Computer Science and Telecommunications Board
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Position Statement for the Study Group:
What Every literate Citizen Should Know About Computers and Information Technology

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In defining what every literate citizen should know about computers and information technology we focus on the concepts, skills, and ideas that should be introduced and explored in precollege years. The core of this position statement is the answer to the second question "What should all high school graduates/students know...". The answer to this question outlines a curriculum framework for the pre-college years. The answers to the remaining questions are based on this curriculum.

1. What should information technology literate individuals be prepared to do in the future? What sort of lifelong personal, career, and policy decisions should such individuals be prepared to make? Why?

A technology literate individuals should be prepared to use the computer as a tool in nearly all aspects of personal and professional life. Specifically, they should be able to use a computer to:

- record data and information
- access and search for data and information
- process and analyze data and information
- communicate with others using computer-based communication modes

The ability to use a computer for these tasks does not come just from drill in certain computer manipulation skills. The next section describes the concepts behind these uses of computers that all high school graduates should understand. The knowledge of the fundamental concepts behind computer systems and their use provides a framework for literate use of computers in a variety of tasks and for understanding the many societal implications of computer use and misuse.

The knowledge of these fundamental computer science concepts will also provide a basis for making decisions regarding any particular use of computers. We will return to this topic after we discuss the fundamental concepts.

2. What should all high school graduates/students know about information technology to achieve information technology literacy? (elements of knowledge, why this is important, what about it should be taught at what grade levels)

I believe the following concepts are fundamental and should be understood by all information literate individuals:

Representation of information
Processing of information: the concept of algorithms

Encoding of algorithms: the concept of languages
Management of complex systems: the concepts behind OS and networks
Sense of scale

In addition, intertwined throughout all these topics are the issues of societal impact.

2.1. Representation of Information

• elements of knowledge:

All information literate individuals should understand that there are (at least) two levels of representation of information. On the basic level is the encoding of specific information in the form of bits and bytes so that the data can be stored in the computer memory, transmitted through the networks, or stored in more permanent medium such as CD-ROM or a computer disk. Here we learn about encoding of an image as a sequence of pixel colors, storage of real number values as truncated floating point numbers, characters encoded in ASCII or Unicode. This is important, in order to understand that any memory location can represent any type of data.

At the higher level are the concepts of encoding the human knowledge about a particular phenomenon in form of data that can be stored in a computer, or conversely, representing the data stored in a computer in a form that is best understood by a human. Some of the basic examples here are an array of data values represented as charts for the human reader, pixel data displayed as an image.

Additionally, information literate individuals should understand that different pieces of data can be linked together through indices, search tables, data bases and other mechanisms - to simplify the access to a particular piece of information.

• why this is important:

By understanding how data and information is stored in a computer and retrieved at a later date, information literate individuals will better appreciate both the power of computer stored information and the potential for misuse - either intentional or inadvertent. They will also understand the limitations of current computers, the need for further research, and the need for careful policy decisions related to the use of computer based information.

• what about it should be taught at what grade levels:

Pupils in the first grade learn about the number system and continue learning formal arithmetic throughout the elementary grades. They also learn the alphabet and how to use it to read and write. It would be easy to include other methods for representing numbers, and letters throughout the elementary grades. Paint by numbers pictures are nice examples of pixel based image representation. Various secret alphabets have captured imaginations of children for ages.

In the middle and high school the topics related to encoding and decoding information provide a great setting for practicing problem solving skills and enhance student's understanding of the standard topics in algebra and geometry.

Additionally, students learning to use a database should also discuss how the information is stored and how the chosen database design impacts how difficult it is to answer some of the queries.

2.2. Processing of information: the concept of algorithm

• elements of knowledge:
All information literate individuals need to understand that any computer operation is controlled by the program written by humans. They need to know that each program represents instructions for carrying out a sequence of steps needed to perform a specific task.

To understand the difficulty of the task of writing programs, all information literate individuals should also know what are some of the basic building blocks of algorithms (decision, repetition, calculation, recursion) and understand the basic problem solving strategies (stepwise refinement, iteration, divide and conquer, backtracking, hierarchical decomposition) used in algorithm design. They should be able to follow (perform) a simple algorithm, be able to write a simple algorithm (possibly expressed in pseudocode or precise English statements).

• why this is important:
Computers would be useless if they only stored information. The key ingredient that turns a computer from a data storage device into a useful tool is its ability to process data and information according to a given algorithm - i.e., by following a prescribed process. Only by understanding that anything a computer does is a result of human decision to make the computer behave that way, will the information literate individuals truly appreciate the power of the computer and (again) the danger of its misuse.

There is another reason why this topic is essential. Not only do computers follow algorithms - a large number of other processes that an individual performs daily fall into the realm of algorithms. Problem solving techniques that form the foundation of algorithms creation, implementation, testing, and evaluation, can be employed to face the ordinary challenges of everyday work. By looking at basic components of algorithms - repetition, decision, decomposition into simpler parts, we are giving students tools for understanding the nature of controlled processes in general.

• what about it should be taught at what grade levels:
Anybody who played a card game or a board game knows what an algorithm is. In the early grades pupils often need to learn to follow directions - in effect acting out a given algorithm. Programming a Logo turtle has been a common way of introducing algorithms into elementary school curriculum.

In later years, students should understand reasonably well what an algorithm is - see examples not only from the computer science domain, but also as they appear in the context of sciences, and social sciences. They should learn the basic problem solving techniques - iteration/repetition, decision, divide and conquer, recursion, backtracking, and hierarchical decomposition. All of these can be presented in the context of playing games, solving mazes, solving real life problems, and simple computational problems.

When learning to work with spreadsheet, students may try to deduce the underlying algorithms, discuss possible ways of organizing the program to make it do all what it does, etc. Students may even write simple macros to add functionality to the spreadsheet - thus learning a little bit of programming while becoming more competent users of a valuable tool.

2.3. Encoding of algorithms: the concept of languages

• elements of knowledge:
All information literate individuals need to understand that an algorithm needs to be expressed in a language that both the writer of the algorithm and the performer of the algorithm understand. They should be aware of the variety of languages we encounter in our daily lives, and understand the need for the precise definition of the syntax and semantics of a programming language. They should also be aware of the fact that a compiler is needed to translate the program into simpler instructions that the computer is designed to carry out.

Another important topic that arises from studying languages is the issue of naming objects in an unambiguous manner. All information literate individuals need to understand the principles behind naming and scoping, especially in hierarchically organized name spaces (computer directories, URL's, e-mail addresses, etc.).

• why this is important:
Computer science is not the only field of human endeavor that uses specialized languages. Chemistry, medicine, stock market, cooking, knitting, dance, and music all have their own languages and grammars used to communicate ideas and descriptions of processes. By understanding the nature of languages, grammars, the syntax to define well-formed sentences and the semantics to assign meaning to phrases, students will be able to express their ideas in a clear and coherent manner and will learn to extract precise meaning from sentences written by others.

Naming and name spaces permeate our daily computer use. By understanding how the names are designed, what is the meaning of the various components of a name, and how the names are looked up and connected to the appropriate object, will help in remembering names, in making decisions about assigning new names to objects, and in participating in decision making on matters related to name spaces.

• what about it should be taught at what grade levels:
Kids love special languages. They may know about pictorial directions for finding a fire exit, for leaving an airplane, they may have used various forms of pig-Latin, they may be studying a foreign language. They are well aware of the need for naming objects - indeed, learning names of objects is one of their major goals in the early years.

In upper grades students should become aware of the number of different languages that people use and get the first glimpse of the principles behind the definition and implementation of a formal language. They can learn about simple formal grammars (for example for arithmetic expressions), see what strings or expressions are legal, what are the restrictions, etc.

They should learn about the different name spaces used in the world of computers, use them in communicating on the Internet, and when dealing with their own directory name space.

2.4. Management of complex systems: the concepts behind OS and networks

• elements of knowledge:

All information literate individuals need to understand that a computer is a complex system managed by a special program named operating system. They should understand the role of the memory, the processor, the storage devices, the communication devices, and the protocols for controlling them. They should also understand the principle of layered systems - these are encountered daily in many different contexts. The key issues here are the design of interfaces and understanding of the competing forces of information hiding and information giving.
We should include here also topics that relate to management of networks - protocols, reiteration of the naming concept, routing, bandwidth, etc.

• why this is important:
The world around us is very complex. To perform any task requires the ability to identify the level at which we need to operate and to define carefully the inputs (initial assumptions, the available resources or data, the control signals that will select among several options) and the outputs (the resulting product, data, or action). The ability to comprehend and be able to manage complex tasks is crucial in today's world.

Networks support communication. By understanding the underlying principles one is better equipped to be concerned about the dangers, be aware of the limitations, and be ready to explore the full range of options available.

• what about it should be taught at what grade levels:
In early grades pupils should learn how computer works from a conceptual point of view. They should understand a bit about 'who is responding' to their mouse clicks, possibly by imitating a computer in role playing games.

In middle school and high school students working with computers should take time to learn about the various components, their role, and how the interaction between the various parts is controlled by the operating system. While using the computer for communication and 'library search' students should also become aware of the need for network protocols, routing algorithms, search engines, etc.

2.5. Sense of scale

• elements of knowledge:
Computers allow us to deal with problems at a scale nearly impossible to comprehend. It is important that all information literate individuals have a sense of scale - i.e., understand what is the rate of growth, "how fast is fast, how slow is slow" and how two different rates of growth compare.
All information literate individuals need to understand why some algorithms cannot be performed in any reasonable time and why other algorithms arrive at the answer very fast. (Examples such as binary search contrasted with towers of Hanoi bring the point home very quickly.) They should also be aware of the fact that not all problems can be solved by a computer (the halting problem).

• why this is important:
Some people think computers can do everything. Others wonder why do we need faster and bigger computers all the time. By understanding the complexity of computation, these questions are answered clearly.

Again, the issue of rate of growth, and the growth of complexity is not restricted to the world of computing. The demographics, the economy, the use of natural resources - all use the rate of growth arguments to predict future behavior and to assess past events.

• what about it should be taught at what grade levels:
The two examples mentioned above are comprehensible to upper elementary grade students. More examples of similar sort, as well as a bit of time for reflection and comparison of different rates of growth can be done in middle and high school. High school students also encounter the issues related to the rate of growth in other subjects (sciences and social sciences).

2.6. Societal impact.

By understanding the topics outlined above an information literate individuals will be able to make informed decisions about many issues related to the use of computers in daily lives and policy decisions regarding computing.

3. What learning experiences do students need to achieve the technological literacy described above?

Some of what has been described above. In addition, students should be using computers as tools for science projects, English papers, social studies, mathematics exploration, and language study - as appropriate. The learning of the computer science concepts should serve to provide background and context for competent use of computers.

4. What technological environment...?

Most of what has been described in 2. can be learned without ever touching a computer. So, minimally, we need skilled and knowledgeable teachers.

At the other end, the computer environment should resemble the computer environment in the world of work - ubiquitous access to the needed tool for all students at all times would be ideal.

Minimally, every classroom should have several computers with the access to the Internet, and software appropriate for the subject matter - as well as a teacher skilled in its use. There should be a way to display to the whole class what is happening on the computer screen - without doing excessive setup.