# Being Fluent with INFORMATION TECHNOLOGY

Committee on Information Technology Literacy

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## Box ES.1
## The Components of Fluency with Information Technology

*NOTE:* Readers are urged to read Chapter 2 for more elaboration of these items.

**Intellectual Capabilities**

1. Engage in sustained reasoning.
2. Manage complexity.
3. Test a solution.
4. Manage problems in faulty solutions.
5. Organize and navigate information structures and evaluate information.
6. Collaborate.
7. Communicate to other audiences.
8. Expect the unexpected.
9. Anticipate changing technologies.
10. Think about information technology abstractly.

**Information Technology Concepts**

1. Computers
2. Information systems
3. Networks
4. Digital representation of information
5. Information organization
6. Modeling and abstraction
7. Algorithmic thinking and programming
8. Universality
9. Limitations of information technology
10. Societal impact of information and information technology

**Information Technology Skills**

1. Setting up a personal computer
2. Using basic operating system features
3. Using a word processor to create a text document
4. Using a graphics and/or artwork package to create illustrations, slides, or other image-based expressions of ideas
5. Connecting a computer to a network
6. Using the Internet to find information and resources
7. Using a computer to communicate with others
8. Using a spreadsheet to model simple processes or financial tables
9. Using a database system to set up and access useful information
10. Using instructional materials to learn how to use new applications or features

# 2

# The Intellectual Framework of Fluency with Information Technology

## 2.1 WHAT IS FLUENCY WITH INFORMATION TECHNOLOGY?

Fluency with information technology (abbreviated as FITness) goes beyond traditional notions of computer literacy. As noted in Chapter 1, literacy about information technology might call for a minimal level of familiarity with technological tools like word processors, e-mail, and Web browsers. By contrast, FITness requires that persons understand information technology broadly enough to be able to apply it productively at work and in their everyday lives, to recognize when information technology would assist or impede the achievement of a goal, and to continually adapt to the changes in and advancement of information technology. FITness therefore requires a deeper, more essential understanding and mastery of information technology for information processing, communication, and problem solving than does computer literacy as traditionally defined. (Box 2.1 addresses the difference between literacy and FITness in more specific terms.) Note also that FITness as described in this chapter builds on many other fundamental competencies, such as textual literacy, logical reasoning, and knowledge of civics and society.

Information technology is a medium that permits the expression of a vast array of information, ideas, concepts, and messages, and FITness is about effectively exploiting that expressive power. FITness enables a person to accomplish a variety of different tasks using information technology and to develop different ways of accomplishing a given task.

FITness comes in degrees and gradations and is tied to different pur-

**Box 2.1**
**I Use Computers All Day—Am I FIT?**

Many Americans use information technology daily in their work, but such contact does not automatically bestow fluency with information technology. Although many jobs—medical records data entry, submitting credit card transactions, building spreadsheets in an accounting department, designing homes using architectural computer-aided design tools, and numerous others—require facility with the tools provided by specific information technology systems, this kind of expertise is often restricted largely to the skills dimension of FITness. Developing FITness as described in this report requires more than sustained contact with information technology, though such experience can nevertheless provide a good point of departure. Common fears about "breaking something" will have been overcome, certain common protocols will have been learned, and unusual situations will have been encountered.

There are highly FIT individuals across America and the world, of course. Through a combination of classes, experience, reading, curiosity, and probably persistence, these individuals not only have acquired skills that make information technology useful in their work and personal lives, but they also have learned a base of concepts and intellectual capabilities sufficient to acquire new knowledge about information technology independently, allowing them to expand their use and to adapt to change. Some are "techies," but many are simply individuals who by various means have gained enough basic knowledge to become independent, lifelong learners. As they learn more, they become more FIT, more adept at applying information technology to personally relevant tasks.

poses. FITness is thus not an "end state" that is independent of domain, but rather develops over a lifetime in particular domains of interest involving particular applications. Aspects of FITness can be developed by using spreadsheets for personal or professional budgeting, desktop publishing tools to create or edit documents or Web pages, search engines and database management tools for locating information on the Web or in large databases, and design tools to create visualizations in various scientific and engineering disciplines.

The wide variety of contexts in which FITness is relevant is matched by the rapid pace at which information technology evolves. Most professionals today require constant upgrading of technological skills as new tools become useful in their work; they learn new word processing programs, new computer-assisted design environments, or new techniques for searching the World Wide Web. Different applications of information technology emerge rather frequently, both in areas with long traditions of using information and information technology and in areas that are not usually seen as being technology-intensive. Perhaps the major challenge for individuals embarking on the goal of lifelong FITness involves deciding when to learn a new tool, when to change to a new technology, when to devote energy to increasing technological competency, and when to allocate time to other professional activities.



The above comments suggest that FITness is personal, graduated, and dynamic. FITness is personal in the sense that individuals evaluate, distinguish, learn, and use new information technology as appropriate to their own sustained personal and professional activities. What is appropriate for an individual depends on the particular applications, activities, and opportunities for FITness that are associated with the individual's area of interest or specialization, and what is reasonable for a FIT lawyer or a historian to know and be able to do may well differ from what is required for a FIT scientist or engineer. FITness is graduated in the sense that it is characterized by different levels of sophistication (rather than a single FIT/not-FIT judgment), and it is dynamic in that it requires lifelong learning as information technology evolves.

Put differently, FITness should not be assessed according to whether a person "has/does not have" all ten capabilities, and is not a single "pass/fail judgment." People with different needs and interests and goals will have lesser or greater stakes in the various components of FITness—they will obviously have greater stakes in those components that are most directly linked to their own individual needs. Nevertheless, the committee believes that all of the elements discussed below are necessary for individuals to exploit effectively the power of information technology across even a relatively small range of interests and needs.

## 2.2 THE ELEMENTS OF FITness

FITness involves three types of knowledge. These types, described briefly below, interact to reinforce each other, leading to deeper understanding of information technology and its uses.

- *Intellectual capabilities.* The intellectual capabilities of FITness refer to one's ability to apply information technology in complex and sustained situations and to understand the consequences of doing so. These capabilities transcend particular hardware or software applications. Indeed, the items listed as capabilities in Section 2.4 have general applicability to many domains other than information technology. But a great deal of research (and everyday experience as well) indicates that these capabilities do not easily transfer between problem domains,[1] and in general, few individuals are equally adept with these capabilities in all domains. For this reason, these capabilities can be regarded as "life skills" that are formulated in the context of information technology.

- *Fundamental concepts.* Concepts refer to the foundations on which information technology is built. This is the "book learning" part of fluency, although it is highly doubtful that a decent understanding of the concepts described in Section 2.5 can be achieved strictly through the use of textbooks. The concepts are fundamental to information and computing and are enduring in the sense that new concepts may become important in the future as qualitatively new information technologies emerge, but the presented list of fundamental concepts will be augmented with rather than replaced by new concepts.

- *Contemporary skills.* Skills refer to the ability to use particular (and contemporary) hardware or software resources to accomplish information processing tasks. Skills embody the intent of the phrase "knowing how to use a computer" as that phrase is colloquially understood. Skills include (but are not limited to) the use of several common software applications. The "skills" component of FITness necessarily changes over time because the information technology products and services available to citizens continually change. The enumeration given in Section 2.6 is appropriate for today, but the list would have been different five years ago and will surely be different five years from now.

Section 2.3 discusses the relationship of capabilities, concepts, and skills, as well as the role of knowledge in particular domains.

Intellectual capabilities and fundamental concepts of information technology are instantiated in or relevant to a wide variety of contexts. Intellectual capabilities and skills relate to very practical matters, getting at the heart of what it means to function in a complex technology-oriented world. And all have the characteristic that the acquisition of information technology skills, the understanding of information technology concepts, and the development of intellectual capabilities are lifelong activities. Over a lifetime, an individual will acquire more skills and develop additional proficiency with those skills, understand information technology

[1]See for example, National Research Council. 1999. *How People Learn: Brain, Mind, Experience, and School*, Chapter 3, "Learning and Transfer," National Academy Press, Washington, D.C.



concepts in a richer and more textured manner, and enhance his or her intellectual capabilities through engagement in multiple domains.

The discussion below proposes a "top ten" in each classification. (The ten are not listed in any order of priority.) Experts will doubtless recognize omissions and the list could easily be extended. But it is easy to generate longer lists, and at some point, the length of a list exceeds need, practicality, and even feasibility. The committee believes that it is important to identify the items of highest significance among possible alternatives, and the ten items in each category represent the committee's collective judgment of the most important. It is the committee's hope that all who draw from, build on, critique, or modify these lists will also impose a limit of ten on themselves.

## 2.3 A TRIPARTITE APPROACH TO FITness

Capabilities, concepts, and skills—the three different types of knowledge basic to FITness—occupy separate dimensions, implying that a particular activity involving information technology will involve elements of each type of knowledge. Learning information technology skills and concepts and developing the intellectual capabilities can be undertaken without reference to each other, but such an effort will not promote FITness to any significant degree. The three elements of FITness are co-equal, each reinforcing the others, and all are essential to FITness.[2]

- Study that emphasizes skills without fundamental concepts and intellectual capabilities meets some needs for utility in the short term. But although these skills enable one to perform basic tasks with a word processor (for example), they may not help much in countering the frustration felt when the computer freezes, the printer cannot be accessed, or the paragraphs mysteriously develop new fonts. Similar frustration is often experienced by an individual learning a new word-processor. The fundamental concepts underlying information technology are the basis for a mental model of how a specific application is (or is not) working, a model that enables reflective thought about what might be done to fix a problem or how a new application might work. The capabilities of FITness enable a person to deal with unexpected consequences and make appropriate decisions about learning new features or new software, and they are nec-

[2]The statement that "concepts, capabilities, and skills are co-equal" applies only to their epistemological importance to FITness. It does not argue that the appropriate pedagogies for each type of knowledge are, or should be, identical. This point is addressed at somewhat greater length in Section 4.3.

essary for one to engage in any kind of sustained effort using information technology.

• Study of information technology concepts in isolation from skills or capabilities is reminiscent of computer science education in the days before computers became abundant. The concepts represent abstract information about deep and interesting phenomena. They are worthy of study for their inherent interest, like studying sub-atomic particles and the structure of matter. But taught in the context of skills and capabilities, concepts also become the foundation on which one codifies one's experience, abstracts to new situations, and reasons about information technology. As information technology changes, concepts provide the basis for adapting to the change, inasmuch as the new systems adhere to the same principles the old systems did. Further, concepts provide the raw material needed to engage in capability-based action such as engaging in sustained reasoning and managing complexity.

• Study that emphasizes capabilities at the expense of concepts and skills will lack the essential connection to information technology. Although the intellectual capabilities are quite general, their development in the context of FITness requires a substantive connection to information technology that is provided by exposure to the concepts and skills. For example, to learn to "debug" a program or test an application, students need to understand the concepts implemented in the artifact. To implement their designs and work with others they need communication and search skills.

FITness integrates skills, concepts, and capabilities into an effective understanding of information technology, enabling citizens to use information technology to solve personally relevant problems and apply their knowledge of information technology to new situations. This integration is an essential element for individuals to learn over a lifetime. Thus, a pedagogical approach that balances the treatment of these three elements is essential—this is the subject of Chapter 4.

## 2.4 INTELLECTUAL CAPABILITIES FOR FITness

Within the framework of FITness as described above, the intellectual capabilities integrate knowledge specific to information technology with problem domains of personal interest to individuals. Many of the capabilities on this "top ten" list might be familiar in other disciplines—engineering design, library science, or general education—or even from an understanding of what is needed to live a productive life. Indeed, no assertion is made that these capabilities are unique or "belong" to information technology. However, the prominence and importance of information technology in society today take them out of the world of the designer or engineering specialist and put them squarely in the lives and workspaces of us all.



The essential elements of FITness include the ability to:

1. *Engage in sustained reasoning.*

Sustained reasoning starts with defining and clarifying a problem. Understanding exactly what problem is to be solved and knowing when it has been solved are often the most difficult aspects of problem solving. And, because information technology will in general operate in the way in which one directs it to operate, rather than the way in which one intends it to operate, precise specification of the problem to be solved with information technology is even more critical for solving other types of problems.

Once the problem has been defined, multiple attempts at formulating a solution are often required. An initial solution is often revised or improved by iteration, which often causes a refinement in the definition of the problem. Reasoning is used for planning, designing, executing, and evaluating a solution.

The "sustained" aspect of this capability is intended to convey an integrated effort that covers days or weeks rather than a one-time event. Thus, individuals might use desktop publishing programs, computer-assisted design tools, visualization and modeling environments, Web-search engines, or a variety of other technological resources to help implement a solution.

2. *Manage complexity.*

Problems often have a variety of solutions, each with its advantages and disadvantages, and trade-offs are often necessary in determining the most appropriate solution. One solution may require extensive design but result in a relatively straightforward implementation; another may require the opposite—a simple design but a costly implementation. Furthermore, any given approach to a solution will often result in components of a system interacting in complex, unexpected ways.

A sustained activity involving information technology will typically be complex, involving a number of tasks, such as problem clarification, solution formulation, solution design and implementation, and testing and evaluation of the outcome. The solution developed for the problem will often contain several components, including both hardware and software. A person needs to be able to plan a project, design a solution, integrate the components, respond to unexpected interactions, and diagnose what is needed from each task. Some of the steps of the project may involve some type of computer programming. Such programming could entail configuring system control panels, using and adapting existing software packages for one's needs, or writing code in some programming language.

Another source of complexity is the need to manage the resources that technology provides, especially when the resources available are inadequate. Thus, a user of information technology needs to be able to manage resources: Do processes require too much time? Too much disk space? Is the bandwidth available to download what is offered? And of course, are there ways to perform necessary tasks that will not exceed the limits imposed by resource availability and/or adequacy?

A third source of complexity is the fact that large information technology-based systems often have interdependencies. That is, small changes in one part of the system can have large effects on another part of the system that is "apparently" separate from that part. Such interdependencies can be reduced by enforcing a rigid separation between different system parts, but this practice is much easier to describe than to implement.

3. *Test a solution.*

Determining the scope, nature, and conditions under which a technological solution is intended to operate can be difficult. A solution to a problem must be tested in two ways—to determine that the design is correct or appropriate to the problem at hand (i.e., that the solution, when implemented correctly, will meet user needs) and to determine that the implementation of a given design is correct.

Testing entails determining whether a proposed solution meets design goals and works under diverse conditions, taking into account that most systems will be used in ways that were not intended, as well as in expected ways. Testing involves identifying the uses most likely to cause a failure, developing ways of testing for all normal modes of operation, determining typical misuses of the system, and designing the system so that it responds gracefully when misused. Furthermore, because some fixes to problems may introduce more problems, special care is necessary to fix (or manage) the initial flaws. Testing is also best seen as an activity concurrent with design, because the alternative is to implement a complete system before knowing whether the implementation is correct.

4. *Manage problems in faulty solutions.*

When systems crash and technological tools fail, users need the ability to "debug," that is, to detect, diagnose, and correct problems and faults (i.e., bugs). Debugging is a complex process that often goes beyond the technology and includes the personal and social aspects of the undertaking (e.g., when a system has multiple interacting components, each of which is the responsibility of a different individual). Debugging also involves other capabilites, such as sustained reasoning, managing complexity, and testing.



Debugging is necessary because the best-designed and best-integrated systems will still exhibit unanticipated behavior. Bugs are inevitably encountered in any ongoing effort using information technology, and thus users must anticipate the need to identify them, diagnose their sources (e.g., by recognizing patterns in observations or in fault reports, distinguishing root causes from derivative but proximate causes, and designing systematic diagnostic experiments), understand the implications of eliminating those sources, and take steps to modify the system appropriately. Alternatively, the appropriate response to a faulty system that is vital to some application may well be to structure the environment in which the system operates to limit the risk associated with its use.

Testing reveals bugs, but once discovered, bugs need to be repaired cleanly and correctly. Good design also involves designing systems that are more easily fixed when something goes wrong (a process often known as "anti-bugging"). For example, a well-designed system has clear documentation. Well-designed systems avoid hidden dependencies, so fixes at one point do not create new flaws at another. The system design itself facilitates examination of what the system is doing and enables the reporting of unexpected events.

Debugging also involves making the everyday elements of technology work. When something goes wrong, it is desirable to be able to trace the chain of events upon which correct operation depends. A typical example today starts with a person who tries to print a document prepared with a word processor, and the printer doesn't produce any output. There could be a flaw anywhere along a chain of potential causes: the printer isn't plugged in or is turned off; the printer isn't connected to the computer; the wrong driver is selected; the printer queue is blocked; improper parameters were set in the print command; and many other possible events. A user needs to recognize that this is a solvable problem, find the broken link in the chain, and either solve the problem or call the appropriate expert.

5. *Organize and navigate information structures and evaluate information.*

Most sustained activities involve the location, evaluation, use, and organization of information. Often searching for and locating information involve other aspects of FITness, including evaluating the validity of information and resolving conflicting accounts of situations. (Note also the connection to information literacy, discussed in Section 3.2.)

This capability also involves the ability to find and evaluate information at different levels of sophistication. Tasks range from reading a manual to finding and using online help. Web searches may be necessary to find more complex information. Of course, as the level of complexity rises, it becomes increasingly important (and more difficult) to ascertain accuracy. An individual must be prepared to evaluate the reliability of a source, understand the nature of a shared information space such as the Web, and regard with appropriate caution the quality of the information retrieved.

This capability also suggests that one must be able to structure information appropriately to make it useful. The information created must be retrievable and useful for the intended purpose. Thus, the design process for information structures involves elements of communication (and may involve programming of some sort).

6. *Collaborate.*

When project responsibilities must be divided among a number of people, collaboration abilities are involved. Among other things, collaboration involves a strategy for dividing a task into pieces that can be worked on individually. In practice, how a problem is divided is based on both the structure of the problem and the organizational structure of the team that will solve it (e.g., different individuals may have different talents). In collaborating, individuals need to avoid duplication of effort as well as inconsistencies in the parts that they deliver for integration into the final product. Furthermore, each must have a clear sense for how the various parts of a solution are made to operate together as well as the expectations for his or her own part, the importance of clearly specified interfaces as a technique for increasing the likelihood that parts of a solution can operate together, and a strategy for ensuring that team members work on an appropriately recent version of the solution.

Information technologies used for collaboration do not change what is required of a collaboration, but they do change how a collaboration takes place. Information technologies such as telephones, e-mail, videoconferencing, shared Web pages, chat rooms, and so on enable collaborators to work together remotely and asynchronously, with relatively less reliance on face-to-face interactions. But learning how to cope with the limitations of technologically mediated interactions thus becomes essential. For example, if team members communicate by e-mail, they may well lose some ability to communicate clearly and unambiguously; at the very least, they may be forced to articulate things explicitly that a face-to-face interaction would not require.



7. *Communicate to other audiences.*

In conveying information to others, it is often necessary to use technology. This may involve the use of images or processes as well as words. Effective communication requires familiarity with and understanding of the pros and cons of various means of communication, because the intervening technology may change the nature of the communication. For example, it is much more difficult to provide driving directions to a given location by using the telephone than by gesturing and pointing to a map.

But a deeper aspect of communication with other audiences is the nature of that communication, independent of media. For example, communicating problem statements or project outcomes to customers, interested individuals, and others requires an understanding of audience needs and background knowledge. An effective communication to experts might involve translating informal needs into formal requirements, for example, moving from a "wish list" expressed during a lunchtime conversation to a more formal tasking to a work team. These formal requirements form the basis for discussing whether or not a project performs correctly, and therefore underlie the ability to test and debug. Without communication that carries nuance and detail, it is impossible to know whether a project component is being built correctly.

A related dimension of communication with other audiences is documentation. Documentation is almost always a component of informing an "outsider" audience about the nature of a system, such as an office system, a manufacturing system, or an information technology system. Documentation makes content more explicit and provides many opportunities for someone to think through the structure of a project. The development of documentation can be regarded as a process of devising the minimum set of information and instructions needed for an unknown task to be performed with a specific tool by a non-expert.

8. *Expect the unexpected.*

Even when a technological system works as intended to solve a problem as it was originally stated, its use may still have unexpected consequences, because the system is embedded in a larger social and technological context that may not have been properly anticipated. In some instances, these unexpected consequences may even overshadow the intended outcome (i.e., the solving of the original problem). Users should understand that such consequences are not uncommon and work to mitigate or exploit them as appropriate.

Unforeseen benefits or drawbacks may result when a technology deployed for one purpose is used for other purposes. For example:

• One of the original "primary" purposes of the ARPANET (the predecessor to the Internet) was to facilitate the use of computers many miles away from one's local desktop; as users learned how to use the ARPANET, they found that it was most useful for its e-mail capabilities.

• Making Web browsers in school libraries available to all students is intended to give students easy access to the rich information content of the Internet. But open access may unintentionally expose students to child molesters, hate speech, and pornography.

In other cases, unexpected side effects may occur because a technological system is deployed on a much larger scale than originally expected. For example:

• Introducing computers into schools on a large scale means that many teachers must be trained to use them effectively.[3]

• Introducing information technology into businesses on a large scale often results in unexpected recurring expenditures to keep hardware and software investments current with evolving applications.[4] Small applications of information technology can be funded on a shoestring (e.g., because problems can be solved in a "quick and dirty" manner). But on a large scale, maintenance, support, documentation, and training become big sources of expense.

Finally, technological systems may be designed for a particular intensity of usage, but may display unexpected behavior or may result in unexpected consequences when the actual intensity of usage is higher. For example:

• Acquisition of a cellular telephone "for emergency use only" for a low monthly payment often results in first-time bills that are much larger than expected, because the user finds the convenience of the cellular telephone irresistible.

[3]See, for example, Panel on Educational Technology. 1997. *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States*, President's Committee of Advisors on Science and Technology (PCAST), Washington, D.C., March, Chapter 5.

[4]Such experiences in the private sector are often reported in the trade press. See, for example, M. Lynne Markus and Robert I. Benjamin. 1997. "Are You Gambling on a Magic Bullet?", *Computerworld*, October 20; Clayton M Christensen. 1997. "Fatal Attraction: The Dangers of Too Much Technology," *Computerworld*, June 16; Vaughan Merlyn and Sheila Smith. 1997. "Be Careful What You Wish For: Managing Technology's Unintended Consequences," *Computerworld*, January 20.



• A server designed for a particular load may crash when subject to too many requests for service arriving at the same time, as often happens when access is sought to a popular Web site.[5]

9. *Anticipate changing technologies.*

While no one can predict accurately the future course of technology, technology inevitably changes. FITness entails the capability to adapt to new technology efficiently and how to learn a new language or system, building on what is already known about older, perhaps similar technologies and facilities. For example, new versions of technology and tools will almost certainly appear, and they may offer benefits over older versions (e.g., the new version may be faster or offer more features). At the same time, additional functionality often comes at a cost (e.g., the need to upgrade system resources such as memory, or the need to learn the new set of features). Users thus must be prepared to weigh whether the benefits of the inevitable new version outweigh its costs. Decisions as to when or whether to upgrade, which tool to use, and how many features to learn are examples of such adaptation.

10. *Think about information technology abstractly.*

A person who effectively determines how to apply information technology to his or her needs will think about information technology abstractly. For example, she will reflect on her use of information technology, identifying characteristics and commonalities that cut across technological experiences. She will transfer the principles of technological solutions from one setting to another. She will recognize technological analogies, and use them to become adept with new technology quickly. She will have high expectations for technological solutions, and she will find work-arounds when technology falls short.

A second dimension of thinking abstractly about information technology is to consider what aspects of information technology affect a policy issue. For example, a person engaged in such thought will try to determine if and how the technology makes previous policy solutions inadequate. He or she will think deeply about proposed metaphors, such as assertions that putting up a Web page is equivalent to publishing.

[5]William Stallings. 1996. *Data and Computer Communications*, 5th Edition, Prentice-Hall, New York. See also Keynote Systems, Inc. 1998. "Top 10 Discoveries About the Internet," and "How Fast *Is* the Internet?" Available online at, respectively, <http://www.keynote.com/measures/top10.html> and <http://www.keynote.com/measures/howfast.html>.

## 2.5 INFORMATION TECHNOLOGY CONCEPTS[6]

If information technology were unchanging, then most people would find it unnecessary to learn information technology concepts. The information technology skills could be taught once and for all, and the conceptual foundation underlying information technology would be of interest only to specialists. But information technology changes daily and often dramatically, rendering present-day skills obsolete but also offering new opportunities to solve personally relevant problems. How can one prepare for this inevitable change? How can one quickly upgrade one's skills to exploit new opportunities?

The answer lies in understanding a few of the basic ideas and concepts underpinning information technology. These concepts are approximately independent of particular technology or applications, though they are instantiated in different ways in different technologies and applications. In particular, the new and improved information technology of the future will also depend on these concepts, and an understanding of the principles on which information technology rests will continue to enable a person to acquire information technology skills more easily. And, because these concepts are fundamental, they are far more enduring than information technology skills that are tied to specific technologies.

The topics given in the following list touch on ideas of computation, communication, and information that are deep and intellectually challenging. Although any of the topics could be the basis of years of graduate study for a specialist, the basic ideas are straightforward and accessible, having been regularly taught to nonspecialists for years. Note also that the time and effort required to teach and learn each concept may vary widely.

The concepts presented below reflect the committee's judgments about the most important conceptual foundations of information technology contributing to FITness. There is no intended order.

[6]The discussion in this section identifies various information technology concepts in a form that approximates that of a catalog description of a course. A full explanation of the concepts would be appropriate for a textbook, but not for a report attempting to outline a basic framework for understanding information technology. Some of these concepts may not be familiar to non-specialists, a point that previews a pedagogical approach discussed in Chapter 4 involving the joint teaching efforts of information technology specialists and domain experts.



1. *Computers*

Key aspects of a stored-program computer, including:

- The program as a sequence of steps,
- The process of program interpretation,
- The memory as a repository for program and data (including notions of memory hierarchy and associated ideas of permanence/volatility), and
- Overall organization, including relationship to peripheral devices (e.g., I/O devices).

The appropriate emphasis is not necessarily a specific electronic realization such as a particular computer, but rather the idea of a computational task as a discrete sequence of steps, the deterministic interpretation of instructions, instruction sequencing and control flow, and the distinction between name and value. Computers do what the program tells them to do given particular input, and if a computer exhibits a particular capability, it is because someone figured out how to break the task into a sequence of basic steps, i.e., how to program it.

2. *Information systems*

The general structural features of an information system, including, among others, the hardware and software components, people and processes, interfaces (both technology interfaces and human-computer interfaces), databases, transactions, consistency, availability, persistent storage, archiving, audit trails, security and privacy and their technological underpinnings.

Most knowledge workers in the labor force interact with one or more information systems, becoming knowledgeable about their characteristics and idiosyncrasies. Understanding the abstract structure of such systems prepares students for employment, enhances job mobility, enables workers to adapt to new systems more quickly, and helps them to exploit more fully the facilities of a given system.

3. *Networks*

Key attributes and aspects of information networks, including their physical structure (messages, packets, switching, routing, addressing, congestion, local area networks (LANs), wide area networks (WANs), bandwidth, latency, point-to-point communication, multicast, broadcast, Ethernet, mobility), and logical structure (client/server, interfaces, layered protocols, standards, network services).

Computers are generally much more useful when connected to each other and to the Internet. The goal is to understand how computers can be connected to each other and to networks, and how information is routed between computers. The appropriate emphasis is how the parameters of communication, such as latency and bandwidth, affect the responsiveness of a network from a user's point of view and how they might limit one's ability to work.

4. *Digital representation of information*

The general concept of information encoding in binary form. Different information encodings: ASCII, digital sound, images, and video/movies. Topics such as precision, conversion and interoperability (e.g., of file formats), resolution, fidelity, transformation, compression, and encryption are related, as is standardization of representations to support communication.

The appropriate emphasis is the notion that information that is processed by computers and communication systems is represented by bits (i.e., binary digits). Such a representation is a uniform way for computers and communication systems to store and transmit all information; information can be synthesized without a master analog source simply by creating the bits and so can be used to produce everything from *Toy Story* animations to forged e-mail; symbolic information in machine-readable form is more easily searchable than physical information.

5. *Information organization*

The general concepts of information organization, including forms, structure, classification and indexing, searching and retrieving, assessing information quality, authoring and presentation, and citation. Search engines for text, images, video, audio.

Information in computers, databases, libraries, and elsewhere must be structured to be accessible and useful. How the data should be organized and indexed depends critically on how users will describe the information sought (and vice versa), and how completely that description can be specified. In addition to locating and structuring information, it is important to be able to judge the quality (accuracy, authoritativeness, and so forth) of information both stored and retrieved. Section 3.2 provides some additional discussion.

6. *Modeling and abstraction*

The general methods and techniques for representing real-world phenomena as computer models, first in appropriate forms such as systems



of equations, graphs, and relationships, and then in appropriate programming objects such as arrays or lists or procedures. Topics include continuous and discrete models, discrete time, events, randomization, and convergence, as well as the use of abstraction to hide irrelevant detail.

Computers can be made to play chess, predict the weather, and simulate the crash of a sports car by abstracting real-world phenomena and manipulating those abstractions using transformations that duplicate or approximate the real-world processes. One goal is understanding the relationship between reality and its representation, including notions of approximation, validity, and limitations; i.e., not all aspects of the real world are modeled in any one program, and a model is not reality.

7. *Algorithmic thinking and programming*

The general concepts of algorithmic thinking, including functional decomposition, repetition (iteration and/or recursion), basic data organizations (record, array, list), generalization and parameterization, algorithm vs. program, top-down design, and refinement. Note also that some types of algorithmic thinking do not necessarily require the use or understanding of sophisticated mathematics. The role of programming, which is a specific instantiation of algorithmic thinking, is discussed in Chapter 3.

Algorithmic thinking is key to understanding many aspects of information technology. Specifically, it is essential to comprehending how and why information technology systems work as they do. To troubleshoot or debug a problem in an information technology system, application, or operation, it is essential to have some expectation of what the proper behavior should be, and how it might fail to be realized. Further, algorithmic thinking is key to applying information technology to other personally relevant situations.

8. *Universality*

The "universality of computers" is one of the fundamental facts of information technology discovered by computing pioneers A.M. Turing and Alonzo Church in the 1930s, before practical computers were created.[7] Shorn of its theoretical formalism and expressed informally, universality says that any computational task can be performed by any computer. The statement has several implications:

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[7]Alonzo Church. 1936. "An Unsolvable Problem of Elementary Number Theory," *American Journal of Mathematics*, 58:345-363; Alan M. Turing. 1936. "On Computable Numbers, with an Application to the Entscheidungsproblem," *Proceedings of the London Mathematical Society*, Ser. 2, 42:230-265, 43:544-546.

• No computational task is so complex that it cannot be decomposed into instructions suitable for the most basic computer.

• The instruction repertoire of a computer is largely unimportant in terms of giving it power since any missing instruction types can be programmed using the instructions the machine does have.

• Computers differ by how quickly they solve a problem, not whether they can solve the problem.

• Programs, which direct the instruction-following components of a computer to realize a computation, are the key.

Universality distinguishes computers from other types of machines (Box 2.2).

9. *Limitations of information technology*

The general notions of complexity, growth rates, scale, tractability, decidability, and state explosion combine to express some of the limitations of information technology. Tangible connections should be made to applications, such as text search, sorting, scheduling, and debugging.

Computers possess no intuition, creativity, imagination, or magic. Though extraordinary in their scope and application, information technology systems cannot do everything. Some tasks, such as calculating the closing price for a given stock on the NASDAQ exchange, are not solvable by computer. Other tasks, such as that of placing objects into a container so as to maximize the number that can be stored within it (e.g., optimally filling boxcars, shipping containers, moving vans, or space shuttles), can be solved only for small problems but not for large ones or those of practical importance.[8] Some tasks are so easily solved that it hardly matters which solution is used. And, because the programs that run on computers are designed by human beings, they reflect the assumptions that their designers build into them, assumptions that may be inappropriate or wrong. Thus, for example, a computer simulation of some "real" phenomenon may or may not accurately reflect the underlying reality (and a naïve user may be unable to tell the difference between a generally true simulation and one that is fundamentally misleading). Assessing what

[8]In the case of the maximization problem above (often known as the "knapsack" problem), the proper arrangement can be determined by exhaustively trying all arrangements and orientations of the objects. But this calculation cannot be performed in any reasonable length of time when many objects can be placed into the container. Yet the penalty of not being able to find the maximizing arrangement can be high, as when shipping two containers rather than one or launching the Space Shuttle twice rather than once. When the problem is large enough that the maximizing arrangement cannot be practically computed, it is necessary to use "nearly maximal" arrangements that can be more easily determined.



**Box 2.2**
**On Universality—In Principle and in Practice**

The universality property of computers is a theoretical result. Is it true in practice? The answer is yes, definitely, but there are complicating practical issues that can obscure the truth of this fact.

How can a computer without connection to a printer perform the computation, "print the report"? Of course, it cannot. But, the computer can *without change* perform the task, given a printer and the necessary software to format the report and drive the printer. Similarly, a computer embedded in an automobile's carburetor cannot print a report either, because, first, it does not have the proper input/output devices and, second, its software is permanently set to the task of mixing fuel. But the computer, i.e., the central processing unit, is not a limitation in these or other cases. Indeed, it is the universality of computers that explains why they are so ubiquitous in modern America: a computer chip with a program stored in read-only memory (ROM) is more convenient to design, cheaper to build, more reliable, and easier to maintain than specialized circuitry for controlling appliances, automobile subsystems, and other mechanical devices, as well as electronics like cell phones and Global Positioning System (GPS) devices.

Further, the observation that applications like word processing require different software to run on a Macintosh versus a PC seems to contradict the above claims and imply that the instruction set does matter. In a narrow sense it does, since the Mac cannot directly execute the binary encoding of a program specialized to the PC and vice versa. This is because the Mac and the PC use different microprocessor chips and the binary files for software applications are customized for each type of microprocessor. But those two different binary encodings can be created from a single source program by a translator (compiler) that specializes the computation to each instruction set. The two machines are literally running the same source program, i.e., performing the same word processing computation. And there is an indirect sense in which any PC software can run on a Mac and vice versa. A program can be written for one machine to emulate the instruction set of the other machine, allowing it to execute the actual binary encoding used by the other machine. Being indirect, this would be slower than a customized version, but it truly illustrates universality.

information technology can be applied—and when it should be applied—is essential in today's information age.

10. *Societal impact of information and information technology*

The technical basis for social concerns about privacy, intellectual property, ownership, security, weak/strong encryption, inferences about personal characteristics based on electronic behavior such as monitoring Web sites visited, "netiquette," "spamming," and free speech in the Internet environment.

Understanding social issues strongly connected to information technology goes beyond FITness to general principles of good citizenship. Policy issues that relate to information technology, including privacy, encryption, copyright, and related concerns, are increasingly common today, and informed citizens must have a basis for understanding the significance of those issues and for making reasoned judgments about them.

Information technology connects to the world at large in many ways, and characteristics of the technology have implications for everyday issues. Consider, for example, intellectual property. Copyright is accompanied by a well-established body of law, but now that the Web makes images and documents available to a huge audience, it has become much more important for Web users to understand that the ability to see an image on the Web does not automatically imply that the image can be copied or reused.

Numerous other issues are apparent today on which many non-technologists are asked to make judgments. Is the Internet just another form of publication, and therefore subject to the same First Amendment and copyright protections that newspapers enjoy? Is encryption a potential weapon that needs to be kept out of foreign hands? Why are standards important, and how do we promote the use of standards without permitting unregulated monopolies to stifle innovation? Does inviting technologically skilled workers from other countries create or destroy jobs? How do we encourage children to achieve the highest levels of technological competence? Does information technology cause job displacement and/or upskilling? How is it possible to promote social equity regarding access to information technology?

*Discussion*

These fundamental concepts represent major ideas underpinning information technology. The claim that FITness demands an understanding of these concepts is most frequently challenged by an analogy: If most people can drive without understanding how an automobile works, why should anyone need to know how a computer works?

The weakness in this analogy is embodied in the difference between the two kinds of machines. Automobiles perform essentially one task, transporting people and things from one location to another, and are incapable of other physical tasks, say, mixing concrete. Any computer can perform any information processing task—this is the concept of universality. It is not only a principle; it is a fact used every day. When one wants to manage a household budget, one doesn't buy a new computer for budgeting. Rather, one buys and installs software to add budgeting to the computer's other capabilities. Not being specialized like other machines that directly affect the physical world, computers may well affect our lives more than these other machines have, including automobiles. Knowing the conceptual foundations, then, is essential to understanding this impact—what information technology can do, what it cannot do, what risks computers and access to information bring, and so on. Armed with such knowledge, individuals can make informed choices ranging from personal decisions (like taking precautions against computer viruses) to matters of public policy such as protecting privacy interests.



An equally important motivation for learning information technology concepts is that they provide foundational knowledge to be used when acquiring and applying the intellectual capabilities. To perform the reasoning and thinking activities embodied in the capabilities, it is necessary to have some understanding of the range of possibilities. Furthermore, understanding these concepts enables an individual to be more versatile and more creative in his or her use of information technology tools.

Finally, Box 2.3 points out that even in a world in which the public's exposure to information technology is through specialized information appliances rather than desktop computers or through technologies that adapt to user needs and knowledge, the fundamental concepts of information technology will still be useful in understanding how to use such devices effectively.

## 2.6 INFORMATION TECHNOLOGY SKILLS

Skills such as managing a personal computer, using word processing, network browsers, mail, and spreadsheet software, or understanding an operating system are what are most usually subsumed under the label of "computer literacy."

Because information technology skills are closely tied to today's applications, the set of necessary skills can be expected to change at about the same rate that commercial information technology changes, i.e., quite rapidly. (Note, for example, that a list of skills developed five years ago would not have mentioned the Web or the Internet.) Changes in the specific interests and needs of the individual involved also have a significant effect on what skills are (or become) necessary. Over the course of a lifetime, individuals who use information technology must regularly evaluate their skills and determine which new skills they need for their workplace or personal success. FITness entails a continuing acquisition of new skills and adaptation of a set of skills to a changing environment.

The list of skills below is appropriate for today's technologies (circa

**Box 2.3**
**FITness, Personal Computers, Information Appliances, and Adaptive Technology**

Today, desktop computers are a primary platform through which individuals interact with information technology. But whether this proposition will remain true in the future is an open question. Some reports suggest that information appliances—single-purpose devices that manipulate information—may become more common and ubiquitous in the future. Indeed, those making this prediction argue that information appliances can be made so easy to use that no knowledge of information technology will be necessary to operate them.

Predictions of the future technology environment are notoriously uncertain. It is likely that today's desktop computers (or their equivalents) will continue to be used by information workers. But the intellectual framework outlined in this chapter for FITness will continue to have applicability even to individuals dealing with information appliances. Of course, the specific skills needed will be different. But the basic concepts and intellectual capabilities of FITness will continue to be relevant. For example:

- An algorithm of some sort will be driving the operation of an information appliance. Understanding the general characteristics of algorithms will help the user to understand the limitations of a given device. For example, a navigation system for a car may provide the "best" route from Point A to B; the user may find it useful to know whether "best" refers to the most scenic route or the shortest route or the fastest route.
- Input to an information appliance is likely to remain "brittle," in the sense that the device will respond to the input that the user actually provides, not the input that the user intended to provide. This is a consequence of several concepts, including the digital representation of information and the nature of computational devices and information systems.



- A wireless information appliance that facilitates interaction with large amounts of data will require a local database for a fast response. The navigation system described above, for example, will in general not receive maps through the air, but rather will require maps "pre-stored" in some way that is local to the device.
- Identifying and correcting faults will always be necessary for the user to understand how he or she used the device improperly.

Furthermore, a knowledge of the basic concepts of FITness will enable a person to move more freely among information appliances. For example, a user will need to know to look for a way to correct mistaken input.

None of this is to argue the impossibility of operating an information appliance by the memorized application of a particular set of keystrokes—which today enables some individuals to obtain something useful from a computer. But gaining the full value from either a computer or an information appliance will require the full intellectual range of FITness.

In a similar vein, it can be argued that information technology should be—and someday will be—designed to minimize what the individual must know in order to use it. For example, some information technology applications attempt to adapt to a particular user's style and needs. Other applications attempt to conceal their internal operation to reduce the burden on the user.

Such technological adaptations to the relatively naïve user are unquestionably helpful. But they do not—indeed, cannot—eliminate the need for FITness. For example, it is hard to imagine that a complex application has no operating faults in it, and thus users will always have to cope with things that don't work. All of the rationales articulated above for FITness in the context of information appliances equally apply to well-engineered and user-adaptive information technology applications.

1999) and focuses on what one would need to know to buy a personal computer, set it up, use the principal software that comes with it, subscribe to an Internet service provider, and use its services. These items and other similar ones emerged from a question posed to attendees at the committee's January 1998 workshop about what an information technology-literate person should know.

This list of skills extends in one important way the content of "computer literacy" courses that teach individuals how to use specific software packages. It is true that students need to use specific software and hardware to acquire skills with information technology. But the skills involved in the committee's list are generic skills, rather than the specific skills needed to operate a particular vendor's product. For example, "word processing" refers to the use of functionality common to most or all word processors, rather than the specific commands, key-bindings, or dialog boxes of one vendor's software. Acquiring these skills includes understanding what similarities and differences to expect between different products for the same task.

Today's set of ten essential skills includes:

1. *Setting up a personal computer*

A person who uses computers should be able to connect the parts of a personal computer and its major peripherals (e.g., a printer). This entails knowing about the physical appearance of cables and ports, as well as having some understanding of how to configure the computer (e.g., knowing that most computers provide a way to set the system clock, or how to select a screen saver and why one may need to use a screen saver).

2. *Using basic operating system features*

Typical of today's operating system use is the ability to install new software, delete unwanted software, and invoke applications. There are many other skills that could reasonably be included in this category, such as the ability to find out from the operating system whether there is sufficient disk space.

3. *Using a word processor to create a text document*

Today, minimal skills in this area include the ability to select fonts, paginate, organize, and edit documents. Integration of image and other data is becoming essential. In the near future, requirements in this area will likely include the creation of Web pages using specialized authoring tools.

4. *Using a graphics and/or artwork package to create illustrations, slides, or other image-based expressions of ideas*

Today, this skill involves the ability to use the current generation of presentation software and graphics packages.

5. *Connecting a computer to a network*

Today, this process can be as simple as wiring the computer to a telephone jack and subscribing to an Internet service provider, although as more powerful communications options become available, this process may become more complex.

6. *Using the Internet to find information and resources*

Today, locating information on the Internet involves the use of browsers and search engines. The use of search engines and browsers requires an understanding of one's needs and how they relate to what is available and what can be found readily, as well as the ability to specify queries and evaluate the results.



7. *Using a computer to communicate with others*

Today, electronic mail is a primary mode of computer-based communication. Variants and improvements, as well as entirely new modes of communication, are expected in the future.

8. *Using a spreadsheet to model simple processes or financial tables*

This skill includes the ability to use standard spreadsheet systems and/or specialized packages (e.g., tax preparation software).

9. *Using a database system to set up and access useful information*

Today, SQL-based systems[9] are becoming ubiquitous in the workplace, and personal information managers are becoming increasingly common. In the future, different approaches, perhaps Web-oriented, may become the prevalent mode.

10. *Using instructional materials to learn how to use new applications or features*

This skill involves using online help files and reading and understanding printed manuals. One aspect of this process is obtaining details or features of systems one already comprehends; a second aspect is using the tutorial to grasp the essential models and ideas underlying a new system.

## 2.7 FITness IN PERSPECTIVE

The intellectual content of FITness is rich and deep. But the depth and richness of this content are determined by the nature of information technology. Although different individuals need different degrees of familiarity with the different elements of FITness, a good understanding of and facility with all of the skills, concepts, and capabilities of FITness are necessary for individuals to exploit the full power of information technology across a range of different applications.

Nevertheless, such depth and richness raise the question of the extent to which it is reasonable to expect that the content of FITness is accessible to a wide range of the citizenry. For perspective on this question, it is useful to consider the National Council of Teachers of Mathematics'

[9] SQL is an acronym for Structured Query Language, a common language used in interactions with databases.

(NCTM) standards for mathematics education and the National Research Council's standards for science education. As described in Appendix B, such organizations focus on the mathematical and scientific education of all students, rather than a special few with previously demonstrated aptitude for mathematics or science. The organizations that produced these standards for mathematics and science education make the case that the intellectual content articulated in the standards is rich, deep, and most importantly not "dumbed down." These organizations believe that learning about science and mathematics is valuable not just for future scientists and mathematicians, but also for a very wide range of the citizenry.

The essentials of FITness are not for the most part dependent on knowledge of sophisticated mathematics. Indeed, the capabilities and concepts, though not the skills, are intellectually accessible even without computers per se. For example, the concept of an algorithm can be expressed and conveyed in an entirely qualitative and non-mathematical manner even to a 4th grader by discussing the rules of a game or following a recipe in the kitchen. Thus, the committee believes that the intellectual content of FITness is no less accessible to citizens than the mathematics and science contained within the NCTM and NRC standards.

A second issue is the following: by design, FITness is a body of knowledge and understanding that enables individuals to use information technology effectively in a variety of different contexts. But does being FIT mean that one will never need to rely on an information technology expert? Put differently, does an individual's consultation of an information technology expert imply a lack of FITness for that individual?

There is certainly some level of FITness at which an individual will not need to rely on an expert to fix an information technology problem or to exploit a new opportunity offered by information technology. But even someone who is FIT enough to not have to rely on an expert may find it advantageous to do so anyway. For example, a highly FIT individual may simply decide that it is not worth his or her time to fix a problem, even if he or she could do so. Furthermore, even if an individual with more basic levels of FITness may still need to consult with an information techology expert to solve a technology problem or to describe a technology solution, that basic understanding and knowledge will help him or her to interact constructively with the expert (e.g., to recognize that a problem is indeed solvable; to explain the problem or solution requirements more precisely; or to understand, implement, or dispute an approach that the expert proposes).