has to distinguish these transitions to discriminate between phonemes. It has been hypothesized that a language-impaired child cannot detect these rapid transitions (Tallal et al., 1993). A new training program, called Fast ForWord Language, is thought to be capable of improving the speech and language comprehension abilities of these children.

The researchers developed a computer game that greatly lengthened the sound pattern of each phoneme. Typical game-based rewards were provided for correctly deciphering phonemes.

Then the game gradually was speeded up. Use of the game for several hours a day over a period of four weeks led to a rewiring of the phoneme-processing center of the brain.

More recent Fast ForWord software developed by Scientific Learning Corporation has been used with considerable success in rewiring a reading-processing part of the brains of dyslexic students, actually curing dyslexia (Trei, 2003).

Final Remarks

The introduction to this book contains a brief discussion of instructional design and explains how the instructional design processes draw upon the theories of teaching and learning. SoTL is a vibrant field of research and practice. Thus, every teacher faces the challenge of understanding how computer technology and the current rapid progress in brain science are affecting teaching and learning.

This chapter includes brief introductions to important theories and concepts such as constructivism, metacognition, situated learning, transfer of learning, study skills, learning styles, and brain science. Remember, we just scratched the surface of a large discipline. There are other very important ideas—such as cooperative learning, mastery learning, project-based learning, inquiry-based learning, self-assessment, and so on—that were not discussed.

Perhaps you feel overwhelmed by the breadth and depth of some of the important components of SoTL and may not be clear about their relevance to your teaching responsibilities. If so, here is an idea. Select one aspect of SoTL and select one or two ideas from it that seem particularly relevant to teaching in your discipline. Try out these ideas in one or two class meetings in a course you teach and then spend some class time engaging your students in a discussion of the results. Repeat this process with ideas from another aspect of SoTL. When you find an idea that resonates with you and your students, use it in a larger part of your course. Develop a lifelong habit of trying out some new SoTL ideas in each course you teach.

Chapter 6
Computer-Assisted Learning and Distance Learning

> "Through learning we re-create ourselves. Through learning we become able to do something we never were able to do. Through learning we re-perceive the world and our relationship to it. Through learning we extend our capacity to create, to be part of the generative process of life. There is within each of us a deep hunger for this type of learning." (Peter Senge, 1990)

Distance learning (DL) refers to teaching and learning situations where the teacher and the students do not come together in face-to-face meetings. The roots of current DL lie in correspondence courses where interaction between the teacher and students was carried on using surface mail. Such instruction predates computers. Now, interaction is facilitated by electronic means such as email, the Web, and telephones.

Computer-assisted learning (CAL)—sometimes called computer-assisted instruction—refers to teaching and learning situations in which a computer system provides interactive instruction. I find it helpful to think of this as the computerization of some of the SoTL knowledge, teaching skills, and management skills of human faculty members.

Nowadays it is becoming increasingly common for CAL to be delivered over the Web. That is, we are seeing a gradual merger of the ideas of DL and CAL.

In addition, we are witnessing a paradigm shift in education, with an increasing number of students using CAL and DL for all or part of their higher education. Such forms of instructional delivery are also widely used in precollege education.

Feedback and Learning

Feedback is an important component of SoTL and is essential to learning. Thus, the design of effective instruction is heavily dependent on designing and providing effective feedback. Note, however, that our educational system is not nearly as good as it could be in implementing what we know about feedback. As Walt Haney (1991) notes:

> Common sense, theories of learning, and research on intrinsic motivation … all clearly indicate that the sort of standardized testing now commonly employed in schools and via which students do not get rapid or specific feedback on their work … is simply not conducive to learning.

Feedback that is essential to learning can come from inside or outside the learner. For example, if you listen to a small child babbling, perhaps making random sounds, you may sense that the child is gaining intrinsic internal feelings of pleasure in the process of making the sounds. This is an example of internal feedback. A mother or father may hear sounds that are vaguely similar to *ma* or *pa*. The parent immediately provides feedback, including guidance on better pronunciation of the sounds, enthusiasm, a broad smile, and other responses. This is an example of external feedback.

Internal (Self-Provided) Feedback to the Learner

Think about the situation of when you are reading and attempting to learn from an academic paper. The paper presents research results in a format that meets the standards of a particular discipline or journal. Typically, the format and standards are not particularly well designed to help learners, especially, learners who have a very low level of expertise in the discipline, in the learning process.

As you read, you think about (reflect on) what the article says. You test what it says against what you already know. You ask yourself questions to check on your growing knowledge. You reread sections that seem unclear or in order to better help you answer the questions you are asking. You are actively engaged in constructing new knowledge inside your brain, and you are actively engaged in providing feedback to yourself.

How did you develop these reflective, self-feedback skills? What could your teachers have done to help you gain such skills and help improve the quality of these skills? Are the college students you teach skilled in this type of reading, reflective, metacognitive processes? What do you do in your teaching to help your students get better at providing feedback to themselves?

Here is another example. Suppose you successfully solve a problem or complete a task that was personally challenging. During the process and afterward, do you do metacognition on the process and consider what you learned during the process? Do you think about what went right, what could have been done better, and what you learned? Metacognition and reflection are forms of self-feedback that you can engage in at any time and that will help you learn.

Now transfer the above ideas into your teaching. One of your teaching goals could be to help your students get better at providing feedback to themselves. How do your students develop the discipline-specific insights and maturity that help them detect when they are making mistakes, thinking poorly, or not understanding what they are reading, hearing, or viewing? What do you do to help them get better at these specific activities within the courses you teach? How do you assess this aspect of your teaching and your students' learning?

Feedback Coming from Outside the Learner

Much of the feedback that is essential to learning comes from external sources. There are many different types of such external feedback sources. A teacher asks the class a question, a number of students raise their hands volunteering to provide an answer, and one student provides an answer. However, all students have thought about whether they can provide an answer, and many have mentally rehearsed an answer. As the one student provides an answer, the attentive listeners use the information to check their own answers.

There are many ways to improve feedback from students to the teacher and from the teacher to students in a large lecture-hall situation. Eric Mazur (n.d.), a physics professor at Harvard, has developed a reputation for his innovation and research in this area. As he notes:

> Class time is a precious commodity, but how often do we stop to think about how it's being used? Should class activities merely transmit information that is already printed in the students' textbook? Do our students actually *learn* during class, or do they simply feverishly scribble down everything we say, hoping somehow to understand the material later?
>
> We are investigating ways that instructors can enhance student understanding, by promoting active learning in the classroom and pursuing strategies that meet the needs of diverse students.

Mazur and many other course instructors are now having their students use a handheld response unit (a "clicker") with which they respond to multiple-choice questions. (A computer and projection system accumulate the responses and display the results.) This is a good example where the use of computer technology can improve feedback both to the students and to the teacher in a large lecture setting.

Constructivism plays a significant role in feedback. As an example, consider reading through the course evaluation forms for a course you have just finished teaching. Do you pay special attention to the positive comments and use them to feel better about your teaching? Alternatively, do you pay special attention to the negative comments and use them to feel worse about your teaching? The point is that you construct meaning—you interpret and understand the data—based on your current knowledge, understanding, emotional state, and other factors. You can use this constructed meaning to improve your teaching.

Consider this from a student's point of view when you are making written comments on his or her work. Some students like computer-assisted learning because they feel the feedback is nonjudgmental and that it comes in a timely manner.

Feedback and Instructional Design

There has been considerable research on feedback and learning. B. F. Skinner is well known for his behaviorist work in operant conditioning (stimulus, response, and immediate feedback) as a form of teaching. In more recent times, cognitive learning theories have proven more appropriate to the design of curriculum for use in precollege and higher education.

As Steven McGriff (n.d.) explains:

> Under cognitive learning theory, it is believed that learning occurs when a learner processes information. The input, processing, storage, and retrieval of information are the processes that are at the heart of learning. The instructor remains the manager of the information-input process; but the learner is more active in planning and carrying out his/her own learning than in the behaviorist environment. *Instruction is not simply something that is done to a learner but rather involves the learner and empowers their internal mental processes.* [Italics added for emphasis]

As a teacher, you know the challenge of appropriate interaction with students in which you engage them and provide feedback and encouragement in a manner that facilitates learning of complex and challenging material. As you design a course or an individual class session, you think carefully about how to engage your students.

A commonly used instructional process is to have students interact with each other in small, cooperative learning and discussion groups. Such small-group interactions facilitate student engagement and let students provide feedback to each other. Such collaborative learning can go on in a classroom setting, but it can also go on in ICT-mediated communication. This idea is discussed more in Chapter 9.

Distance Learning (DL)

Here is a tidbit of history on DL (sometimes called distance education) from McIsaac and Gunawardena (1996):

> Distance Education is not a new concept. In the late 1800s, at the University of Chicago, the first major correspondence program in the United States was established in which the teacher and learner were at different locations. Before that time, particularly in pre-industrial Europe, education had been available primarily to males in higher levels of society. The most effective

form of instruction in those days was to bring students together in one place and one time to learn from one of the masters. That form of traditional educational remains the model today.

Actually, distance education has existed since the time of the first available written materials. A book is an excellent vehicle for teaching and learning. The book's author and the learner can be separated in terms of time and distance. The reader plays a major role in providing the feedback needed in learning from a book.

Learning by Reading

In U.S. elementary schools, there is a commonly accepted goal of having students learn to read well enough by the end of the third grade so that they can begin to learn by reading. By about the sixth or seventh grade, the assumption is that students will gain a substantial portion of their education by reading. However, students vary widely in how well they can learn through reading. This is an especially important issue in higher education, where the assumption is that students can and will do the required reading and will learn through this process. This is often a mistaken assumption.

In the past year or so, I have read quite a bit of research literature on students learning through reading. It turns out that there is a significant difference between being able to read and being able to read well enough so that one can readily learn by reading. This is particularly true in material that requires careful attention to details and that focuses on higher-order cognition. There is a huge difference between reading a math or physics book and reading a novel.

As far as I can tell from reading research literature and talking to faculty, we are not doing a particularly good job in helping our students learn to learn by reading their textbooks. This problem is aggravated as we begin to assign readings from the Web. A typical Web-based resource is not nearly as carefully written (not nearly as well designed to assist a student to learn by reading) as a textbook.

Thus, as a teacher you should think about what you are doing to help your students become better at learning by reading in the content areas you teach. What can you do to measure your success in this endeavor?

Improving Feedback in DL

Correspondence courses have a very low rate of interaction between a student and the teacher. However, they do force students into a learn-by-reading mode. Moreover, the nature of the feedback available through correspondence with an instructor places increased emphasis on students learning to provide feedback to themselves.

Of course, it is possible to design written materials specifically to aid students in their learning processes. Historically, distance education became more formal when print materials were developed that contained detailed lessons and assignments to be completed. Feedback might come from an answer key or through asking students questions that required higher-order thinking processes to formulate written answers to be mailed to an instructor.

The development of the telephone and two-way radio added a new dimension to DL because the teacher and student could converse with each other from time to time. DL delivery via television, perhaps with the aid of a telephone connection to individual students or a room full of students, led to a significant increase in its use.

The nature and quality of feedback available through a well-designed DL course can equal or exceed that which is available to students in a traditional large- or medium-sized lecture course. However, many of the types of feedback that can go on in a classroom setting are different from the types of feedback that are possible in a DL course. Thus, when students first encounter DL courses, they face the added challenge of learning to accept and use the types of feedback that are available through DL.

This observation is an underlying source of weakness in much of the DL research. Students spend many years learning to learn in a teacher-led classroom environment. The students then take a DL course, and their learning is compared to the learning of students in the traditional classroom. I find it somewhat surprising that even without the years of experience in DL, the typical result in such studies is that there is no significant difference between the amount of learning that takes place in the two types of courses. Thomas Russell (n.d.) has developed a Website devoted to this "no significant difference" phenomenon. It is a good source of research iterature on the topic.

Asynchronous and Synchronous DL

Correspondence courses are asynchronous—students work on a time schedule that fits their own needs and they work independently of each other. This situation changed when radio broadcasts and, later, TV broadcasts became a common component of DL. The student had to listen to the radio or view the TV when the broadcast was occurring. This synchronous instruction was combined with asynchronous work on assignments, which were mailed to the instructor.

Of course, as tape recorders and inexpensive VCRs became available, tapes could be mailed to the student or the student could record a program for later use. Thus, the use of radio and TV delivery was easily converted to allow for asynchronous DL.

In formal school settings, it became relatively common to have students who were taking a TV-delivered course to meet in classrooms that had a telephone connection to the instructor. A few students could ask questions during the time of a lecture or demonstration. This is not unlike the "call in" radio and TV programs that are now quite common.

Now it is common to use two-way video so that a DL instructor can see and talk to students located at a distance, and vice versa. This type of synchronous instruction is somewhat classroom-like, but a teacher may be simultaneously working with several groups of students from different locations.

Initially, this type of connectivity was relatively expensive. As Internet II and other high-speed networks have become more common, the cost of connectivity in this type of synchronous DL has decreased substantially.

As email became available, asynchronous email-based distance education courses were developed. The email made it easier and quicker for students to interact with the instructor and each other.

More recently, Internet chat groups and Web-based two-way video have significantly changed distance education. While the postal services throughout the world are still used for some DL, the Internet has greatly expanded the use of DL.

Finally, we come to the current situation. The Web can be used to hold ordinary telephone conversations and conduct video interactions. Thus, the Web can be used to deliver synchronous DL. Of course, the Web can also be used to deliver asynchronous DL, with students having access to multimedia course materials at a time that fits their convenience.

The use of asynchronous and synchronous DL is steadily increasing. One can get a high school education, college education, and even a master's and doctorate degrees through accredited DL programs.

Learning in a DL environment is different from learning in traditional school classrooms, where one has daily face-to-face communication with fellow students and the teacher, and the class as a whole follows the same time schedule. Skill in learning via DL is now considered a valuable lifelong skill. Some people are now recommending that all students should take part of their precollege education and college education via DL so that they will gain the knowledge and skills needed to learn in this environment.

Computer-Assisted Learning

Think about the various roles played by faculty members and students, and their interactions in the overall teaching and learning process. Then think about what aspects of these roles and interactions can be aided or facilitated by computer technology. Whatever you can think of probably is part of the fields of computer-assisted learning (CAL) and DL.

Use of Simulations—Early and Continuing Success

People have been thinking about CAL since the early days of the development of the electronic digital computer. A major initial success occurred as the U.S. developed and deployed radar systems that were designed to detect airplanes and missiles in route to the U.S. from the U.S.S.R. The whole radar system was highly computerized. Operators sat at computer display screens that provided information about what the radar systems were detecting and what computer analysis of these signals was showing.

From the point of view of an operator, it is not possible to determine from current radar readings being processed through computers whether the displayed information is live or simulated. The simulated displays could be from stored radar readings or could be simulations created specifically to help train the operators.

This type of very highly realistic CAL works very well. There is now a long history of the use of simulation-based CAL in training airplane pilots, astronauts, tank crews, nuclear reactor operators, and other jobs. Generally, use of such simulations is more effective, more cost effective, and less dangerous than other applicable forms of instruction.

Many different areas of research make use of modeling and simulation. The same models and simulations can often serve as a starting point for developing simulation-based CAL. There is quite a bit of this type of CAL available commercially (Laser Professor, n.d.).

Less Expensive CAL

As computers became less expensive, many people developed and tested a wide variety of forms of CAL. It is quite easy, for example, to develop a drill-and-practice system that is better than just using flash cards that have a question on one side and an answer on the other side. A computer system can keep detailed data on correct and incorrect responses and the speed of the various responses. It can detect patterns of errors. It can stop the drill-and-practice activity and insert specific instructions on a topic that is causing the student trouble. It can increase or decrease the difficulty of the questions.

More sophisticated CAL systems—often called tutorial systems—can present instruction interspersed with questions. The student responses provide information that shapes the instruction. Tutorial CAL systems are a little bit like having an individual human tutor.

An individual human tutor has good knowledge of both content and pedagogy. The human tutor builds a mental model of the student's knowledge and skills. The instruction is thus tailored to fit constructivist learning theory and includes immediate feedback. Wouldn't it be nice if every student could have a personal tutor who was competent in each subject area of interest to the student and available on a round-the-clock basis?

It is easy to understand why so many people have thought about CAL as a vehicle to revolutionize education. Over the years, thousands of CAL systems were developed and many hundreds of research projects were carried out on these products. Eventually people began to do metastudies—studies of the studies. Finally, enough metastudies had been done so that it was feasible to do a meta-metastudy. The first meta-metastudy of CAL, conducted by James Kulik (1994), provided strong evidence of the effectiveness of CAL, with students (on average) learning via CAL 30 percent faster and somewhat better than students in control groups.

Here are four major barriers to the widespread use of CAL in higher education:

1. A human tutor can interact with students orally. We are still many years (perhaps two to three decades or more) away from having computer systems that carry on a high-level, deep conversation at a human level of understanding. However, the quality of voice input/output is improving and now has a number of commercial uses.

2. High-quality, highly interactive CAL is quite expensive to develop. My personal insight into this area suggests that it costs about $5 million to develop a reasonably good quality, semester-length course for use in one specific discipline. Maintaining and regularly updating such a course costs about $1 million a year.

   These costs are modest for high-enrollment courses, if one considers the total national or international enrollment in such courses. In the U.S., there are enough students beginning college each year so that it would be economically feasible to have a half dozen or more competing CAL courses in each of several different subject areas.

3. Education is far more than just the delivery of instruction and learning of content. Residential colleges and universities provide an environment that facilitates students learning about the human condition, their own culture, and other cultures, as well as how to interact with people in many different settings, how to work together in teams, how to learn from each other, etc.

4. Our educational system has a life and character of its own. Its employees, volunteers, students, and graduates all have a vested interest in preserving

our educational institutions and system in their current format. Our educational system is innately highly resistant to change.

Hybrid Courses

The term *hybrid course* is used to describe a course that is some combination of traditional class meeting time (perhaps enhanced by appropriate use of technology during the class meetings), CAL, and DL.

The Open University in England provides a good example of an entire university based on DL along with –some hybrid courses. This university was established in 1969. Television and videotapes originally were the primary mode of instructional delivery. However, courses that traditionally included lab work (such as science courses) scheduled the labs at various colleges and universities, and were thus hybrid courses..

As described in Wikipedia:

> The [Open] University awards undergraduate and postgraduate degrees, diplomas and certificates.
>
> With more than 180,000 students enrolled, including more than 25,000 students studying overseas, it is the largest academic institution in the UK by student number, and qualifies as one of the world's mega universities. Since it was founded, more than 3 million students have studied its courses. *It was rated top University in England and Wales for student satisfaction in the 2005 and 2006 UK government national student satisfaction survey.* [Italics added for emphasis]

The Open University was originally developed mainly to serve students who had previously participated in a vocationally oriented track of secondary school education. A substantial amount of money was invested in developing the courses (perhaps $1 million per course during the 1970s) and keeping them up to date. This large and continuing investment may help explain the high level of student satisfaction mentioned in the quote above.

Entrepreneurial Thinking

The Spellings report on higher education (Spellings, 2006) was discussed briefly in the Introduction to this book. One of its recommendations is that higher education should be more entrepreneurial.

There is a long history of for-profit college and universities. In 2001, Richard S. Ruch authored a book entitled *Higher Ed, Inc.: The Rise of the For-Profit University* (2001). Here is a quote from a review of this book (Flanagan, 2002):

> Although for-profit education in the United States dates from the Colonial era, Ruch traces only the recent developments … [of five specific] for-profit institutions, which have benefited from the economic atmosphere in the United States during the 1990s. He identifies 1996 as a year in which both the advent of the majority of publicly traded higher-educational companies and the U.S. Department of Education's recognition of for-profits as accredited educational institutions "[eligible] for Title IV Funding" helped to increase "the number of institutions in the higher education universe by 7.5 percent" (pp. 60-61). The recent growth of for-profit institutions permits Ruch to assert that they have attained "a new level of legitimacy through the decade of the 1990s. (p. 51)."

In 2005, approximately 4 percent of higher education students in the U.S. were enrolled in for-profit institutions. Many of these institutions are using DL extensively, and their total enrollment is growing. Estimates are that by 2015 they will enroll about 10 percent of U.S. students in higher education (Blumenstyk, 2005).

The Open Learning Initiative (OLI) at Carnegie Mellon University provides a good example of a possible paradigm shift in higher education. OLI has been described this way (Open Learning Initiative, 2006):

> A major difference between OLI and other online education programs is that OLI incorporates extensive research into how people successfully learn undertaken by professors at Carnegie Mellon and the University of Pittsburgh's Learning Research and Development Center. The courses provide real-time feedback, pinpoint students' individual weaknesses and provide them with individualized tutoring so they are able to work at their own pace. Courses currently available include chemistry, French, logic, causal reasoning, and statistics.

According to the research done at Carnegie Mellon, students learned just as well through the DL statistics course as they did through the conventional course. The same article conjectures that OLI students may be able to move through this course twice as fast as they move through the conventional course. There are now plans underway to test this conjecture.

Final Remarks

The movement toward substantially increasing the use of DL and CAI is being aided by a variety of Open Education Resources (OER) movements. The OER (n.d.) Website describes OER materials this way:

> OER are teaching, learning, and research resources that reside in the public domain or have been released under an intellectual property license that permits their free use or re-purposing by others. Open educational resources include full courses, course materials, modules, textbooks, streaming videos, tests, software, and any other tools, materials, or techniques used to support access to knowledge.
>
> …
>
> *At the heart of the movement toward Open Educational Resources is the simple and powerful idea that the world's knowledge is a public good and that technology in general and the Worldwide Web in particular provide an extraordinary opportunity for everyone to share, use, and reuse knowledge.* OER are the parts of that knowledge that comprise the fundamental components of education—content and tools for teaching, learning, and research. [Italics added for emphasis]

Right now we are in a transition from hardcopy books and other print materials being the dominant mode of transferring educational information to the Internet being the dominant mode. But while we are clearly moving in the direction of electronic information retrieval, hardcopy print materials will be with us for a long time to come.

Chapter 7

Expertise and Problem Solving

"It is bad enough to reinvent the wheel. What really hurts is when they reinvent the flat tire." (Lee Shulman, Stanford University)

"An educated mind is, as it were, composed of all the minds of preceding ages." (Bernard Le Bovier Fontenelle, mathematical historian, 1657-1757

Education and training within a specific discipline can have many different goals. However, a unifying goal is to help learners gain an increased level of expertise in solving the problems and accomplishing the tasks of the discipline.

This chapter explores roles of ICT and CIS in helping people gain and use expertise within a discipline. The key idea is that a steadily increasing amount of knowledge and skill is being built into the tools available. These "knowledgeable" tools help people draw upon the accumulated human knowledge within each discipline, and they aid researchers working to advance the frontiers of this knowledge within their disciplines.

What Is a Discipline?

Each academic discipline can be defined by a combination of general things such as:

- The types of problems, tasks, and activities it addresses.
- Its accumulated accomplishments, including results, achievements, products, performances, scope, power, uses, impact on the societies of the world, and so on.
- Its history, culture, and language (including notation and special vocabulary).
- Its methods of teaching, learning, assessment, and thinking. This includes what it does to preserve and sustain its work and pass it on to future generations.
- Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, and recording and sharing accumulated results.
- The knowledge and skills that separate and distinguish among (a) a novice, (b) a person who has a personally useful level of competence, (c) a reasonably competent person, (d) a regional or country-wide expert, and (e) a world-class expert. Each discipline has its own ideas as to what constitutes a high level of expertise within the discipline and its subdisciplines.

Each academic discipline benefits from reading, writing, libraries, telecommunications, and a variety of other tools. However, some academic disciplines are far more tool-use-oriented than others.

Let's spend a short time thinking about the discipline of music. Within music, there is a subdiscipline called *a cappella* singing. Expertise in a cappella performance depends only on the use of human voices. Indeed, a person might become very good at a cappella singing without knowing how to read a natural language or music. Gregorian chant, dating back more than a thousand years, is an early example of a cappella singing.

For another example, consider drawings and other art on cave walls that may date back as much as 40,000 years. These early, low-tech artists used pigments produced from materials gathered from nature. We still have artists who use very little technology in producing their products.

On the other hand, we now have digital music, and many musicians have developed a high level of expertise in digital music. We now have the digital arts, and many artists have developed a high level of expertise in the digital arts. Within some parts of each of the older disciplines, such as art and music, one can have a high level of expertise that does not take into consideration or depend upon the more recent digital technology and tools. On the other hand, within each of the older disciplines, one can develop a high level of expertise in the digital aspects of the discipline.

Expertise

Figure 7-1 is a general-purpose expertise scale. At the left end of the scale, a person's knowledge and skills in an area may be so limited that some unlearning needs to occur to move up the scale. For example, this situation exists in some parts of science, where a person's initial learning is wrong and does not serve as a useful foundation for the topics being taught in a course.

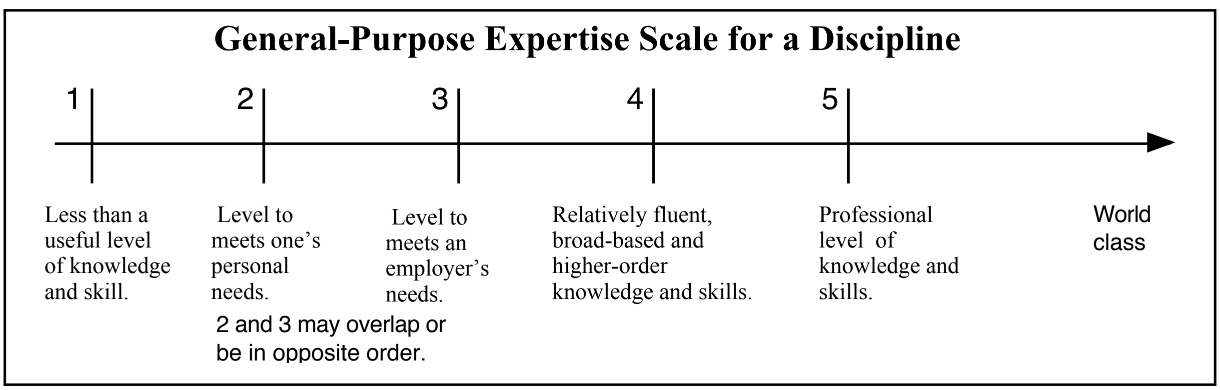

Figure 7-1. General-purpose expertise scale.

Consider a limited subdiscipline you have not previously encountered. Then think about the level of expertise you might achieve in this subdiscipline in 1 hour, 10 hours, 100 hours, 1,000 hours, and 10,000 hours of study and practice. The level of expertise you will achieve depends on a number of things, such as your current level of expertise in closely related areas, your innate ability in the area, the quality of instruction and coaching you receive, and your dedication and perseverance. This simple set of observations lies at the very heart of education. A well-designed and well-implemented educational system helps students gain expertise faster than they would gain it without any outside help.

In gaining an increased level of expertise in any area, both nature and nurture are important. It is not clear whether the extent to which your final level of expertise in an area depends more strongly on your innate abilities (nature, genetic disposition) or on the nurture you receive (Ericsson, n.d.). Moreover, there is the issue of intrinsic motivation and drive versus extrinsic motivation, or being coerced to do the studying and practice. The following quote from Jonah Lehrer (2006) helps capture the basic elements of nature-versus-nurture arguments:

> Two obvious rebuttals to the argument that talent is just a matter of learning by doing are Mozart and Tiger Woods. Mozart famously began composing symphonies as an eight-year-old, and Woods was the world's best golfer at 21. But do they really contradict the "learning by doing" principle?
>
> Not so much. Mozart began playing at two, and if he averaged 35 hours of practice a week—his father was known as a stern taskmaster—he would, by the age of eight, have accumulated Ericsson's golden number of 10,000 hours of practice. In addition, Mozart's early symphonies are not nearly as accomplished as his later works. John Hayes of Carnegie Mellon has shown that modern symphony orchestras almost never perform or record Mozart's childhood compositions, and argues that Mozart's early works would have long ago been forgotten, were it not for his mature masterpieces. In other words, Mozart's genius wasn't innate or instantaneous—he learned how to write immortal symphonies by writing lots of mediocre ones.

Lehrer goes on to say:

> [Tiger] Woods is the best golfer in the world because he has devoted his entire life to golf. Thanks to an encouraging father who happened to be a golf fanatic, Tiger took his first golf swing before he took his first steps. When he was 18 months old, his dad started taking him to the driving range. By the age of three, Tiger was better than most weekend amateurs.
>
> This allowed Woods to get a head start on his current competitors, but what really made him great is how he practices. For starters, his routine is merciless. Rain or shine, Woods sets out. More importantly, he always makes sure his practice sessions revolve around learning by doing. He analyzes sequential snapshots of himself playing, relentlessly scrutinizes the elements of his swing, then drills these subtle alterations into his nervous system through thousands of repetitions. Of course, more practice leads to more new ideas, which leads to more practice. "Other golfers may outplay me from time to time," Woods wrote in his book, "but they'll never outwork me."

In any event, the quantity 10,000 hours is frequently mentioned as the amount of time it takes to achieve one's potential or come close to achieving one's potential. (The figure 10 years is also often used as an estimate, instead of 10,000 hours.) Thus, for example, suppose you have never played a game of chess. In 1 hour, you can learn the rudiments of what constitutes a legal move and what constitutes winning a game. In 10,000 hours, you will approach being as good as you can be.

In chess, however, additional hours of study and practice will likely continue to move you up the expertise scale. For example, the current average age of the world's top-ranked human chess players is about 30. These people have put in 30,000 to 40,000 hours or more in gaining their current level of chess expertise.

For a second example, consider a faculty member with a doctorate who has just been promoted to an associate professorship in a highly ranked research university. This person has probably put in well over 20,000 hours to achieve his or her current level of discipline-specific expertise.

While there are some young prodigies in music performance, world-class instrumentalists typically have put in 20,000 to 30,000 hours to achieve their current level of expertise.

Consider a student who begins to receive some formal instruction in math while in kindergarten, and then takes math every year up through his or her freshman year in college. I would estimate that this student has invested more than 2,000 hours of time at school and home in developing the level of expertise that he or she has attained.

In addition, the student has had a lot of informal instruction and practice in various aspects of math, such as dealing with money, scoring in games, figuring out performance statistics of sports figures, and so on. This is a huge investment of time and effort.

There is considerable agreement that math is a challenging discipline and that spending more than 2,000 hours of instruction, study time, and informal experience only produces a modest level of mathematical. Indeed, the majority of students who go to college tend to give up on their math pursuits at or before the time they take a freshman college algebra course. Thus, they have not studied calculus and most other math developed during the past 300 years.

What is the nature-versus-nurture balance in these math education results? Are we pushing the limits of average human mathematical intelligence, or are the results relatively poor because of the quality of instruction, instruction materials, aids to learning, and other factors? This question has not been well researched.

In recent years, the U.S. National Science Foundation and many other funding agencies have invested heavily in supporting the development of better math curricula, supportive materials, and staff development at the precollege level. The modest level of gains that have resulted from these investments lend credence to the Upper Limit Theory in math education at the precollege level. This upper limit may be due to nature and nurture. A paradigm shift to better nurture may lead to students obtaining a higher level of expertise in math.

The above analysis for math education can be carried out for each academic discipline. The research focusing on one-on-one tutoring suggests that our current upper limited results are not due primarily to nature—that improved nurture (teaching) can move the average student to a much higher level.

Research on Expertise

There has been substantial research on expertise and gaining expertise in various disciplines. Some of this is summarized in (Ericsson, n.d.), who discusses ideas highly relevant to higher education in any discipline:

> *The difference between experts and less skilled subjects is not merely a matter of the amount and complexity of the accumulated knowledge; it also reflects qualitative differences in the organization of knowledge and its representation* (Chi, Glaser & Rees, 1982). Experts' knowledge is encoded around key domain-related concepts and solution procedures that allow rapid and reliable retrieval whenever stored information is relevant. Less skilled subjects' knowledge, in contrast, is encoded using everyday concepts that make the retrieval of even their limited relevant knowledge difficult and unreliable. Furthermore, experts have acquired domain-specific memory skills that allow them to rely on long-term memory (Long-Term Working Memory, Ericsson & Kintsch, 1995) to dramatically expand the amount of information that can be kept accessible during planning and during reasoning about alternative courses of action. The superior quality of the experts' mental representations allow them to adapt rapidly to changing circumstances and anticipate future events in advance. *The same acquired representations appear to be essential for experts' ability to monitor and evaluate their own performance (Ericsson, 1996; Glaser, 1996) so they can keep improving their own performance by designing their own training and assimilating new knowledge.* [Italics added for emphasis]

One of the key ideas here is that experts learn how to learn in their area of expertise, and they learn how to self-assess. This suggests that we might want to place more emphasis on these two general ideas in all of our teaching.

A nice summary of some of the research on expertise—with a special emphasis on research on chess experts—is available in Phillip Ross's (2006) work. In talking about long-term working memory, Ross says:

> The one thing that all expertise theorists agree on is that it takes enormous effort to build these structures in the mind. Simon coined a psychological law of his own, the 10-year rule, which states that it takes approximately a decade of heavy labor to master any field. Even child prodigies, such as Gauss in mathematics, Mozart in music and Bobby Fischer in chess, must have made an equivalent effort, perhaps by starting earlier and working harder than others.
>
> …
>
> *Ericsson argues that what matters is not experience per se but "effortful study," which entails continually tackling challenges that lie just beyond one's competence. That is why it is possible for enthusiasts to spend tens of thousands of hours playing chess or golf or a musical instrument without ever advancing beyond the amateur level and why a properly trained student can overtake them in a relatively short time.* It is interesting to note that time spent playing chess, even in tournaments, appears to contribute less than such study to a player's progress; the main training value of such games is to point up weaknesses for future study. [Italics added for emphasis]

I find the educational implications of these statements quite interesting. Experts in a discipline have learned to do the "effortful study" that advances expertise, and they put in the thousands of hours of effort needed to move to a high level of expertise. A good teacher or a good coach helps students learn to do this type of effortful study.

Ross also gives a brief summary of studies that attempt to get at the issue of nature versus nurture in achieving a high level of expertise. He concludes that, "the preponderance of psychological evidence indicates that experts are made, not born. What is more, the demonstrated ability to turn a child quickly into an expert—in chess, music and a host of other subjects—sets a clear challenge before the schools."

Problem Solving

In discussing problem solving situations, I include the following:

- Question situations: recognizing, posing, clarifying, and answering questions
- Problem situations: recognizing, posing, clarifying, and then solving ill-defined problems and problem situations
- Task situations: recognizing, posing, clarifying, and accomplishing tasks
- Decision situation: recognizing, posing, clarifying, and making good decisions
- All situations: using higher-order critical, creative, wise, and foresightful thinking to do all of the above. Often the "result" is shared, demonstrated, or used as a product, performance, or presentation.

It is common to think of expertise in terms of performance in solving the problems and accomplishing the tasks within a discipline or subdiscipline. There is a large amount of research on teaching and learning problem solving. One can study aspects of problem solving that cut across all disciplines, and one can study discipline-specific aspects of problem solving.

Here is a definition of *problem* that I have found useful in my teaching and writing:

> You (personally) have a problem if the following four conditions are satisfied:
>
> 1. You have a clearly defined given initial situation.
> 2. You have a clearly defined goal (a desired end situation). Some writers talk about having multiple goals in a problem. However, such a multiple goal situation can be broken down into a number of single-goal problems.
> 3. You have a clearly defined set of resources that may be applicable in helping you move from the given initial situation to the desired goal situation. These typically include some of your time, knowledge, and skills. Resources might include money, the Web, and the telephone system. There may be specified limitations on resources, such as rules, regulations, guidelines, and timelines for what you are allowed to do in attempting to solve a particular problem.
> 4. You have some ownership—you are committed to using some of your own resources, such as your knowledge, skills, time, and energy, to achieve the desired final goal.

In many problem-solving situations, ICT and computerized tools are resources of the type mentioned in the third part of the definition. These resources have grown more powerful over the years. That is one reason why it is so important to integrate the use of computers in problem solving thoroughly into the basic fabric of coursework.

The fourth part of the definition of a problem is particularly important. Unless a student has ownership—an appropriate combination of intrinsic and extrinsic motivation—the student does not have a problem. Motivation, especially intrinsic motivation, is a huge topic in its own right, and I will not attempt to explore it in detail in this book. Edward Vockell (n.d) maintains an online book, *Educational Psychology: A Practical Workbook*. The fifth chapter provides a nice introduction to motivation.

George Polya

George Polya was one of the leading mathematicians of the 20th century, and he wrote extensively about problem solving. His 1945 book, *How to Solve It: A New Aspect of Mathematical Method,* is well known in math education circles (Polya, 1957).

In *The Goals of Mathematical Education* (Polya, 1969) transcribes a talk he gave to a group of elementary school teachers. Some of his comments, I think, are relevant to all teachers:

> To understand mathematics means to be able to do mathematics. And what does it mean doing mathematics? In the first place it means to be able to solve mathematical problems. For the higher aims about which I am now talking are some general tactics of problems—to have the right attitude for problems and to be able to attack all kinds of problems, not only very simple problems, which can be solved with the skills of the primary school, but more complicated problems of engineering, physics and so on, which will be further developed in the high school. *But the foundations should be started in the primary school. And so I think an essential point in the primary school is to introduce the children to the tactics of problem solving. Not to solve this or that kind of problem, not to make just long divisions or some such thing, but to develop a general attitude for the solution of problems.* [Italics added for emphasis]

Polya's statements about mathematics apply to any academic discipline. A student who takes one or more college courses in a discipline should gain an understanding of the general nature of the types of problems it addresses. The student should make some progress in thinking like an expert in the discipline.

Polya (1957) provides a general heuristic strategy for attempting to solve any math problem. I have reworded his strategy so that it is applicable to a wide range of problems in a wide range of disciplines—not just in math. This six-step strategy can be called the Polya Strategy or the Six Step Strategy. It is a heuristic. There is no guarantee that use of the Six Step Strategy will lead to success in solving a particular problem. You may lack the knowledge, skills, time, and other resources needed to solve a particular problem, or the problem might not be solvable.

1. Understand the problem. Among other things, this includes working toward having a well-defined (clearly defined) problem. You need an initial understanding of the Givens, Resources, and Goal. This requires knowledge of the domain(s) of the problem, which could well be interdisciplinary. You need to make a personal commitment (Ownership) to solving the problem.
2. Determine a plan of action. This is a thinking activity. What strategies will you apply? What resources will you use, how will you use them, in what order will you use them? Are the resources adequate to the task? On hard problems, it is often difficult to develop a plan of action. Research into this situation suggests that many good problem solvers "sleep on the problem." That is, after working on a problem for quite a while with little or no success, they put the problem out of their minds and do something else for days or even weeks. What may well happen is that at subconscious level the mind continues to work on the problem. Eventually, an "ah-ha" experience sometimes occurs.
3. Think carefully about possible consequences of carrying out your plan of action. Focus major emphasis on trying to anticipate undesirable outcomes. What new problems will be created? You may decide to stop working on the problem or return to step 1 because of this thinking.
4. Carry out your plan of action. Do so in a thoughtful, reflective manner. This thinking may lead you to the conclusion that you need to return to one of the earlier steps. Note that this reflective thinking leads to increased expertise.
5. Analyze the results achieved by carrying out your plan of action. Then do one of the following:
   A. If the problem has been solved, go to step 6.
   B. If the problem has not been solved and you are willing to devote more time and energy to it, make use of the knowledge and experience you have gained as you return to step 1 or step 2.
   C. Make a decision to stop working on the problem. This might be a temporary or a permanent decision. Keep in mind that the problem you are working on may not be solvable, or it may be beyond your current capabilities and resources.
6. Do a careful analysis of the steps you have carried out and the results you have achieved to see if you have created new, additional problems that need to be addressed. Reflect on what you have learned by solving the problem. Think about how your increased knowledge and skills can be used in other problem-solving situations. (Work to increase your reflective intelligence!)

Many of the steps in this Six Step Strategy require careful thinking. However, there are a steadily growing number of situations in which much of the work of step 4 can be carried out by a computer. The person who is skilled at using a computer for this purpose may gain a significant advantage in problem solving over a person who lacks computer knowledge and skill. This type of knowledge and skill in using computers is a way to build on the previous work of others.

Building on Previous Work

One of the most important ideas in problem solving is to build on your own previous work and on the previous work of others. That is, one way to solve a problem is to retrieve from your own memory either a solution to the problem or a method for solving the problem. Another way is to retrieve this information from another person, from a physical library, or from a virtual library such as the Web.

The human race's accumulated knowledge is stored in millions of books, monographs, journals, Web publications, and other forms of publication written in many different languages. Much of the accumulated knowledge in a discipline is only accessible to those who have studied the discipline at a graduate school level. While it is easy to talk about the importance of building on the knowledge of others, it can take many years of hard work to develop the knowledge needed to read and understand the accumulated research knowledge in a discipline.

Moreover, most of the accumulated knowledge in any specific academic discipline is not readily available or easily retrievable. It is scattered throughout the libraries of the world, it is written in many different languages, and much is stored in people's heads. Over time, such difficulties of accessing materials will decrease as the materials are digitized and become accessible through the Web. Progress in the computer translation of languages will help, as will the development of better expert systems (a type of Artificially Intelligent computer system that has a relatively high level of expertise in a narrow field).

To summarize, one goal in the study of an academic discipline should be that students learn to access the accumulated, discipline-specific knowledge that is appropriate to their educational level and needs and to learn to use this accumulated knowledge to solve problems and accomplish tasks.

To Memorize or Not to Memorize: That Is the Question

Researchers in the area of expertise distinguish between rote memory (which involves little understanding) and the type of memorization being done by experts in a discipline. Rote memory is useful in problem solving. However, a focus on rote memory tends to be a poor approach to building a useful level of expertise in any discipline.

As Ericsson (n.d., in press) notes:

> The primary goal for all experts is to excel at the representative tasks in their domains. For example, chess experts need to find the best moves to win chess matches and medical experts have to diagnose sick patients in order to give them the best treatment. … As part of performing the representative task of selecting the best move, the experts encode the important features of the presented information and store them in accessible form in memory. *In contrast, when subjects, after training based on mnemonics and knowledge unrelated to chess, attain a recall performance comparable with that of the chess experts, they still lack the ability to extract the information important for selecting the best move.* [Italics added for emphasis]

The ideas in Ericsson's quote have deep educational implications. As faculty members, many of us create learning and assessment situations in which students must resort to rote memory with only modest understanding in order to pass tests and the course. The questions are at the low end of Bloom's Taxonomy. The long-term retention of such memorized information tends to be quite low, as does its contribution to building a useful level of expertise. Our methods of assessment are a major culprit in encouraging students to take a rote-memory approach to learning.

This suggests that we need a paradigm shift in the education of students who need only a low level of expertise and understanding in a discipline. Learning to retrieve, understand, and use information from online sources is a possible major component of such a paradigm shift.

Final Remarks

Before you start the first day of a course you are teaching, ask yourself the following questions that relate to helping students build expertise:

1. What are the main problem-solving, task-accomplishing, and other higher-order cognitive tasks that are covered in this course?
2. What role does ICT currently play in helping to solve the types of problems and accomplish the types of tasks I want students to be learning about?
3. What is the level of expertise I am assuming as a prerequisite, and what is the level of expertise or the amount of gain in expertise that I expect as outcomes in the course?
4. How will I measure the starting levels of expertise and the ending levels of expertise of my students? To what extent will I measure gains by qualitative and/or qualitative methods that are valid, reliable, fair, and clearly understandable by my students?
5. What will students learn in the course that they will retain and be able to use effectively a year or two after the course ends?
6. What will students learn in the course that will help them to be efficient and effective in relearning old material as well as new material a few years in the future?

Chapter 8
Human and Computer Intelligence

> "Did you mean to say that one man may acquire a thing easily, another with difficulty; a little learning will lead the one to discover a great deal; whereas the other, after much study and application, no sooner learns than he forgets?" (Plato, 4th century B.C.)
>
> "If we understand the human mind, we begin to understand what we can do with educational technology." (Herbert A. Simon)

Right now, computers are not very smart. Here is an amusing or thought-provoking pair of statements:

1. The typical car has an engine rated at approximately 1,000 "person-power." When it comes to brute strength, machines are much "stronger" than people. Humans, unaided by machines or drugs, are approaching upper limits on how fast they can run, how high they can jump, how much they can lift, and so on.
2. The typical modern microcomputer might be rated as approximately .01 "human-brainpower." When it comes to brainpower, people are much smarter than computers. However, computers have by no means reached their upper intellectual limits Some futurists suggest that microcomputers will exceed 1.0 "human-brainpower" sometime in the next 30 years (Kurzweil, 2001).

Measuring computer capacities in terms of "human-brainpower" is suggestive but misleading. In some areas, such as brute force computation, computers are a billion times as capable as human brains. However, it is still a "far out, wild" prediction to suggest we may have artificially intelligent computers and robots equivalent to a 5-year-old human within 15 to 20 years or so.

This chapter explores educational implications of the cognitive capabilities and limitations of humans and machines. Humans are very good at some things that computers are not good at, and vice versa. This observation leads us to explore the general idea of humans and machines working together to solve cognitively challenging problems.

Definitions of Intelligence

Ray Kurzweil (2001), a well-known and highly respected futurist, says this about technological change:

> An analysis of the history of technology shows that technological change is exponential, contrary to the common-sense "intuitive linear" view. So we won't experience 100 years of progress in the 21st century—it will be more like 20,000 years of progress (at today's rate). The "returns," such as chip speed and cost-effectiveness, also increase exponentially. There's even exponential growth in the rate of exponential growth. *Within a few decades, machine intelligence will surpass human intelligence.* [Italics added for emphasis]

One possible beginning point for exploring this thought-provoking and controversial forecast is to examine various widely used definitions of human and machine intelligence.

Human Intelligence

Notice the quote from Plato given at the beginning of this chapter. Attempts to define and measure intelligence have a long and somewhat acrimonious history. Four definitions of intelligence from four different sources are given in the following quotes.

> Individuals differ from one another in their *ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought.* Although these individual differences can be substantial, they are never entirely consistent: a given person's intellectual performance will vary on different occasions, in different domains, as judged by different criteria. Concepts of "intelligence" are attempts to clarify and organize this complex set of phenomena. (Neisser et al., 1995) [Italics added for emphasis]

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> *Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience.* It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do. (Gottfredson et al., 1994) [Italics added for emphasis]

Howard Gardner, whose work is briefly discussed in Chapter 5, is well known for his work on a theory of Multiple Intelligences (Gardner, 2003). He describes intelligence this way:

> To my mind, a human intellectual competence must entail a set of *skills of problem solving*—enabling the individual to resolve genuine problems or difficulties that he or she encounters and, when appropriate, *to create an effective product*—and must also entail the potential for finding or creating problems—and thereby laying the groundwork for the acquisition of new knowledge. [Italics added for emphasis]

Jeff Hawkins founded Palm Computing, Handspring, Numenta, and the non-profit Redwood Neuroscience Institute, a scientific research institute focused on understanding how the human neocortex works. Hawkins and Blakeslee (2004) contains this definition of intelligence in their book *On Intelligence: How a New Understanding of the Brain Will Lead to the Creation of Truly Intelligent Machines*:

> The brain uses vast amounts of memory to create a model of the world. Everything you know and have learned is stored in this model. The brain uses this memory-based model to make continuous predictions about future events. *It is the ability to make predictions about the future that is the crux of intelligence.* [Italics added for emphasis]

Hawkins is particularly interested in AI, and his definition reflects this interest. From Hawkins' point of view, intelligence is the ability to make predictions about the future and to take actions that produce desired outcomes. The prediction process requires a continual comparison between what is occurring and what we expect to occur. Intelligence depends on having a memory of past events so that one can compare predictions against past events and the outcomes of past events.

In brief, human 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. (Here, I am using a very general definition of the term *problem*, such as is given in Chapter 7.)
3. Solve problems. This includes solving problems, accomplishing tasks, and fashioning products (see Chapter 7).
4. Be a futurist. This includes accurately forecasting likely outcomes and consequences of one's possible future activities.

g, Gf, and Gc in Humans and Machines

There is substantial evidence gathered through many years of research that humans possess a general intelligence factor. As noted in Wikipedia:

> Charles Spearman [1863-1945] pioneered the use of factor analysis in the field of psychology and is sometimes credited with the invention of factor analysis. He discovered that schoolchildren's scores on a wide variety of seemingly unrelated subjects were positively correlated, which led him to postulate that a general mental ability, or g, underlies and shapes human cognitive performance. His postulate now enjoys broad support in the field of intelligence research, where it is known as the g theory.

Research on the general intelligence factor has led to a nature-and-nurture theory that divides intelligence into *fluid intelligence* (the nature component) and *crystallized intelligence* (the nurture component). McArdle et al. (2002) describes these concepts this way:

> The theory of fluid and crystallized intelligence … proposes that primary abilities are structured into two principal dimensions, namely, fluid (Gf) and crystallized (Gc) intelligence. The first common factor, Gf, represents a measurable outcome of the influence of biological factors on intellectual development (i.e., heredity, injury to the central nervous system), whereas the second common factor, Gc, is considered the main manifestation of influence from education, experience, and acculturation. Gf-Gc theory disputes the notion of a unitary structure, or general intelligence.

In casual conversations about intelligence and IQ, people tend to forget about the meaning of the "Q" in IQ. The human brain grows considerably during a person's childhood, with full maturity being reached in the mid to late 20s for most people. Both Gf and Gc increase during this time. While a person's level of fluid intelligence tends to peak in the mid to late 20s, growth in crystallized intelligence may continue well into the 50s.

Since the rate of decline in fluid intelligence over the years tends to be relatively slow, a person's total cognitive capabilities can remain high over a long lifetime. Current research strongly supports the idea of "use it or lose it" for the brain or mind, as well as the rest of one's body (Goldberg, 2005; McArdle et al.; 2002).

One can draw a weak analogy between Gf and Gc for humans and the artificial intelligence of machines. Think of a computer system in terms of hardware and software. The hardware provides the memory, processing speed, and connectivity, somewhat akin to Gf. The software provides content—data and information to be processed—as well as the instructions for processing. This is somewhat akin to Gc. Computers get "smarter" through improvements in hardware and improvements in software.

The Gc of humans comes through life experiences and through formal and informal education and training. Each individual faces the challenge of gaining such knowledge and skill. Contrast this with computer software. A large software development project may involve hundreds of designers, programmers, testers, and other support staff. Once a piece of software is completed, it can be installed in millions of computers, thus giving all these computers the same level of software capability.

Measuring Human Intelligence

Over the past century, there has been considerable research on how to measure intelligence. A wide variety of intelligence measures have been developed and tested for validity, reliability, and fairness. The term Intelligence Quotient (IQ) is a person's mental age divided by the person's chronological age, and then multiplied by 100. IQ tests are usually normed with a mean of 100 and a standard deviation of 15 (most common) or 16.

Figure 8-1 is a short table of data from a normal distribution. This table indicates that a total of 68.26 percent of the area under a normal curve lies between –1 and +1 standard deviations. From this table you can deduce that 2.28 percent of the area lies to the left of –2 standard deviations and 2.28 percent lies to the right of +2 standards deviations. Thus, for example, on an IQ test with a standard deviation of 15, only about .37% of people will score 145 or above.

Spread	**Proportion of Cases**
+ or -1 standard deviation	68.26%
+ or – 1.5 standard deviations	86.64%
+ or -2 standard deviations	95.44%
+ or – 2.5 Standard deviation	98.74
+ or -3 standard deviations	99.74%

Figure 8-1. Normal curve data.

IQ tests are useful and widely used. As Gottfredson (1998) explains:

> The debate over intelligence and intelligence testing focuses on the question of whether it is useful or meaningful to evaluate people according to a single major dimension of cognitive competence. Is there indeed a general mental ability we commonly call "intelligence," and is it important in the practical affairs of life? *The answer, based on decades of intelligence research, is an unequivocal yes.* No matter their form or content, tests of mental skills invariably point to the existence of a global factor that permeates all aspects of cognition. And this factor seems to have considerable influence on a person's practical quality of life. *Intelligence as measured by IQ tests is the single most effective predictor known of individual performance at school and on the job.* [Italics added for emphasis]

However, IQ is only one measure of a person's intelligence, and many people argue about the value of this measure. One obvious flaw is that different IQ tests emphasize somewhat different components of IQ. From the work of Howard Gardner (2003) and others, it is clear that a person might have substantially different intelligence scores in different areas of intelligence. Put another way, if two different IQ tests place different weights (for example, by using different numbers of questions) on various types of IQ, then a person might well score quite differently on the two tests.

IQ tests do not measure persistence, drive, passion, intrinsic motivation, emotional intelligence, social intelligence, and other traits that make a huge difference in learning, problem solving, and other human activities. Some students use their intellectual gifts much more effectively than do other students with similar IQs.

The Speed and Quality of Human Learning

The Science of Teaching and Learning provides us with some insights into how to help students learn better and faster. We also know that on average, people with higher IQs learn quite a bit faster and better than people with lower IQs. For the range of students who can effectively participate in the regular classroom environment in precollege education, the lower 5 percent probably learn half as fast and not as well as those with IQs in the mid range (say plus or minus one standard deviation)), while the upper 5 percent probably learn twice as fast or more, and quite a bit better, than those with the mid range students.

Thus, teaching to the "middle of the class" does a considerable disservice to the bottom and top of the class. This same situation exists in higher education, although the average IQ of students is somewhat above 100.

Gottfredson (1998) provides information about the rate of learning of slow learners versus fast learners:

> High-ability students also master material at many times the rate of their low-ability peers. Many investigations have helped quantify this discrepancy. For example, a 1969 study done for the U.S. Army by the Human Resources Research Office found that enlistees in the bottom fifth of the ability distribution required two to six times as many teaching trials and prompts as did their higher-ability peers to attain minimal proficiency in rifle assembly, monitoring signals, combat plotting and other basic military tasks. *Similarly, in school settings the ratio of learning rates between "fast" and "slow" students is typically five to one.* [Italics added for emphasis]

The findings about slower learners versus faster learners are applicable to students in higher education. The typical four-year undergraduate degree program is based on students taking an average of about 15 credits per term. The general expectation is that one credit corresponds to an hour of class meeting per week (actually, 50 minutes) and two hours of study outside of class for each hour in class. Thus, for an average student getting average grades, 15 credits correspond to about 45 hours per week. Students who learn quite a bit faster and better than average are able to carry a significantly heavier course load and earn better than average grades.

Measuring Machine Intelligence

Consider an inexpensive solar battery calculator. It can add, subtract, multiply, divide, and calculate a square root. It takes hundreds of hours of instruction and practice for an average human to learn to reasonably accurately and reasonably rapidly carry out these operations in a paper-and-pencil environment. Moreover, humans are somewhat error prone in using paper-and-pencil calculation technology.

Thus, one might claim that in doing eight-digit calculations, the inexpensive calculator has more intelligence than a well-educated or well-trained human. I have a calculator that only cost me a dollar. In well under a second, it can tell me that the (positive) square root of 235 is 15.329709.

Of course, my calculator has no "understanding" of what a square root is. It does not know about mathematical functions and that a square root is a mathematical function with a wide range of uses. One of the uses is in determining the length of one edge of a right triangle, given the lengths of the other two edges. This involves knowing the Pythagorean theorem. My calculator does not know about surveying land to determine the corners of a plot of land after a flood. It does not know about the Nile River, the ancient Egyptians, and so on.

The point is that computer hardware and software can be developed to solve or help solve a wide range of problems that previously required human intelligence to solve. However, this does not give us much insight into the intelligence of a computer system or how to measure machine intelligence.

Some researchers in AI have put a tremendous amount of effort into developing and studying chess-playing computer systems. IBM even designed computer hardware that would be especially fast in analyzing chess moves. In 1997, this computer system (a combination of hardware and software named Big Blue) defeated Gary Kasparov, the reigning human world chess champion.

Wow! That certainly impressed some people. Of course, Big Blue did not know what a human being is, what a game is, why people enjoy learning how to play a game such as chess, why it took Gary Kasparov tens of thousand of hours of effort to become world champion, or what a world champion is.

Consider a simple personal computer equipped with CAL software designed to help a human get better at fast keyboarding. The software provides instruction that has been carefully designed by a team of humans. The computer system can keep track of the performance of each finger of the human keyboarder. If a particular finger or combination of fingers is somewhat slow or inaccurate, it can adjust the training to give specific help to the finger or combination of fingers. It can provide an appropriate combination of speed drills and accuracy drills to help the user gain both speed and accuracy.

In summary, it is possible to develop keyboarding CAL that can outperform a good human tutor in certain areas, and that is as good as an individual human tutor in other areas. Do you have pity for all of the humans who used to teach typing? Perhaps you should. If you do a Google search on *free typing tutor,* you will see that part of what they used to do for a living can now be done by software that is available free on the Web. The AI of keyboarding CAL has proven sufficient to substantially change the jobs of humans who teach typing (keyboarding).

To carry the keyboarding example further, consider voice input systems. This has proven to be a challenging AI problem. However, this task has been solved well enough so that many people now use voice input. When the user detects a computer voice recognition error, the error can be corrected by use of voice input and/or a keyboard and mouse. Voice input systems get better (smarter, more intelligent) through continued research and the development of better hardware and software. A system can also get better by training itself to a particular user's voice. Voice input is now good enough that it has wide commercial uses.

All of the examples given above fall into what is called *weak AI*. Contrast this with *strong AI.* As explained in Wikipedia:

> In the philosophy of artificial intelligence, strong AI is the supposition that some forms of artificial intelligence can truly reason and solve problems; strong AI supposes that it is possible for machines to become sapient, or self-aware, but may or may not exhibit human-like thought processes. The term strong AI was originally coined by John Searle, who writes: "according to strong AI, the computer is not merely a tool in the study of the mind; rather, the appropriately programmed computer really is a mind."

Ray Kurzweil and the others see the steady progress in weak AI and agree it will continue. Ray Kurzweil believes we will have strong AI that far exceeds human intelligence before the year 2050. Others believe that we will never have strong AI that in any sense rivals the intelligence of humans

The educational implications of this issue are immense. Pick any academic discipline and the problems it addresses. Now, divide these problems into two categories. Into the first category, place the problems where a properly educated and trained person working with the best of current AI systems can substantially outperform an equally well-educated and well-trained person who does not have access to the computer systems. The second category of problems contains those where current levels of AI do not make an appreciable difference.

Now think about the first category of problems steadily increasing in size through a combination of steady progress in weak (and possibly strong) AI and through improved education for people who will work in this collaborative environment. That describes the world as it is today and in the future. We are living during a time of continual and substantial increase in the capabilities of computer systems. Our educational system is struggling with what it should be doing about this change.

Human and Machine Memory

It is clear that memory is an important aspect of intelligence. Here is a repeat of the quote from Hawkins and Blakeslee (2004) given earlier in this chapter:

> The brain uses vast amounts of memory to create a model of the world. *Everything you know and have learned is stored in this model. The brain uses this memory-based model to make continuous predictions about future events*. It is the ability to make predictions about the future that is the crux of intelligence. [Italics added for emphasis]

One of the advantages that computers have over humans is their ability to quickly store and quickly retrieve large amounts of information. We are impressed by a person who can memorize a book (Garden, 2005) or a musical performer who can memorize music that totals tens of thousands of notes in length. Such memorization takes considerable time and effort. Contrast this with storing information on a 300-gigabyte computer disk at the rate of many millions of bytes per second. Such a hard disk and its disk drive can now be purchased for under $100—and can store the equivalent of 300,000 full-length novels.

In 1956, George A. Miller published a seminal paper about human memory: "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information." The unifying theme in this paper is that for a typical person, short-term working memory can only store about five to nine chunks of information. This means, for example, that a typical person can read or hear a seven-digit telephone number and remember it long enough to key it into a telephone keypad.

Here are descriptions of three different types of human memory:

- **Sensory memory** stores data from one's senses, and for only a short time. For example, visual sensory memory stores an image for less than a second and auditory sensory memory stores aural information for less than four seconds.

  One can draw an analogy between human sensory memory and the memory of certain computerized sensing devices. For example, here is a description of a charge-coupled device from Wikipedia:

> A charge-coupled device (CCD) is an image sensor, consisting of an integrated circuit containing an array of linked, or coupled, light-sensitive capacitors.
>
> …
>
> Under the control of an external circuit, each capacitor can transfer its electric charge to one or other of its neighbours. CCDs are used in digital photography and astronomy (particularly in photometry, sensors, optical and UV spectroscopy and high speed techniques such as lucky imaging).

A capacitor loses its charge over time, sort of like a human sensory memory fades away over time.

- **Working memory** (short-term memory) can store and consciously, actively process a small number of chunks. It retains these chunks for less than 20 seconds.

  One can draw a parallel between the central processing unit (CPU) of a computer and the working memory of a human. The CPU has some storage used in processing pieces of information, so it can be thought of as both a storage and a processing unit.

- **Long-term memory** has large capacity and stores information for a long time. Human long-term memory is both a storage and a processing system. Millions of neurons may be working together (in parallel) to carry out a task.

  The analogy between computer long-term memory (such as disk memory) and human long-term memory is not a good one. It is not correct to think of a specific neuron as storing a specific chunk of information or one byte of data. Moreover, the processing done by a human brain is somewhat like that done by an analogue computer, and it is not like the processing done by a digital computer. A human brain stores and processes patterns, using a large number of neurons to store a pattern and a large number of neurons when it is processing a pattern or group of patterns.

Working memory has a quite limited capacity. However, the research on expertise by Ericsson (n.d., in press) and others indicates that experts train their long-term memory in their areas of expertise so that it has some of the characteristics of working memory. One way to think about this is that working memory processes information at a conscious level and long-term memory processes information at a subconscious level. By dint of thousands of hours of study and practice, one can gain a certain amount of conscious control over parts of one's long-term memory.

Artificial Intelligence

As noted earlier in this chapter, many AI experts like to distinguish between weak AI and strong AI. Some see us moving toward AI systems that can far exceed the mental capabilities of people. It is important that educators and students understand some of the mechanisms for increasing AI and areas of weakness of AI relative to human intelligence.

Rote Memory

The discussion of computer memory and CPUs gives us part of the foundation needed to discuss ways of increasing the AI of computer systems. Suppose, for example, that IQ depended mostly upon having a large memory that could quickly memorize and regurgitate what it has memorized, and that never forgets, even over a period of many years. With that measure, computers beat people hands down. Moreover, we are still in a technology development phase in which the cost effectiveness of computer storage devices is improving very rapidly. In addition, the Internet makes it possible for hundreds of millions of people to access the Web, a huge and rapidly growing virtual library.

Rote memory is an important component of increasing expertise in a variety of disciplines. For example, a world-class chess player must memorize many thousands of sequences of opening moves and end game moves. However, the number of different sequences of possible moves in a chess game overwhelms a human's rote-memory approach to achieving a high level of expertise. Indeed, it overwhelms a computer's rote-memory approach. A computer can easily memorize a trillion different sequences of chess moves. However, that is a very small number relative to the number of different sequences of moves possible in a chess game.

Algorithmic and Heuristic Procedures

An algorithmic procedure is a step-by-step procedure that can be proven to succeed in its task. To increase the weak AI of a computer, problem situations can be analyzed and new or better algorithms can be developed.

A heuristic procedure (often called a rule of thumb) is also a step-by-step procedure, but not one that can be proven to always work. We all frequently use heuristic procedures. Before I walk across a one-way street, I look in the direction from which the traffic is coming, in order to avoid getting hit by a car or a bicycle. However, this heuristic procedure fails if a car or bicycle is driving the wrong way on the road.

Much of the recent progress in weak AI has been in developing better heuristics. A typical AI program contains a combination of algorithms and heuristics. A spelling checker uses an algorithmic procedure to see if a word is in its spelling dictionary. If a word is not in the dictionary, a heuristic procedure is used to suggest an alternative word or spelling. I increase the intelligence of my spelling checker when I add words to my custom dictionary.

Grammar checking is a far harder problem than spelling checking. At the current time, grammar checking is based on heuristics, and the results are only of modest quality. Current levels of Weak AI are not well suited to the task of grammar checking.

Voice input to computers is a relatively difficult AI problem. It has gradually gotten better as better heuristics have been developed.

Language translation is a still harder problem. current levels of success are still rather modest, but significant progress is occurring (Tanner, 2007). The language translation problem gives us some interesting insights into the power of a human brain. Material to be translated comes into one's brain through reading or listening. The brain translates this into meaningful ideas. Then the brain translates these meaningful ideas into a target language and produces the output. The key is that the brain understands the meaning of the input materials. This would require strong AI on the part of a computer. Current computerized language translation systems do not have an understanding of the meaning of what they are translating.

Machine Learning

Still another way to increase the intelligence of a computer system is to have the computer system actively involved in learning on its own. For example, to develop a better chess-playing program, the program can use the analyses that have been carried out by chess masters, and can also "study" thousands of games that have been played by chess masters. A somewhat similar approach can be used in developing computer systems that can carry out medical diagnostic tasks. In both the chess-playing and medical diagnostic work, the computer studies what actually occurred (the game or the actual diagnosis, along with the medical data that was gathered) and then uses the outcomes (who won, whether the treatment based on the diagnosis worked).

Final Remarks

Weak AI systems can solve a variety of cognitive problems and accomplish a variety of cognitive tasks. In some of these problems and tasks, AI systems readily outperform humans. However, the weak AI we currently have is substantially different than human intelligence.

At the current time, there are thousands of researchers and programmers working to improve the software and underlying theory of weak and strong AI. When any significant progress occurs, it can be widely disseminated and readily implemented on millions of different microcomputers.

It is evident that weak AI will continue to improve. However, weak AI tends to be domain-specific in that a particular AI system deals with a narrow range of problems. It also tends to be quite limited in the problem areas that require understanding of human language and what it means to be human.

Figure 8-2 provides a simple summary of physical and cognitive tools available in the context of education. Students need an education that prepares them to function well in team environments where other members of the team will be (1) people, (2) tools that extend mental capabilities, and (3) tools that extend physical capabilities. We will continue to see substantial progress in the development of such tools, and many of the tools will have both physical and cognitive capabilities. Robots provide a good example of this.

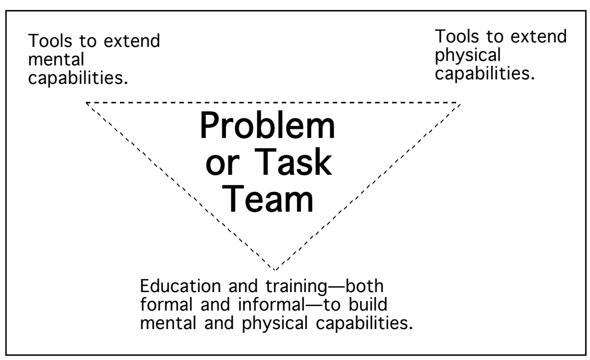

Figure 8-2. Problem or task team: people and machines working together.

Part 3:Theory into Practice

"It takes a whole village to raise a child." (Ancient African Proverb)

"The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom." (Isaac Asimov's *Book of Science and Nature Quotations,* 1988)

Previous chapters of this book have provided an overview of many important aspects of the discipline of education and the Science of Teaching and Learning. A variety of ICT applications have been explored. Part 3 focuses specifically on roles of ICT in education.

Chapter 9 explores some general types of applications of ICT in higher education. Some of the topics have also been discussed in previous chapters.

Chapter 10 contains some speculations about possible future uses of ICT in higher education.

These final two chapters are followed by an extensive set of References and an extensive Index.

Chapter 9
Some ICT Applications in Higher Education

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

Each aspect of the teaching and learning processes in higher education can be examined for potential improvements that might be brought about by appropriate use of ICT and its underlying CIS. This chapter provides brief summaries of some ICT/CIS based ideas covered in previous chapters and of others that have not yet been mentioned.

Evidence-based change involves the fundamental idea that before we make changes in how we teach or what we teach there should be convincing evidence that the changes will be beneficial. We want changes in education to lead to improvement in student expertise and how well we achieve other goals of education.

We know that students tend to forget most of the details covered in a course unless they use them regularly after a course has ended. However, we also know that some big ideas are retained, and that the initial learning contributes substantially to later relearning. Thus, we need to examine potential ICT uses that contribute significantly to these two important ideas.

Introduction

Much of the early research and development of electronic digital computers in the United States was done by college and university faculty. As noted in Wikipedia:

> ENIAC, short for Electronic Numerical Integrator and Computer, [1] was the first large-scale, electronic, digital computer capable of being reprogrammed to solve a full range of computing problems, [2] although earlier computers had been built with some of these properties. ENIAC was designed and built to calculate artillery firing tables for the U.S. Army's Ballistics Research Laboratory.
>
> …
>
> The contract was signed on June 5, 1943 and Project PX was constructed by the University of Pennsylvania's Moore School of Electrical Engineering from July, 1943. It was unveiled on February 14, 1946 at Penn.

The Association for Computing Machinery (ACM) is a professional society that was started in 1947. The ACM's *Curriculum '68* document helped define college and university computer science curriculum.

Work on time-shared computing (many people making simultaneous use of a computer) at Dartmouth in the early 1960s led to the development of an educationally oriented computer programming language called BASIC, which is still in wide use. One of the two developers of BASIC went on to become President of Dartmouth and was perhaps the first college or university president to regularly use a time-shared computer terminal in his office.

Eventually Dartmouth had about one computer terminal for every 10 students. (Remember, this was long before the development of microcomputers.) Programming in BASIC was integrated into required freshman mathematics courses, and the faculty throughout the college came to expect that all students in upper division courses could write simple programs and could use databases and other stored information effectively.

As microcomputers came into wide use in the early 1980s, many institutions began to install microcomputer labs, and eventually many students bought microcomputers. As Wikipedia notes:

> In 1982, Stevens [Institute of Technology] was the first institution in the U.S. to require all incoming freshman undergraduate students to purchase and use a personal computer. Around this time, an intranet was installed throughout the campus, which also placed Stevens among one of the very first universities with campus networks.

In 1984, Virginia Tech became the first public university to require incoming students to have a microcomputer.

However, even if students own a microcomputer, student labs are important because they often provide access to a much broader range of software than the typical student can afford. Steady progress has occurred in wireless networking of campuses. Kenneth Green (2006) describes their prevalence:

> Wireless networks now reach fully half (51.2 percent) of college classrooms compared to just over two-fifths (42.7 percent) in 2005 and a third (31.1 percent) in 2004, according to new data from the annual Campus Computing Survey. … By sector, the proportion of classrooms with wireless access ranges from a third (31.7 percent) in community colleges (up from 26.8 in 2005) to almost three-fifths (58.0 percent) in private research universities (compared to 52.8 percent in 2005 and 47.4 percent in 2004).

It is clear that a steadily increasing number of students and faculty in higher education feel that it is beneficial to have easy access to computers and know how to use them effectively. However, there is a considerable difference between a student owning a computer and the student knowing how to use it well enough that it makes a significant contribution to the quality of education he or she is receiving. There is a considerable difference between faculty members feeling that students should have easy access to computers and faculty members teaching in a manner in which computer ownership makes a significant contribution to a student's education.

Some Pervasive ICT Uses in Higher Education

Essentially all college students and faculty use ICT routinely. It is now common practice to assign all new students an email account and to assume that they know how to use email. It is now commonly expected that all students know how to use a word processor, how to access the Web, and how to use a search engine to locate information on the Web.

Thus, for example, faculty members feel free to tell their students to contact them and their fellow students by email, and they do not hesitate to require an assignment to be word-processed and turned in as an attachment to an email message. Students who lack experience in these areas will quickly learn from each other or from a free help session or tutorial. Faculty members do not expect to have to use class time to teach such uses of ICT.

Even at this level of use, however, a number of students have trouble and need help. For example, faculty members often create a distribution list for a class and send email to the entire class via this list. Many students do not know how to respond directly to the message sender rather than to the whole list. Indeed, many do not even think about where their response message is going.

As another example, many students do not know how to do an effective Web search, separate the "wheat from the chaff," and appropriately cite their Web-based references.

As a third example, many students do not know how to save and organize their files or understand the need to routinely back up their saved files.

Learning and/or Course Management Systems

It is now common for higher education institutions to provide a learning management system or a course management system for use by their faculty and students. Here, I will use the term learning management system (LMS) to refer to both. An LMS is designed to help students learn and faculty teach. As noted in Wikipedia:

> A Learning Management System (or LMS) is a software package that enables the management and delivery of online content to learners. Most LMSs are web-based to facilitate "anytime, any place, any pace" access to learning content and administration.
>
> Typically an LMS allows for learner registration, delivery of learning activities, and learner assessment in an online environment. More comprehensive LMSs often include tools such as competency management, skills-gap analysis, succession planning, certifications, and resource allocation (venues, rooms, textbooks, instructors, etc.).

An LMS is a complex piece of software. Moving beyond a novice level of understanding and use requires a significant amount of learning on the part of faculty and students. Moreover, an LMS tends to help shape some of the routine practices that a faculty member is accustomed to.

For example, a faculty member may be used to facilitating small-group or whole-class discussions, making mental or written notes about who seems to be participating and their level of participation. This in-class approach is somewhat different from what is needed to facilitate and assess online discussions conducted using an LMS system. Faculty members tend to resort to requiring each student make some specified number of different contributions to an online discussion. This misses the idea that a timely, high-quality contribution is important and that good learning can occur by merely listening to (or reading online) discussions and thinking about what is being said. Often the required participation merely becomes another somewhat meaningless hoop to jump through.

It is important to understand that there is a considerable difference between a small group holding a face-to-face discussion and the same small group holding an email- or chat room-based discussion. However, inexpensive equipment now exist for face-to-face videophone over the Web, and in many situations this can be an excellent alternative to using class time or communicating only by keyboarding.

Another example is provided by electronic gradebook software. The electronic gradebook software provided by an LMS may well be different (it may contain more features or fewer features) than other electronic gradebook software or the paper-and-pencil approach to which faculty members have become accustomed. Students are coming to expect that grades on assignments and tests will be posted and made accessible electronically.

An LMS typically includes provisions for online testing. That opens up a new can of worms for a faculty member. Do you use online tests just for the purposes of student self-assessment, or do you use them for grading? If used for grading, how to you prevent cheating?

After learning how to use some of the features of an LMS, both faculty and students tend to believe that an LMS is a useful, convenient aid to facilitating communication, providing information, and providing feedback. These are all tasks that were accomplished before the development of LMSs. However, research on LMS educational effectiveness is weak. As George Siemens (2006) notes:

> Aggressive sales and state or province-wide licenses resulted in WebCT and Blackboard—now merged as one company (Blackboard, 2006a) cornering over 75% of the market (Mullin, 2005). *The rapid penetration of learning management systems as key tools for learning occurs in a vacuum of solid research as to their effectiveness in increasing learning—or even indication of best practices for technology implementation.* Pedagogy is generally a secondary consideration to student management; some researchers attempted to bridge research from face-to-face environments to technology spaces (Chickering & Ehrmann, 1996)—a practice that may be convenient, but errs in assuming that the online space is an extension of physical instruction, not an alternative medium with unique affordances. Learning management systems became the default starting point of technology enabled learning in an environment largely omitting faculty and learner needs. [Italics added for emphasis]

As the above quote indicates, Blackboard now dominates the LMS commercial market. However, there are several free competing systems. The potential for LMSs is very large, as such systems begin to integrate in more diagnostic testing, feedback, and individualized instruction into their features. A somewhat different way of viewing the situation is that for many years, computer-assisted learning systems (often called integrated learning systems) have included a variety of LMS features. Thus, one might expect that eventually we will see a substantial merger of computer-assisted learning systems with LMSs. The research supporting computer-assisted learning is much stronger than the research supporting LMSs.

Wireless Student Response Systems

Even in a large lecture class, faculty members encourage student questions and attempt to obtain feedback from students during the lecture. Now, ICT exists that can facilitate such interactions. A report from University of Minnesota (2006) describes these systems:

> Functionally, the system allows students to respond to questions posed by an instructor, and allows instructors to view student feedback in real-time, thus allowing them to modify instruction based on individual student or group responses. Some systems also potentially allow students to send real time questions to the instructor during the presentation.
>
> The use of a student response system can add a higher level of interaction and participation in class and allows comprehension to be assessed in real-time. The immediate feedback provided by the SRS enables the instructor to gauge the effectiveness of his or her training. This allows the instructor to alter the presentation and address problem areas for any topics that the students are having difficulty understanding.

The simplest of the student response systems are often called *clickers* because a student can click on a response to a multiple-choice or true-false question.

More sophisticated systems may include a keyboard and a display. Thus, for example, a question may be displayed on a student's screen and the student might provide either a "clicker" response or key in a short response. (This is like instant messaging on a cell telephone.)

When used in a clicker mode, such a system could provide immediate feedback to the student on the correctness of the clicked response, and could even provide instruction on why a given response is incorrect. Thus, the system can act like a CAL system.

As with class management systems, the research-based evidence of effectiveness of student response systems is limited. Eric Mazur, a Harvard professor, heads a research center exploring the effectiveness of such aids to teaching and learning. He describes the effectiveness this way (Mazur Group, n.d.):

> Methods of presenting information in large lectures have changed over the years; from the blackboard, to the overhead projector, to the television, and now the computer. The problem with education, however, is not the method of presentation—it is the assimilation of material presented. Unfortunately, most early uses of technology in education focused on the presentation of information.
>
> Our efforts are aimed at using technology to enable new modes of learning—to make possible what hitherto was not. For example, we have developed ways to facilitate communication between instructor and students and between students both inside and outside the classroom. The goal is to provide a structure that is conducive to learning and helps both instructors and student focus attention and the areas that require most attention.

Word Processing and Desktop Publication

One evening many years ago, my younger daughter, a high school sophomore, came to me and asked if I would teach her how to use a computer. She had a written report that was due the next day, and she believed that it would be helpful to write it using a word processor. She was a good typist—I had required all of my children to take a typing course. Aha, a teachable moment!

With about two minutes of instruction, she was started. There is a great deal of transfer of learning that can occur when one knows how to use a typewriter. Correcting keyboarding errors and making small edits to a sentence are very easy to learn to do in a word-processing environment. Perhaps a half hour later she asked if there was an easier way to get back to earlier parts of the document than just repeated back spacing. Aha, another teachable moment. Still later came the question of how to save and to print out the completed document.

Even for a long-winded professor like me, the total amount of instruction time was less than ten minutes, and my daughter was pleased by the results. Moreover, she is apt to remember the value of word processing for the rest of her life. Now I lament, "If only all of my teaching experiences had been so successful."

Moving Beyond Using a Computer as a Typewriter

It is not necessary to be a fast typist to benefit from using a word processor. Indeed, one of my doctoral students worked with first grade children whose parents were Spanish speaking migrant workers. Many of these children did not know the alphabet, so she had all of her students learn to use a word processor about the same time that they were learning the alphabet and learning to read and write English words.

Even a rudimentary level of knowledge and skill in using a word processor is valuable to a student—even a student who uses a hunt-and-peck approach to keyboarding. However, a word processor is a quite powerful tool, and it takes considerable effort to gain a reasonable level of expertise in using this tool.

A student can learn fast keyboarding, and a student can learn to use some additional features of a word processor. Since touch typing has been a school subject for many years, there is a lot known about how long it takes an average person to achieve a level of automaticity that does not decline rapidly when not being used. For example, a typical fourth- or fifth-grade elementary school student can learn to type (or keyboard) about twice as fast as hand printing or handwriting. It takes perhaps 30 to 40 hours to gain a speed of 25 words per minute, or higher. Typing classes in middle school or high school used to be a half-year or a full year in length. The longer courses tended to stress skills related to becoming a professional secretary or typist.

The microcomputer-based word processor blossomed into a transformational technology when sophisticated desktop-publication software and a relatively inexpensive laser printer became available in 1984. The linotype that had been a mainstay in publishing for nearly a hundred years was doomed. The combination of microcomputer, desktop publication software (even a good word processor sufficed), and the laser printer completely transformed an industry. Some of the areas of expertise of a linotype operator were no longer useful.

This is a key idea. It took a considerable amount of training and experience to become a skilled linotype operator. Moreover, there was a certain amount of danger involved in the job, since it included working with very hot molten type metal. Linotype operation was a skilled and respected occupation.

However, the overall publication process also involved content editors, copy editors, and layout designers. Many people acquired the hardware and software to do desktop publication without thinking much about these other areas of expertise required to produce high-quality products.

It is helpful to keep this example of word processing versus desktop publishing in mind as we explore some other computer applications. Typically, a new computer hardware or software tool is developed to help solve some problem or accomplish some task where there is considerable demand for "a better way." Often the computer system is powerful enough so that it can empower a novice with just a little training to accomplish tasks that previously required many hundreds—indeed, thousands—of hours of training and experience. However, the computer system has some severe limitations. For example, even the best of modern computer-based spelling checkers are not as good as a good human spelling checker. The best of computer-based grammar checkers are not nearly as good as a good human copy editor. We are a very long way from having computer systems that are good at content editing.

Amplification, and Moving Beyond Amplification

Remember what the first steam or gasoline-powered cars looked like? They looked like "horseless" carriages. They are an example of a first-order application of a technology, an amplification level. As is often the case with a new technology, the initial horseless carriages were relatively hard to maintain and use, the needed infrastructure—paved roads and gas stations—was not yet available, and only a relatively few early adopters were venturesome enough to purchase and try out the new-fangled invention. Eventually the technology got a lot better, the infrastructure got a lot better, and cars transformed our society.

The story about my daughter first learning to use a word processor illustrates an amplification involving the use of a computer. She could just as well have typed the paper using a typewriter. However, a few minutes of instruction in the use of a word processor amplified her ability to correct her typing errors, do some simple editing, and print out a nice clean copy. She gained a personally useful level of expertise in the use of a word processor.

Nowadays, essentially every student entering college has developed a personally useful level of knowledge and skill in using a word processor, email, and the Web. This person likely has a number of other ICT-related areas of personal expertise, such as using a cell telephone, digital camera, and video camera; driving a car that contains a number of microcomputers; making use of digital music; and so on. In all of these examples, the ICT is so transparent that the typical user does not think about the underlying ICT or the roles of computers. In any application where parts of the learning curve are steep, the user may decide that these parts (these features) are not essential to having a personally useful level of expertise.

This idea is worthy of consideration by every college teacher. A person taking your course is likely to have some interest in initially gaining a personally useful level of expertise or increasing his or her current level of expertise in the area your course covers. Ask yourself if there are aspects of the course content and uses of the course content where a little ICT knowledge and skill would be very beneficial to the student in both the short run and the long run. For example, suppose you are teaching a course in which the written material requires the use of special symbols, superscripts, subscripts, math formulas, and so on. It might be helpful for you students to learn those features of a word processor.

Suppose that five years after taking your course, a student discovers the need to relearn key ideas from your course. Where will the student find information about these ideas and aids to learning them? Is there a good Website that is apt to still exist in five years? What are the key search terms and search ideas to use in finding a good Website? Are there computer programs that can solve or help solve some of the important problems discussed in the course? Where can one find the new ides that are being developed and are relevant to the course?

Gaining a Competitive Advantage

Even a low level of knowledge and skill in using a word processor, email, and a Web search engine gives a student a competitive advantage over those who lack this knowledge and skill. However, the effort to gain this initial low level of knowledge and skill is so small that we now assume all students have achieved it. The same holds true for many other pieces of productivity software. With a few minutes of instruction, a student can learn to enter some data into a spreadsheet and then instruct the computer to graph the data. With a few minutes of instruction, a student can learn to enter a function or an equation into a "graphing" calculator and have the calculator graph the function or solve the equation.

Only a modest amount of instruction is needed for a person to learn to take a digital picture, load it into a computer, save it, crop it, and post it to a Website or attach it to an email message. With just a few minutes of instruction a student can lean to copy a picture from a computer file or Web page, size it, and insert it into a word-processing document.

With only a modest amount of instruction, a grade school student can learn to write a very simple computer program using the BASIC or Logo programming language. In this learning environment, a student can be learning about testing and debugging a program as well as some of the difficulties of developing bug-free software.

The learning in each of the examples discussed above may lead to very long-term retention of the basic idea of what can be done. A student who learns to copy, size, and paste a picture into a document may forget the details over time, or be faced by different software sometime in the future. However, relearning is not particularly difficult because it is supported by having successfully learned in the past, having an understanding of the desired outcome of the relearning, and having the motivation to do the relearning.

With most pieces of applications software, one can gain a competitive advantage by learning to use the software at a higher, deeper level than one's "competitors." A seemingly mundane but quite important example is provided by keyboarding skills. Suppose that it takes 50 hours of instruction and practice to learn to keyboard using the "correct" fingering so that one gains a speed of perhaps 30 to 35 words per minute. What competitive advantage does one gain by this expenditure of time and effort over a novice who hunts ands pecks?

One answer is speed—one can type perhaps twice as fast as one can handwrite or hunt and peck. Moreover, achieving this speed produces changes in one's long-term procedural memory. Much of this speed will be retained even if one does not use it for a period of months, such as during a summer vacation. A modest amount of practice will bring one back "up to speed."

Another good word-processing example is provided by learning to make a table with borders. This is a considerable challenge using a typewriter, but quite simple when using a word processor. Many additional capabilities are built into a typical word processing program. A typical novice user understands and makes use of well under five percent of these capabilities.

In summary, there are many pieces of applications software one can easily learn to use at an amplification level. With each of these, there is a vast potential for gaining a higher level of expertise. Moving beyond a novice level of amplification use may take a significant amount of time and effort. However, the increased level of expertise can give one a considerable competitive advantage.

Students need to learn about this idea with respect to any course they are taking. They need to gain a personally useful level of knowledge and skills in software relevant to the course content, and they need to be pointed in the direction of making a higher order (beyond amplification) level of use. As a teacher, it typically is not your duty to help students gain this beyond-amplification level of knowledge and skill. The exception is when you are teaching a course where that is a major goal. However, it is part of your job to help students learn what advantages will accrue to them in the future if they decide to take coursework or learn on their own in an effort to move beyond amplification.

Email

It is easy to gain a novice level of skill in using email. If one can read and write, then a few minutes of instruction and practice allow one to send and receive email messages. Compare this with the time and effort it took telegraph operators a little over 150 year ago to learn Morse code and use the telegraph system.

However, there is much more to learn about email. How does one organize, save and later retrieve message one has received? How does one avoid getting unwanted ads and other spam? How does one deal with email mailing lists. For example, how does one avoid responding to the whole list when one wants to respond just to one person? How does one create a mailing list? How does one send and retrieve attachments? How does one add an automatic signature to one's messages being sent? When should one use email in communication, and when is this a bad idea? In summary, it is easy to learn to use email at an amplification level. It is not so easy to learn to use the various additional features and to use them wisely.

As a faculty member, suppose you decide to make use of email to communicate with your students, as sort of an extension of office hours. Suppose, also, that you encourage or require students to turn in assignments as email attachments. These uses present several difficulties.

First, suppose you are a slow keyboarder. Then your rate of communicating with students will be slow. Even if you are a fast keyboarder, your rate of talking and the efficiency of face-to-face communication is far superior to communicating by email.

Second, consider the possibility that your students use a variety of brands of word-processing software, perhaps some that are not even available on the model of computer you are using. They turn in homework as a file attached to email, but you lack the software to open their file. This can be a major challenge. An alternative is to require all students to use the same word processor, and you may have major objections to such a requirement.

Even more difficulties occur when students use a wide range of software in doing assignments and expect to turn in electronic copies of their work. Unless students are restricted to a small, uniform list of pieces of software, almost every instructor will be overwhelmed.

As a final comment in this section, I have found in recent years that all of my students have access to Microsoft Word. I edit their papers online. This means I have had to learn to be a critical content editor in my online reading, I have had to learn the online editing features of Microsoft Word, and my students have had to learn to understand how these online editing features work. My personal opinion is that the time and effort to learn to use this feature in Microsoft Word has increased my productivity in providing quality feedback to students.

Spreadsheet

An entry in Wikipedia describes the development of VisiCalc, a 1979 spreadsheet program:

> Dan Bricklin has spoken of watching his university professor create a table of calculation results on a blackboard. When the professor found an error, he had to tediously erase and rewrite a number of sequential entries in the table, triggering Bricklin to think that he could replicate the process on a computer, using the blackboard as the model to view results of underlying formulas. His idea became VisiCalc, the first application that turned the personal computer from a hobby for computer enthusiasts into a business tool.
>
> VisiCalc went on to become the first "killer app," an application that was so compelling, people would buy a particular computer just to own it. In this case the computer was the Apple II, and VisiCalc was no small part in that machine's success.

Most of the first people to learn to use spreadsheet software already knew quite a bit about bookkeeping or accounting. Thus, it was relatively easy for them to learn to create simple spreadsheets. However, over time, spreadsheet software grew much more powerful and many people with no business background found it useful to learn to use the software. Often they had to deal with business-oriented examples and instruction manuals as they tried to learn to use the software as an aid to solving problems in science and other disciplines.

Over the years, spreadsheet software has come to contain many of the features of a computer programming language. Indeed, a spreadsheet software package may well contain a computer programming language such as BASIC as one of its features. Excel, Microsoft's spreadsheet program, is exceedingly powerful and exceedingly complex, and it includes BASIC.

One of the key uses of spreadsheet software is spreadsheet modeling and simulation. How does one use a spreadsheet to develop a model of a business operation such as payroll or inventory? One needs to know the business operations and one needs to know how to design, create, test, and debug the relatively complex spreadsheet model and simulation. This means one must have a reasonably high level of expertise in the business areas and in the software. Similar statements hold for developing spreadsheet models in other disciplines.

Overhead Projectors Versus a Computer Projection Systems

The overhead projector was invented in 1944 and eventually came into common use in classrooms throughout our country. Slides (foils, transparencies) could be purchased or created in advance of a class meeting and could be created or modified during a class. It took only a modest number of minutes to learn to gain a personally useful, amplification level of knowledge and skill. (Note that there are many stories of teachers who have mistakenly used a marking pen to draw on the display screen. Sometimes a little knowledge is dangerous!)

I am not personally aware of any research-based evidence that students learn better or faster when an overhead projector is used instead of a chalkboard. However, it is obvious in some situations that the slides are more legible and better fit the needs of a large class. There are the obvious advantages that slides can be prepared in advance of a class meeting and that they can contain pictures. Other types of projection systems make it possible to show 35mm color slides, and this is very useful in many different courses.

In using an overhead projector, there is the disadvantage that each new slide projected replaces the previous one. Thus, students cannot look back at earlier parts of the presentation. This is a serious disadvantage when compared to a well-done blackboard-based presentation.

It has taken many years for high quality, moderately priced computer projection systems to become available. These are not nearly as easy to learn to use as an overhead projector. One must learn to make effective use of software to create the slides, the classroom needs to have appropriate lighting for use of the projection system, and the teacher needs to know how to use the computer and projection system. The overall technology is not as reliable as an overhead projection system.

Some teachers learn to use a keyboard to make "real time" notes (like writing on a backboard, but instead keyboarding to a computer) in a class setting. However, this overall process is a daunting challenge for most faculty members. Thus, students tend to lose out on some of the spontaneity that can be generated during a class in which the instructor uses a blackboard effectively.

Both overhead projectors and computer projection systems have a potentially significant educational advantage to students. They tend to force the faculty member to do more careful advance planning. Research evidence indicates that the careful design and advance preparation for a class improve the quality of student learning. In addition, computer projection systems can project pictures and videos. Thus, they are supported by the research on effective uses of multimedia (slides, film strips, recordings, movies) that was done well before computer projection systems became available.

A faculty member's use of a computer projection system has another distinct advantage to students. The slides can be made available on a computer network so that students can access them at a time that is most convenient to them.

Applications That Are Inherently Beyond Amplification

There are a number of computer applications that are so powerful that they make it possible for the user to solve problems and accomplish tasks well beyond what can readily been done by hand. A few examples include computer modeling and simulation, statistical packages, computer algebra systems, Geographic Information Systems (GIS), MIDI (music) interface systems, computer-assisted design (CAD) and computer-assisted manufacturing (CAM) systems, and digital audio, photo, and video editing systems.

These applications are so powerful that they have significantly changed entire disciplines. For example, consider computer modeling and simulation in the sciences. In 1998, one of the winners of the Nobel Prize in chemistry received the prize for his many years of work in computational chemistry (computer modeling and simulation in chemistry). Computational biology, chemistry, mathematics, and physics are now major components of their respective disciplines.

Here is a personal experience I had with powerful software. More than 15 years ago, I was teaching a computers and mathematics course for preservice and inservice precollege teachers. One day I opened my (surface) mail and found that I had received a copy of the computer algebra system Mathematica, designed to run on an Apple microcomputer. After a little experimentation, I took the software and my old freshman calculus book to the class meeting later in the day. I first demonstrated that the software could do various impressive calculations, such as exactly calculating 50 factorial. I then began to give the program problems from the end of the book chapters. After seeing success on the easier problems, I began to use the "starred" problems in later chapters. My class and I were "blown away" by what this software could do.

Mathematica is a product of Wolfram Research. Quoting from their company history Website:

> It is often said that the release of Mathematica marked the beginning of modern technical computing. Ever since the 1960s, individual packages had existed for specific numerical, algebraic, graphical, and other tasks. But the visionary concept of Mathematica was to create once and for all a single system that could handle all the various aspects of technical computing--and beyond--in a coherent and unified way. The key intellectual advance that made this possible was the invention of a new kind of symbolic computer language that could for the first time manipulate the very wide range of objects needed to achieve the generality required for technical computing using only a fairly small number of basic primitives.

Over the years, computer algebra software has been greatly improved and microcomputers have become thousands of times more powerful. Quoting from Wikipedia:

> 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.
>
> …
>
> The symbolic manipulations supported typically include:
>
> - simplification, including automatic simplification with assumptions and simplification with constraints
> - substitution of symbolic, functors or numeric values for expressions
> - change of form of expressions: expanding products and powers, rewriting as partial fractions, constraint satisfaction, rewriting trigonometric functions as exponentials, etc.
> - partial and total differentiation

- symbolic constrained and unconstrained global optimization
- partial and full factorization
- solution of linear and some non-linear equations over various domains
- solution of some differential and difference equations
- statistical computation, theorem proving, graphing, etc.

In computer algebra systems and in many other powerful applications, software has been developed that incorporates a significant amount of the accumulated knowledge of one or more disciplines. However, one cannot learn to use the software at a worthwhile level without having some knowledge of the discipline. While use of the software can be taught independently of a content course in the discipline, it is highly appropriate to integrate instruction in the software with instruction in the content of the discipline.

Such powerful software is disruptive to traditional coursework in areas where the software is particularly useful. For example, suppose that a person is taking a traditional freshman calculus course in which the existence of computer algebra systems software is not even mentioned. Students will spend a great deal of time learning to do a variety of procedures by hand and by use of math tables that computers can do very rapidly and accurately. The issue is this: Should the course continue to be taught in the traditional fashion or should it be taught with content that effectively merges the traditional content with the capability of the software? Various research projects conducted over the past 20 years have produced strong evidence supporting the merged course. Most mathematics departments have been slow to adopt this change.

Here is a final example of powerful software described in Wikipedia:

> A geographic information system (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, and present the results of all these operations. Geographic information science is the science underlying the applications and systems, taught as a degree program by several universities.
>
> Geographic information system technology can be used for scientific investigations, resource management, asset management, Environmental Impact Assessment, Urban planning, cartography, criminology, sales, marketing, and route planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, a GIS might be used to find wetlands that need protection from pollution, or a GIS can be used by a company to find new potential customers similar to the ones they already have and project sales due to expanding into that market.

Maintain Your Own Professional Website and/or Blog

Many faculty members have their own professional Websites and/or blogs. This activity can serve a number of purposes, including:

1. Providing a way to share your professional teaching, research, and service work with colleagues throughout the world.
2. Providing students with access to course syllabi and course support materials before and during the time they take a course and for a number of years after they take a course.

3. Providing evidence of scholarly work that can contribute to retention, promotion, and tenure.

It is easy to get started in having a Website or blog. If you lack the personal knowledge of how to get started, get a colleague or a teaching support center on campus to help you. Once you are started, making additions to a site is not much different than using a word processor.

Having your own detailed professional Website or blog ties in well with the strong worldwide movement among scholars and others to share their work. My own publication of this book and eight previous books—all available free under a Creative Commons Attribution Non-Commercial license—provides an example.

Collaborative Writing

You probably have noticed that I have quoted Wikipedia a number of times in this book. Wikipedia was created by and is a continually growing product of thousands of volunteers. Figure 9-1 was retrieved from Wikipedia on February 20, 2007:

Figure 9-1. Wikipedia in English and other languages.

There are a variety of pieces of software that facilitate groups of people working together to produce a document. Here is a related definition from Wikipedia:

> The terms collaborative writing and peer collaboration refer to projects where written works are created by multiple people together (collaboratively) rather than individually. Some projects are overseen by an editor or editorial team, but many grow without any top-down oversight.

As exemplified by Wikipedia, this collaborative writing may involve thousands of writers working over a period of years. In a teaching environment, it may involve small teams of students working for part of one term.

It is relatively easy for members of a class to be given access to a Wiki, or a Website that allows them to easily compose and edit materials. Learning to write in such a collaborative environment can be a challenge, but it is often a very valuable learning experience.

From a course instructor's point of view, such collaborative writing presents the same types of assessment challenges as does other forms of project-based learning. One approach to assessment is to have the faculty member signed up as a member of each writing team. Using this approach, the faculty member can monitor all additions and changes being made on a site. Unfortunately, this can be very time consuming.

In addition, there is the challenge of helping students gain an increased level of expertise in collaborative writing. Are you experienced in collaborative writing and in helping students learn to do collaborative writing? Where should students be gaining such knowledge and skills? Perhaps this should be a component of the Freshman English composition course that is required in many colleges and universities.

Developing and Sharing Reusable Course Modules

On a worldwide basis, there is a growing collection of "reusable" modules—pieces of curriculum. Sharable Content Object Reference Model (SCORM) is a widely accepted collection of standards and specifications allowing for the interoperability, accessibility, and reusability of digital learning materials. A simpler version of this concept is merely the sharing of text, audio, and video segments that are made available via an appropriate Creative Commons license on the Web.

As a teacher, you can consider making increased use of course segments available on the Web and/or Webcasting your courses or segments of your courses. This may involve simple activities such as posting old quizzes and exams to your Website or posting your course notes. Once you start to do this, you might think about polishing the course notes, thus making a start on writing a book.

Some faculty members regularly have their lectures videoed and then post them. However, there is a considerable difference in quality between such "talking head" videos and well-designed and more professionally produced teaching videos. A compromise is that you might want to pick some small components from your courses—components that you tend to use over and over again—and develop them into high-quality, reusable videos that are posted to the Web and made available to teachers and students throughout the world.

Electronic Portfolios

It has long been common for students in some degree programs such as art, architecture, dance, musical performance, and theater, to create a portfolio of their work. Progress in ICT has led to the potential for students in all disciplines to create electronic portfolios. Here is Wikipedia's description of the concept:

> An electronic portfolio, also known as an e-portfolio, or digital portfolio, is a collection of electronic evidence (artifacts, including inputted text, electronic files such as Word and PDF files, images, multimedia, blog entries and Web links etc.) assembled and managed by a user, usually online. E-portfolios are both demonstrations of the user's abilities and platforms for self-expression, and, if they are online, they can be maintained dynamically over time. Some e-portfolio applications permit varying degrees of audience access, so the same portfolio might be used for multiple purposes.

Nowadays, some elementary school teachers help their students to develop portfolios of their schoolwork, and these may well be stored electronically. This type of portfolio provides a historical record of some of a student's accomplishments. In addition, the process of selecting which items to use and documenting why they were selected can be a valuable learning experience.

The same ideas hold for students in higher education. As an example, many College of Education teacher education programs require their students to create electronic portfolios. Often this requirement is partially fulfilled through taking a course that teaches students how to design and begin creating their electronic portfolios. The final portfolio contains a variety of samples of a student's work and probably some video of his or her practice teaching. Such electronic portfolios are useful both to students and to their faculty and departments. In the latter case, portfolios are used sometimes used as evidence in accreditation of programs of study.

Student Creation of Interactive Multimedia

I grew up in a communication environment that included text, movies, television, and audio recordings. I learned to use a telephone, to take (still) photographs, and to use a motion picture camera.

Now, all these technologies have merged. Moreover, the technological changes make it possible for K-12 students to design, create, edit, and publish interactive multimedia. The creation and publication of multimedia documents is now quite easy. From a teaching and learning point of view, this raises questions such as:

1. How do students gain the knowledge and skill to move to higher levels of expertise in the creation of multimedia? Remember, in the "good old days" teacher education programs for K-12 preservice teachers often included an overhead projector course. Aspiring filmmakers and photographers often spent years in filmmaking programs and apprenticeship-type jobs.
2. How do faculty members deal with (accept and encourage, or perhaps reject and discourage) students using interactive multimedia to represent and present their work? How do faculty members gain the knowledge and skill to separate the glitz of interactive multimedia from the deep content that they are looking for in a student's work?

The second point is a particular challenge to faculty. We all know how to read and write, and we all are able to provide constructive feedback on a student's written papers. Some of us are much better than others at this task.

Consider just the small technology-based change of students writing using a word processor with a spelling and grammar checker, inserting graphics and pictures, doing desktop publication, and submitting a paper electronically. Many faculty members are uncomfortable reading and editing a paper online. Many faculty members do not know the rudiments of desktop publication.

Now add in all of the capabilities needed to create interactive multimedia. It takes a huge amount of knowledge and skill to do an appropriate assessment and provide appropriate feedback on interactive multimedia documents.

Computational Thinking

Chapter 1 quoted Jeannette Wing's 2006 article about computational thinking. Since writing that short article, she has been selected to head the National Science Foundation's new Computer & Information Science & Engineering Directorate. Beginning July 1, 2007, she will oversee a $527 million budget. Wing answered the following questions posed by Gary Anthes (2007) in an interview he conducted with her:

> **What from your background was of interest to the National Science Foundation (NSF)?**
>
> … But looking ahead, one of the things that intrigued NSF and the whole computer science community is my philosophy about computational thinking. The ideas in computing, the abstractions we bring from CS, will pervade all other disciplines—not just other sciences and engineering—but also humanities, arts, social sciences, entertainment and everything.
>
> **What does that mean for NSF programs?**
>
> It means [funding] research in the basics of CS so that an algorithm we invent today will have a use tomorrow [that] we didn't even predict. And [it means making] sure we are working with the other disciplines to help them do their science and engineering or media technology or whatever. So, this just says that CS is all over the place.
>
> **What does this mean for CS education?**
>
> CS is more than programming, and we have to convey that message to the general public and inspire the young to the deep intellectual challenges that remain in the field. We need the next generation to be working on those.

Final Remarks

This chapter briefly examines a wide variety of ICT uses in teaching and learning. The strength of the underlying research varies considerably. In some cases, this lack of research is troubling to educators. Suppose, for example, that all students were to be provided with voice input, handheld calculators before they even started school, and were allowed to use them at any time. (This could be a wristwatch-like device that also tells time.) How would this affect the level of mathematical understanding that students gain through our "traditional" math education system? This issue and type of question provokes considerable debate in the world of precollege math education.

For another example, in the early history of the widespread use of word processing, research was done on whether the quality of a student's writing was improved by use of a word processor. In the typical study, students who had gained a modest amount of skill in keyboarding and in word processing were compared with control-group students who had spent an equivalent amount of learning time doing something else—perhaps using a computer to do electronic searches, or perhaps doing paper-and-pencil writing.

Such studies tended to miss the whole point: The value of word processing lies in the ease of editing it offers, the ease of sharing copies with others, increased legibility, ease of reuse of parts of a document, and as a step toward desktop publication. Such studies were also weak in examining the computer-oriented writing preparation of students. It takes a significant amount of study and practice to become fluent in composing at a keyboard and in doing one's first draft of writing in a word-processing environment.

Evidence (or the lack thereof) for many other integrations of ICT into the everyday repertoire of teachers and students can be thought of in the same manner. We can do research on how well students can retrieve information from a school library that catalogs its holdings on hard-copy index cards versus students who access the same library electronically. However, hard copy index cards are rapidly disappearing from libraries, while electronic searches are useful in accessing the Web and libraries located throughout the world. The change from card catalog to electronic search has occurred independently of the advantages or disadvantages to students.

Here is a final example, and it doesn't even involve ICT. When handwritten essays were introduced on the SAT exams for the high school class of 2006, just 15 percent of students wrote their answers in cursive. The rest printed their essays. For quite a few years now, there has been debate about whether to allow students to use a word processor in such assessments of writing. In my opinion, this is no longer an issue of the "hand printing is on the wall." Rather, it is an issue of how soon the "word-processed writing will be on the wall."

Chapter 10
Speculative Ideas

"It takes a whole village to raise a child." (African proverb.)

"The best way to predict the future is to invent it." (Alan Kay)

Previous chapters of this book have discussed many possible changes to our current educational system. This final chapter contains some speculations about the future of higher education.

Historical Trends in Education

This section contains a simplified model of a historical trend in education. It posits six phases that range from the distant past to current times. We are now in the beginning of the sixth phase, which will likely continue for many years into the future. However, a seventh phase is on the horizon, and it is included in the list.

1. **Hunter-gather,** learning from a limited environment of people and the stimulation of movement from place to place. A hunter-gather group (tribe, clan) was often relatively small and constantly on the move. Children growing up in this environment were raised by an extended family, perhaps with all members of the tribe contributing. In smaller tribes, everybody could know everybody else. Children learned by imitating others, by doing, and by commonly receiving direct one-on-one instruction.

   Our race evolved to have the physical, mental, learning, and other characteristics necessary to survive in a hunter-gatherer environment. The people in these societies had speech and oral tradition—they did not have books, reading, and writing. Oral linguistic intelligence was very important. Naturalistic intelligence—one of the eight intelligences in Howard Gardner's multiple intelligences list—was essential to learning to survive in a world where nature was often harsh and unforgiving. People were highly dependent on others within their small group for survival, so interpersonal intelligence (also on Gardner's list) was important. Spatial intelligence (also on Gardner's list) was essential to hunters so that they could find their way to predetermined locations and find their way back "home" again. Contrast the important types of intelligence in the hunter-gatherer era with areas of learning in our current school system, with its great emphasis on reading, writing, and arithmetic.

   During the hunter-gather era, educational assessment was authentic. That is, people learned by doing and they then used their increased knowledge and skills to perform useful tasks such as fire making, tool construction, hunting, gathering, and communicating, including telling stories while seated around the campfire.

2. **Agriculture,** beginning approximately 11,000 years ago but developing independently at different times in different parts of the world. Agriculture

facilitated an environment of larger groups of people and their infrastructure, such as villages, towns, and then cities. In larger communities, a person could know only a modest percentage of the people. For many, travel was limited. A person might grow up in a small community and never wander as much as ten miles from the community. Spatial intelligence was much less needed for survival. The increased population and stability of the home site helped some people become specialists, and with this trend came the idea of an apprenticeship type of education. Through a combination of nature and nurture (especially, when one was apprenticed to an appropriately capable master), a person could become an expert relative to others in the community. It might take many years to achieve a level of expertise somewhat comparable to the master.

In a hunter-gather society, children learned to contribute to the overall welfare of the group when they were quite young. This situation continued in agrarian societies because young children could perform useful farming and herding duties.

3. **Invention of reading, writing, arithmetic,** schools, and then universities. The first invention of reading and writing occurred somewhat more than 5,000 years ago. This invention was subsequently repeated at several other times in various locations. It takes a considerable period of time to learn to read and write, and it requires an educational system different from an apprenticeship type, or one in which a person learns by imitating others. Quite early in the history of learning to read and write, a teacher-and-classroom approach was developed. Reading and writing facilitated the accumulation and sharing of knowledge in a form not previously available. A person could become a scholar, accumulating knowledge over a lifetime, and sharing this knowledge with students and colleagues by teaching, writing, and lecturing. For many thousands of years, only a small percentage of the population learned to read, write, and do arithmetic by making use of reading and writing.

   Reading and writing brought a new problem to our educational system. A significant percentage of people, perhaps in the range of 5 percent to 20 percent, have some level of *dyslexia*, a brain structure and disorder that makes it difficult to learn to read. This brain difference does not affect IQ; in fact; it may even add to a student's development of problem-solving skills.

   Well after the invention of reading and writing, institutions of higher education developed. These institutions are described in Wikipedia:

   > If we consider a university as a corporation of students, then Takshashila University [fifth century B.C.] and Plato's Academy [387 B.C.] are the earliest, historically-documented universities. … Another Indian university whose ruins were only recently excavated was Ratnagiri University in Orissa. Al-Azhar University, founded in Cairo, Egypt in the 10th century, offered a variety of post-graduate degrees, and is often regarded as the first full-fledged university. … The University of Constantinople, founded in 849, by the regent Bardas of emperor Michail III, is generally considered the first institution of higher learning with the characteristics we associate today with a university (research and teaching, auto-administration, academic independence, et cetera.

4. **Improvements in travel, and the development of printing presses.** Good roads, such as the Romans built, and improvements in ships made a significant contribution to the accumulation and spread of accumulated information. Wikipedia describes on of these accumulations of information:

   > The Royal Library of Alexandria in Alexandria, Egypt, was once the largest library in the world. It is generally thought to have been founded at the beginning of the 3rd century BC, during the reign of Ptolemy II of Egypt.

   The history of printing using a carved wooden block or metal plate goes back nearly 2,000 years. Moveable type was developed in China between about 1045 and 1058. Moveable metal type was developed by Johannes Gutenberg about 1450. The printing press eventually made it possible for ordinary people to own books. It made it possible for the mass production and distribution of newspapers and magazines. The printing press increased the value of a person becoming literate.

5. **Industrial Age,** education for the masses, and high-tech communication systems. The Industrial Age began about 230 years ago. It brought us railroads, steamships, telegraph, telephone, cars, airplanes, and mass production of a wide variety of goods. It brought us rapid improvements in transportation and communication. It also led to the implementation of mass public education, which required young children to go to school and prohibited them from working in factories.

   The education system developed in this period is often called a "factory model," which focuses on efficiency of information delivery. Children are grouped by age, and the overall educational process is structured in some sense like an assembly line in a factory. Over the decades, the need for moderately educated workers grew, as did the need for some highly educated people with a reasonably high level of expertise in narrow disciplines. Large numbers of students received their formal education through a system that depended on a modest number of textbooks and a few reference books—and upon teacher presentations—as the main sources of information.

   Trade schools and community colleges developed to help meet the need for craftspeople and others who formerly received their education in an apprenticeship system. Technology such as recordings, movies, and then television aided the presentation process.

   This fifth phase is now well entrenched throughout the world. All of the previous phases are still present, but often in somewhat altered forms. For example, many preschool children now grow up in an environment that includes a quite limited number of people that they personally interact with, but this is significantly affected by television and video recordings. Those growing up in an intellectually or financially rich home environment tend to gain significant educational advantages over those who do not have these benefits.

6. **Information and Communication Technology (ICT) Age**. The ICT Age is characterized by a still more rapid pace of change in many areas of research, development, and implementation. The totality of collected human

knowledge is growing much faster than in the past. An NSF report (2003) describes the situation:

> The first decade of digital library research provided ample evidence that humankind's ability to generate and collect data exceeds our ability to organize, manage, and effectively use it. This trend is unlikely to abate without continued research and development. For the foreseeable future, data of many types will be increasingly abundant and "technologically" available. But these data will continue to seem chaotic, lacking sufficient organization, stability, and quality control.
>
> …
>
> *Digital resources have demonstrated the potential to advance scholarly productivity, easily doubling research output in many fields within the next decade*. [Italics added for emphasis]

Rapid improvements in telecommunications have made the world smaller. The Science of Teaching and Learning is increasingly facilitated by ICT aids to research and implementation. A rapidly growing global library (the Web) and steady progress in the development of new ways to provide somewhat individualized, interactive, high-quality instruction are beginning to compete with the factory model of schooling from phase 5. Tools are growing "smarter" and are playing a steadily increasing role in creating expertise within a wide variety of disciplines.

Education in phase 6 is different than the uniformity and rote memory approaches to education of phase 5. It is being led by research on the values of individualization and education for higher-order thinking and problem solving. It is attempting to face the challenge of the rapid pace of change in the totality of human knowledge, tools that embody and make use of this accumulated knowledge, and aids (both tools and education) to making use of the accumulated knowledge.

7. **Merger of biology and technology.** This is speculation; many futurists have made such speculations. The general idea is that the dividing line between our biological selves and technology-produced aids and augmentations to our biological selves will gradually disappear. We are used to this in terms of simple aids such as eyeglasses, cataract lens implants, hearing aids, pacemakers, and replacement joints. We are used to replacement heart valves, bypass surgery, and grafts of veins and arteries.

   We are beginning to make significant progress in connecting individual neurons into electronic circuitry and in using electronic (not direct-wired) connections between a brain and computers. Eventually it will become common for people to have some combination of ICT brain implants that are hardwired into their brain and external ICT devices that connect to their brains without the use of wires.

   We are developing a variety of cognitive improvement drugs. At the current time, drugs that enhance physical performance are a major issue in athletics. Imagine the challenges our educational system will face as students gain access to new drugs that enhance their mental capabilities (we already have caffeine and Ritalin), and as genetic engineering eventually is used for cognitive enhancement.

Our current educational system is having a hard time in dealing with currently available technology. As a simple example, nearly 20 years ago one of my sons was a student in an engineering school. Students there were expected to own and learn to use quite sophisticated, programmable calculators in doing their homework and taking tests. However, such calculators have a substantial amount of memory. Thus, students soon figured out that they could store formulas and other notes inside the calculator and access this information during tests. This developed into a contest between the faculty and the students, with the faculty trying to prohibit such "cheating."

A key aspect of phase 6 that will become even more apparent in phase 7 is that people and machines working together can far outperform and out produce people without the physical and cognitive aids. Many of the physical and cognitive tools require a substantial amount of formal and informal education to use. We currently have an educational assessment system that is not well aligned with the reality of humans learning to use these tools and then using these tools to solve problems and accomplish tasks. In the jargon of education, we say that assessment is not *authentic* (Wiggins, 1990).

One of my forecasts—and strong hopes—for the future is that our educational system will move firmly in the direction of authentic assessment of students as they use tools to solve problems, accomplish tasks, and in other ways demonstrate their increasing levels of expertise. Note that this would bring us full circle, back to the authentic assessment of the hunter-gather era.

Universities of the Future

Here is a quote from Peter Drucker (1997), one of the leading gurus of business management during the past half century:

> Thirty years from now the big university campuses will be relics. Universities won't survive. It's as large a change as when we first got the printed book. Do you realize that the cost of higher education has risen as fast as the cost of health care? ... Such totally uncontrollable expenditures, without any visible improvement in either the content or the quality of education, means that the system is rapidly becoming untenable. Higher education is in deep crisis. … Already we are beginning to deliver more lectures and classes off campus via satellite or two-way video at a fraction of the cost. The college won't survive as a residential institution.

We are now 10 years into this 30-year forecast. So far, Drucker's forecast is proving to be quite accurate. Use of distance learning has been growing rapidly, and for-profit colleges and universities are making extensive use of this approach to the delivery of instruction and other educational services.

However, I disagree with Drucker's overall forecast. Higher education has a large cultural and social interaction component. My forecast is that these social and historical aspects of higher education will continue to preserve residential colleges and universities.

In addition, research universities have made a large and continuing investment in high-tech facilities needed in research. The research groups, research seminars, doctoral programs, and other programs associated with this expensive equipment will continue to be a major drawing force, bringing students into a residential mode of study and research.

Residential colleges and universities will steadily increase their use of a combination of CAL and DL. Students in a residential institution will draw more heavily on DL courses offered by other institutions located throughout the world. For most four-year and graduate programs of study, the dividing line between residential and DL will become quite fuzzy.

Star Trek

I have thoroughly enjoyed the various Star Trek television series and movies. One of the things that impresses me about this vision of the future in how problem situations are identified, more clearly defined, and then solved. In the Star Trek television series, each week brings new problems, some so serious that they threaten all of humanity.

The captain and a few high-ranking officers get together to clarify the problem situation. They interact with the highly intelligent ship's computer that contains much of the accumulated knowledge of the human race and many other races. They ask quite complex questions of the computer, and have the computer solve a variety of sub problems for them.

They often draw upon the knowledge of a science officer. In The Next Generation, this is Data, an android (a robot). In the Voyager series, the Doctor (an emergency medical hologram) often plays an important role. In essence, the Doctor is a virtual human, created by and run by the starship's computer.

Finally, the starship's leaders decide on a course of action and implement their plan. Often they have to modify their plan based on what they learn as they have successes and failures in implementing the plan.

Here are two important ideas about Star Trek from an educational point of view:

1. The computer system, humans, and others work together collaboratively on a problem, each contributing what they can. Each brings a different type of expertise and intelligence to the task.
2. Emotions, human values, the values of other sentient life forms, and the preciousness of all life forms play a major role. Emotional intelligence and people skills are highly valued.

The Holodeck

The Holodeck was introduced in the Star Trek television series, The Next Generation. The Holodeck is a virtual reality system that can create very realistic simulations in which real and simulated characters interact. Thus, for example, a human might participate in a conversation about scientific research with Albert Einstein, Richard Feynman, and John von Neumann. Instead of going to school to sit in a class of 30 students, one might have individual tutors in various subjects but also participate in small classes in which some or all of the other students are virtual students.

It is clear to me that eventually something akin to a Holodeck will play a major role in education. We see signs of this in the increasingly high-quality simulations used both for educational purposes and entertainment.

Education as a Business

Certain aspects of our current instructional system in higher education can be characterized as a cottage industry. However, many aspects of higher education are like big business and are run like modern businesses. We can examine some of the major components of a higher education system in terms of their dependence upon a cottage-industry approach versus a big-business approach.

For example, every institution of higher education has personnel. This entails maintaining staff records, managing the staff, paying the staff, and so on. The institution has infrastructure needed by staff and by students, unless the institution does all of its teaching via DL. The institution needs to maintain detailed records on its students, recruit new students, and retain its students. If we think of a student as being somewhat like a customer, then all of these activities are similar to what a business needs to do.

Historically, an institution of higher education has had a library designed to serve students and faculty. A public or private library is a type of business that can be organized and run in a business-like manner.

Historically, an institution of higher education has been divided into units (such as schools or department), which have faculty members who develop and teach individual courses and programs of study. The division into such units is in line with the need for a high level of specialized expertise within the various discipline areas. In some sense, an institution of higher education is a little like a business that has a number of somewhat independent divisions. Some of the aspects of an academic department are much like an independent business, while other aspects draw heavily from the overall conglomerate of departments—the overall institution.

We begin to see aspects of a cottage industry when we get down to the level of individual courses and individual faculty members. At all levels of education, we are used to the idea of a teacher and a group of students coming together in a classroom, and with the teacher having considerable individual responsibility and authority in the classroom.

The educational research literature provides solid evidence that some teachers are much more effective than others and that these difference lead to substantial differences in student learning.

I suspect that the teacher effect is somewhat smaller in higher education than in precollege education because college students assume a greater level of responsibility for their own learning than do precollege students. In higher education, there is a general rule of thumb that undergraduates are supposed to study for two hours outside of class for each hour in class, and that graduate students are supposed to study for three hours outside of class for each hour in class. This is significantly different than the typical situation in precollege education.

At the college and university level, a single course is somewhat like a one-person business. Here is a list of six major aspects of an individual course or course of study in higher education, each followed by my forecasts for the future.

1. **Course design**. This includes the design of course content, the instructional processes, and the assessment.

   Forecast: In courses that have reasonably large enrollments, we will move toward more and more use of highly interactive, intelligent computer-assisted learning (HIICAL) delivered over the Internet. Two of the reasons for this are economy of scale and increase in quality. The HIICAL components of these courses will be designed by teams. A HIICAL course or major HIICAL components of a course will have course design, instructional processes, and assessment all rolled together, and will be used in many different colleges and universities throughout the world. Such a course will be improved over time. Residential campus institutions will tend toward hybrid courses that combine whole-class meetings with HIICAL.

2. **Course management.** This involves the management of many details, such as providing students with a detailed syllabus and assignments, record keeping for each individual student, perhaps keeping attendance at class meetings, and so on.

   Forecast: A variety of course management systems are commercially available or available as open source. Faculty are finding that course management systems are not too difficult to adopt and that doing so is helpful to their students. Doing so also reduces the pressure on faculty for not being "with it." The trend toward use of course management systems is now well established and such use will continue to grow until it is a commonly accepted and expected practice.

3. **Individual student responsibility.** The design of traditional higher education forces students to take more responsibility for their own education than they had to at the precollege level. Moreover, college students are expected to have a higher level of maturity so that they can assume an increased level of responsibility. The amount of "hand holding" that college students get varies considerably from institution to institution.

   Forecast: In recent years, it appears that there has been a trend toward higher education students expecting and needing more hand holding than in the past. It appears to be more common for faculty members to hear students saying, "Just tell me exactly what to do and I will do it." To the extent that this is occurring, it may well reflect a decrease in the accomplishment of one goal in education: helping students become independent, self-sufficient, lifelong learners who can take responsibility for themselves and play a leadership role in areas determined by their education and other life experiences.

   The models of DL that are being widely adopted in higher education tend to contribute to this trend. A DL course often provides very precise specifications of what the students are expected to do. Indeed, this is often considered a hallmark of a well-designed and well-implemented DL course.

   CAL also tends to diminish a student's responsibility for his or her own education.

   In my mind, this is a serious dilemma. If we carefully align tests with what students are being taught, then we need to carefully specify what they are being taught and what they are being expected to learn. However, we are not good at measuring or testing individual creativity, developing powers of taking individual responsibility, or developing powers of leadership. Thus, we seem to be creating an educational system in which students will score better on tests but will be less well educated.

   My forecast in this area is not optimistic. It seems to me we are headed in a wrong direction and that we are apt to continue down that road. It may well be that CAL and DL will contribute to this downhill slide.

4. **Human relationship facilitation.** Education is often described as "a human endeavor." Some of these ideas are captured in the work of Lev Vygotsky in his theories of social constructivism. As described in Wikipedia:

   > Vygotsky investigated child development and how this was guided by the role of culture and interpersonal communication. Vygotsky observed how higher mental functions developed through

social interactions with significant people in a child's life, particularly parents, but also other adults. Through these interactions, a child came to learn the habits of mind of her/his culture, including speech patterns, written language, and other symbolic knowledge through which the child derives meaning and affected a child's construction of her/his knowledge. The specific knowledge gained by a child through these interactions also represented the shared knowledge of a culture.

In an oral tradition, the method of storing information goes back to the development of spoken language, many tens of thousands of years ago. This oral tradition was eventually supplemented and largely supplanted by writing and the use of the printing press. The Web and other digital libraries are a result of a rapidly changing technology for storing information.

Over this same time period, face-to-face communication has been supplemented by written communication, the telegraph, the telephone, radio and television broadcasting, email, and now cell telephones.

Every faculty member is a communicator and a facilitator of communication. Every course can be analyzed from the point of view of how it contributes to facilitating communication among people who are involved with and/or touched by the course.

Forecast: The world's telecommunication system (the "C" in ICT) is improving quite rapidly. In the year 2006, approximately a billion cell phones and about 230 million laptop and desktop microcomputers were sold. In the U.S. and other parts of the world, we see huge changes in the way people are interacting with each other through use of email, instant messaging, chat groups, personal blogs, ICT-based social networking systems (such as YouTube, Bebo, MySpace, Facebook, and Second Life), massively multiplayer online games, and other ways of sharing and communicating information, such as Wikis. The 2006 Time Magazine Person of the Year was "you." What this means is that huge numbers of us are involved in contributing to a major change

Our formal education system, at all levels, faces the challenge of this rapid and massive change in social networking. Businesses are adjusting to this much more rapidly than our education systems. My forecast here is that our traditional higher education system will become more "out of tune" with students. Those educational organizations, institutions, and courses that can incorporate and build upon the general idea that "you" were the Time Magazine Person of the Year in 2006 will gain significant market share.

5. **Effectiveness and cost effectiveness.** Each course has a variety of goals—some explicitly stated and some more implicitly assumed. Thus, for example, an explicit goal in a math course might be to have students gain an increased understanding of the concept of function and to learn about some specific functions such as polynomials. Another goal, often not made explicit, might be to help students get better at reading, writing, speaking, and listening in the language of mathematics.

   An educational institution might measure cost effectiveness just in terms of dollar costs and measurable learning outcomes. How can the costs of delivering instruction be reduced, without reducing outcomes as measured by student learning? Such a simple-minded approach to cost effectiveness fails to take into consideration implicit learning goals and the social learning that is inherent in traditional courses.

The simple cost-effectiveness approach also fails to consider the inputs of student time and effort. How can the time and effort needed for students to achieve a specified level of expertise be decreased?

Forecast: Cost effectiveness is a difficult issue. For example, consider how to measure effectiveness. We want students to learn in a manner that facilitates transfer of learning and that facilitates long-term retention of knowledge and skills that contribute to increased (long-term) expertise in the areas being studied. We want students to learn to learn and to make lifelong use of such increased expertise as a learner.

We know that highly qualified individual tutors and small classes taught by very good teachers increase the effectiveness of education—but they cost a lot! Consider the other extreme. We can give students access to a good library and tell them, "go learn." The cost is very low (no formal courses, few faculty). Effectiveness is measured by final exams given once a year. The amount and nature of the learning will vary considerably from student to student, but the overall cost effectiveness may be very impressive because the cost is so low.

Most colleges and universities are sorely pressed fiscally and challenged in the task of maintaining the quality of education they are currently providing. Thus, many are making a considerable effort to decrease the cost of instruction. The idea of providing students with books and saying, "go learn," has limited effectiveness. However, suppose we have something much better than books. Suppose we have highly interactive, multimedia-based, intelligent CAL with lots of feedback and formative and summative assessment delivered over the Web. These materials are made available to students and then they are told to "go learn." Students who want to be in an interactive network of other students who are studying the same materials are able to become part of discussion groups and cooperative learning groups where the interaction is synchronous or asynchronous and is done over the Internet.

Such course materials are costly to develop and maintain. However, as the *Futuristic Scenario* given later in this chapter illustrates, this approach can be quite cost effective when used by large numbers of students. I believe that this will be a significant component of the future of higher education and of steadily growing importance in precollege education.

6. **Apprenticeships.** The ideas of an apprenticeship-type education forms the core of many doctoral and postdoctoral programs of study. This has some aspects of a cottage industry. However, nowadays the cottage may be quite large and tied in with similar cottage industries and larger groups throughout the world. This makes it possible to study with and work with the best, the brightest, and the most successful people in one's field of study. It places the student in an environment that includes the people and facilities necessary to be at the leading edge of education.

Forecast: Many areas of research require quite expensive facilities and teams of people working together. Collaboration may involve researchers from around the world. This is quite different from the historically romanticized image of an individual researcher working alone with inexpensive facilities. It is also quite different from a master working with one or two apprentices in a small, localized, craft-based business.

I believe this modern version of the research apprenticeship will continue to be an excellent approach to advanced research-oriented doctoral and postdoctoral education. Apprenticeships offer one-on-one, small-group, and learning-by-doing educational benefits. Apprenticeships allow students to immediately use what they are learning in the learning environment. An apprenticeships type of education is consistent with the current best practices in the science of teaching and learning.

Futuristic Scenario

Here is an interesting scenario for the future. (Please note that this is pure speculation on my part.)

Executive Summary

Computer-Assisted Learning Report to the 2020 California Legislature

In 2009, the California Legislature looked at the growing costs of providing a good-quality college education to the hundreds of thousand of new students entering the system each year. The majority of these students were entering community colleges and the majority of all beginning students needed remedial coursework. A great many of the students were bilingual, with English not being their first language.

Some of the legislators argued that community colleges and other state-supported institutions of higher education should not offer such remedial coursework since the students should have learned this material in elementary and secondary school. They proposed a plan for such students to take remedial courses by enrolling in their local high schools.

Others argued that many of the students had completed high school quite a few years ago and that many others had dropped out of high school. Businesses in the state needed better-educated employees. The greatest need was for employees who could think and solve problems at a higher level than the average high school graduate could.

The legislature eventually decided to commit $1 billion a year (nearly two percent of the education budget) to create high-quality, highly interactive CAL courses that could be used to supplement traditional courses, be integrated within hybrid courses, and act as standalone DL courses. These would cover large-enrollment courses at each of the grade levels 9 to 14. Each course would be based on the current theory and practice of the Science of Teaching and Learning. There would be ongoing research on the effectiveness of each course, with ongoing funding to revise courses to reflect this research as well as general new findings in the Science of Teaching and Learning.

The implementation model that was used involved contracting with private companies to develop the courses, and it was designed to create competition among such companies. Thus, for example, three different companies would each develop a year-long high school geometry course. In addition, each course had to be available in English, Spanish, and at least one other language. The companies competing to develop these courses could gain some competitive advantage by making their courses available in additional languages.

The typical one-year course contract that was established offered $12 million for course development, appropriate field-testing, and then full use of the course for two years. If such a course was proven to be effective and had an appropriate level of demand (student enrollment) during its first year of full use, the company could then apply for continued funding at the rate of $2 million a year. These additional funds were to be used to update and improve the course. The continued funding was subject to rigorous external evaluation.

The courses that were developed belonged jointly (50-50) to the developers and the state of California. Within the state of California, the materials were made available free to schools and other appropriate institutions, such as prisons. The state of California received a 10-percent royalty for sales and licensing outside the state.

Most of the organizations that bid to produce materials were already publishers of books and supportive software for current courses. In many cases, the bidders were consortiums of such companies, educational research organizations, and higher education institutions. Building on their previous work, these organizations were able to meet the goal of having new materials available in just one year.

Many people felt that an investment of $1 billion a year was much too large and the state could not afford it. However, several things combined to make this a highly successful investment.

1. The continuing $1 billion a year investment was large enough to fund the creation of more than 300 courses, that is, three competing year-long, multilingual courses in each of 100 different topic areas.
2. Research proved that students taking these courses learned more (on average) than students taking courses taught without the use of this technology. The students were more satisfied with this form of instruction than they were with traditional means of instruction. In addition, these courses proved to be more cost effective than traditional courses.
3. Over time, it turned out that savings in books, building construction and maintenance, and overall school staffing exceeded $1 billion a year. The courses proved to be quite popular and effective in the prison system, which was an unanticipated bonus.
4. Annual royalties from this business have been approximately $100 million a year over the past six years. These royalties have been used to create additional courses at the middle school level.

------- End of Futuristic Scenario -------

As noted elsewhere in this book, my success as a futurist has been rather limited. However, I enjoy putting together what I know with my insights into possible futures. I hope this scenario has caused you to think about possible futures of our educational system.

Some Futuristic Literature

There is quite a bit of solid, futuristic-oriented research being done. As Doug Barney (2006) notes:

> Three years ago, William Henry Gates III ordered Microsoft Research to launch a Science division. Money was one motive—by staking out a position in the growing field of scientific computing, future profits were insured. Fortunately Microsoft Research doesn't have to turn every dollar and man-hour into marketable products. *The Science group has the wonderful freedom to work on the big problems: global warming, disease, the future of medicine, the origin of the universe and the creation of life—those sorts of things.*
>
> ...
>
> [The] main goal is to blend computer science and traditional science, and in the process transform both. "*We are at a profoundly important point in time where computer science and computing have the potential to completely revolutionize the sciences.*" [Italics added for emphasis]

ICT is beginning to have a significant impact in the humanities and social sciences. On December 18-19, 2006, a conference entitled Spatial Thinking in the Social Sciences and Humanities was held at the University of Illinois. As an example of the types of ideas discussed there, here is part of the abstract of a presentation (NCSA, 2006) by Ruth Mostern, University of California, Merced:

> In the past 10 years, historical GIS [Geographic Information Systems] has been a robust and rapidly developing field, spawning national projects of enterprise scale, digital publications and websites focused on particular research domains, books and articles making use of spatial analysis, and special journal issues about the field. HGIS [Historical GIS] practitioners, implicitly or explicitly, have devoted themselves to the admirable goal of centering spatiality in their analysis, and identifying how to abstract spatial change over time. I want to frame the problem the other way around. What if, instead of thinking about geography (as it is transformed over time), we inquire instead about history (which has a spatial element)?

The March 23, 2006, issue of *Nature: International Weekly Journal of Science* includes eight articles grouped together under the heading "2020—Future of Computing." While most of the articles are oriented toward the various sciences, a number of the ideas apply to other disciplines of research and study. As described on *Nature*'s Website (Nature, 2006):

> In the last two decades advances in computing technology, from processing speed to network capacity and the internet, have revolutionized the way scientists work. From sequencing genomes to monitoring the Earth's climate, many recent scientific advances would not have been possible without a parallel increase in computing power - and with revolutionary technologies such as the quantum computer edging towards reality, what will the relationship between computing and science bring us over the next 15 years?
>
> This *Nature* web focus combines commentaries from leading scientists and news features analysis from journalists assessing how computing science concepts and techniques may transform mainstream science by 2020.

Here are Web addresses where one can read the various articles at no cost, along with selected quotes from some of the articles:

> Ball, Philip (3/23/06). *2020 computing: Champing at the bits.* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440398a.html.

> Despite some remaining hurdles, the mind-bending and frankly weird world of quantum computers is surprisingly close. Philip Ball finds out how these unusual machines will earn their keep.

Brent, Roger, and Bruck, Jehoshua (3/23/06). *2020 computing: Can computers help explain biology?* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440416a.html.

Butler, Declan (3/23/06). *2020 computing: Everything, everywhere.* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440402a.html.

> These new computers would take the form of networks of sensors with data-processing and transmission facilities built in. Millions or billions of tiny computers—called "motes," "nodes" or "pods"—would be embedded into the fabric of the real world. They would act in concert, sharing the data that each of them gathers so as to process them into meaningful digital representations of the world. Researchers could tap into these "sensor webs" to ask new questions or test hypotheses. Even when the scientists were busy elsewhere, the webs would go on analyzing events autonomously, modifying their behaviour to suit their changing experience of the world.

Foster, Ian (3/23/06). *2020 computing: A two-way street to science's future*. Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440419a.html.

> A more sophisticated narrative says that science is increasingly about information: its collection, organization and transformation. And if we view computer science as "the systematic study of algorithmic processes that describe and transform information," then computing underpins science in a far more fundamental way. *One can argue, as has George Djorgovski, that "applied computer science is now playing the role which mathematics did from the seventeenth through the twentieth centuries: providing an orderly, formal framework and exploratory apparatus for other sciences.*"
>
> …
>
> First, the scientist of 2020 will be adept in computing: not only will they know how to program, but they will have a solid grounding in, for example, the principles and techniques by which information is managed; the possibilities and limitations of numerical simulation; and the concepts and tools by which large software systems are constructed, tested and evolved. This knowledge has been picked up on the job by many pioneering scientists and will hopefully be instilled in the next generation by more formal training. *The idea that you can be a competent scientist without such training will soon seem as odd as the notion that you need not have a solid grounding in seventeenth-century mathematics (such as algebra).* [Italics added for emphasis]

Muggleton, Stephen H. (3/23/06). *2020 computing: Exceeding human limits.* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440409a.html.

> The collection and curation of data throughout the sciences is becoming increasingly automated. For example, a single high-throughput experiment in biology can easily generate more than a gigabyte of data per day, and in astronomy automatic data collection leads to more than a terabyte of data per night. Throughout the sciences the volumes of archived data are increasing exponentially, supported not only by low-cost digital storage but also by the growing efficiency of automated instrumentation. *It is clear that the future of science involves the expansion of automation in all its aspects: data collection, storage of information, hypothesis formation and experimentation (see table).* Future advances will have the ability to yield powerful new forms of science that could blur the boundaries between theory and experiment. However, to reap the full benefits it is essential that developments in high-speed automation are not introduced at the expense of human understanding and insight. [Italics added for emphasis]

Ruttimann, Jacqueline (3/23/06). 2020 computing: *Milestones in scientific computing*. Retrieved 3/3/07:

http://www.nature.com/news/2006/060320/multimedia/computing_timeline/html/computing_timeline.html.

Szalay, Alexander and Gray, Jim (3/23/06). *2020 computing: Science in an exponential world.* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440413a.html.

> Scientists are trained early to keep careful records in their laboratory notebooks—recording both experimental procedures and observations, so that they can analyze their results and so that others can replicate what they have done. Galileo did it, Mendel did it, Darwin did it, and we are supposed to do it. This worked fine when small amounts of data were entered into notebooks and the analysis was computed alongside them. But data volumes are doubling every year in most areas of modern science and the analysis is becoming more and more complex, exceeding the capacity of the paper notebook. With data correlated over many dimensions and millions of points, none of the old steps—do experiment, record results, analyze and publish—is straightforward. Many predict dramatic changes to the way science is done, and suspect that few traditional processes will survive in their current form by 2020.

Vinge, Vernor (3/23/06). *2020 computing: The creativity machine.* Retrieved 3/3/07: http://www.nature.com/news/2006/060320/full/440411a.html.

> All this points to ways that science might exploit the Internet in the near future. Beyond that, we know that hardware will continue to improve. In 15 years, we are likely to have processing power that is 1,000 times greater than today, and an even larger increase in the number of network-connected devices (such as tiny sensors and effectors). Among other things, these improvements will add a layer of networking beneath what we have today, to create a world come alive with trillions of tiny devices that know what they are, where they are and how to communicate with their near neighbours, and thus, with anything in the world. Much of the planetary sensing that is part of the scientific enterprise will be implicit in this new digital Gaia. The Internet will have leaked out, to become coincident with Earth.
>
> How can we prepare for such a future? Perhaps that is the most important research project for our creativity machine. We need to exploit the growing sensor/effector layer to make the world itself a real-time database. In the social, human layers of the Internet, we need to devise and experiment with large-scale architectures for collaboration. We need linguists and artificial-intelligence researchers to extend the capabilities of search engines and social networks to produce services that can bridge barriers created by technical jargon and forge links between unrelated specialties, bringing research groups with complementary problems and solutions together— even when those groups have not noticed the possibility of collaboration. In the end, computers plus networks plus people add up to something significantly greater than the parts. The ensemble eventually grows beyond human creativity. To become what? We can't know until we get there.

The eight articles from Nature all tie in nicely with the ideas about computational thinking discussed earlier in this book. The same is true for the work of the 2020 Science Group, a Microsoft-funded a group of scientists. In 2006, the 2020 Science Group published an 86-page report that includes seven main findings. Here are two of the findings (Microsoft Research, 2006):

> An important development in science is occurring at the intersection of computer science and the sciences that has the potential to have a profound impact on science. It is a leap from the application of computing to support scientists to 'do' science (i.e. 'computational science') to the integration of *computer science concepts, tools and theorems* into the very fabric of science. While on the face of it, this change may seem subtle, we believe it to be fundamental to science and the way science is practiced. *Indeed, we believe this development represents the foundations of a new revolution in science.*
>
> *Conceptual and technological tools developed within computer science are, for the first time, starting to have wide-ranging applications outside the subject in which they originated,* especially in sciences investigating complex systems, most notably in biology and chemistry. Indeed, we

> believe computer science is poised to become as fundamental to biology as mathematics has become to physics. We postulate this because there is a growing awareness among biologists that to understand cells and cellular systems requires viewing them as information processing systems, as evidenced by the fundamental similarity between molecular machines of the living cell and computational automata, and by the natural fit between computer process algebras and biological signaling, and between computational logical circuits and regulatory systems in the cell. We believe this is a potential starting point for fundamental new developments in biology, biotechnology and medicine. [Italics added for emphasis]

The Growth of Volunteer Labor

Volunteer labor is an important and growing aspect of our society and economy. Yochai Benkler is a Yale law professor who studies this area. Benkler's (n.d.) Website is a Wiki where people can discuss and contribute to ideas about volunteer labor and where one can read Benkler's book, *The Wealth of Networks: How Social Production Transforms Markets and Freedom*. As Benkler notes:

> Information, knowledge, and culture are central to human freedom and human development. … In the past decade and a half, we have begun to see a radical change in the organization of information production. Enabled by technological change, we are beginning to see a series of economic, social, and cultural adaptations that make possible a radical transformation of how we make the information environment we occupy as autonomous individuals, citizens, and members of cultural and social groups.
>
> …
>
> A series of changes in the technologies, economic organization, and social practices of production in this environment has created new opportunities for how we make and exchange information, knowledge, and culture. These changes have increased the role of nonmarket and nonproprietary production, both by individuals alone and by cooperative efforts in a wide range of loosely or tightly woven collaborations. These newly emerging practices have seen remarkable success in areas as diverse as software development and investigative reporting, avant-garde video and multiplayer online games. Together, they hint at the emergence of a new information environment, one in which individuals are free to take a more active role than was possible in the industrial information economy of the twentieth century.

Final Remarks

The computer industry is confident about its ability to produce ICT systems that are substantially more cost effective than current systems. A continuing stream of research and development publications strongly supports their confident forecast.

There are arguments about how long Moore's law of exponential improvement will continue to hold. However, it seems clear that we will see continued substantial increases in the world's total ICT capabilities and uses for many years to come.

This book stresses three key ideas:

1. ICT is of steadily growing importance as part of the content of each academic discipline. Part of a student's growing expertise in a discipline must include learning the capabilities and limitations of ICT as a component of the discipline and learning to use ICT effectively in the discipline.

2. ICT will lead to substantial changes in our educational delivery system. Distance learning combined with highly interactive intelligent computer-

assisted learning (HIICAL) is poised to take over a significant portion of our traditional modes of instruction.

3. Computational science and computational thinking are becoming fundamental aspects of the knowledge and skills needed as part of a high level of expertise in many different academic disciplines.

References

Notice that most of the references are to Websites. This is deliberate. I am trying to encourage you to do follow-up reading on the various topics I write about. Of course, this has the disadvantage that some of the Websites may disappear at some time in the future. It also means that I seldom reference primary resources that are only available in hardcopy.

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