The Fourth R

David Moursund

Using a somewhat old-fashioned measure of length, this short book is less than 80 pages long. For readers who want to "cut to the chase," I suggest you read Chapter 1. In brief summary, it discusses a **4th R** (**R**easoning; critical thinking; problem solving) using the combined powers of human brains and artificially intelligent computer "brains." For a review of basic aspects of problem solving, see Appendix 1.

The **4th R** is both a *content area* and a *general-purpose tool* useful throughout all areas of human endeavor. Like **R**eading, '**R**iting, and '**R**ithmetic, the **4th R** of **R**easoning/Critical Thinking is foundational in a modern education.

We know that children can begin to explore and use the **4 Rs** in their infancy. The **4th R** has already been integrated into the informal education of the daily lives of a great many children. Moreover, the use of Information and Communication Technology (ICT) is now commonplace in schools and homes. However, we are making slow progress in thoroughly integrating the **4th R** into the everyday and all day school curriculum at a level commensurate with the emphasis we place on the first 3 Rs.

Comments and suggestions are welcome. Pease send them to the author.

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Front Matter

David Moursund, Author

David Moursund is an Emeritus Professor of Education at the University of Oregon. His professional career includes founding the International Society for Technology in Education (ISTE) in 1979, serving as ISTE's executive officer for 19 years, and establishing ISTE's flagship publication, *Learning and Leading with Technology*.

He was the major professor or co-major professor for 82 doctoral students. He has presented hundreds of professional talks and workshops. He has authored or co-authored more than 60 academic books and hundreds of articles. Many of these books are available free online. See http://iae-pedia.org/David_Moursund_Books.

In 2007, Moursund founded **Information Age Education (IAE).** IAE provides free online educational materials via its *IAE-pedia, IAE Newsletter, IAE Blog,* and books. See http://iae-pedia.org/Main_Page#IAE_in_a_Nutshell.

In 2016, with the help of his son Russell Moursund and daughter-in-law Sonia Moursund, Moursund established **Advancement of Globally Appropriate Technology and Education (AGATE)** as a 501(C)(3) corporation designed to contain and expand Information Age Education (IAE). See details on the next page.

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IAE (Information Age Education)

Information Age Education (IAE) is a non-profit company in the state of Oregon founded in 2007 by David Moursund. Its goal is to help improve worldwide informal and formal education at all levels. Its current list of free resources and activities includes:

- Free books published by IAE. See http://iae-pedia.org/David_Moursund_Books; http://iae-pedia.org/IAE_Newsletter#Free_IAE_Books_by_David_Moursund_and_Robert_Sylwester; and http://iae-pedia.org/Robert_Albrecht#Free_Books_by_Bob_Albrecht.
- Free *IAE Newsletter* published twice a month. See http://iae-pedia.org/IAE_Newsletter.
- *IAE Blog.* See http://iae-pedia.org/IAE_Blog.

- *IAE-pedia*. See http://iae-pedia.org/index.php?title=Special:PopularPages&limit=250&offset=0 for a list of documents ordered by popularity.
- Other IAE documents. See http://i-a-e.org/downloads.html.

AGATE (Advancement of Globally Appropriate Technology and Education)

Advancement of Globally Appropriate Technology and Education (AGATE) was founded in 2016 by David Moursund, Russell Moursund, and Sonia Moursund. AGATE is a 501(C)(3) corporation whose purpose is to continue and expand the work of IAE.

Here is a useful analogy that helps to describe the work of AGATE. Think about a village having a "wise" man or woman who serves as a fount of information, knowledge, and wisdom. Now, think about the implications of partially supplanting that wise person with access to artificially intelligent computer systems that are growing steadily more intelligent.

The wise person has human knowledge and skills. The computer system—which may well be a robot—has a different kind of knowledge and skills. Each has strengths and weaknesses. In solving problems and accomplishing tasks, by working together they can surpass either working alone.

The educational systems of our world face the challenge of educating students for lives in which humans and computer systems will increasingly work together to solve problems and accomplish tasks. The steadily improving capabilities of computer systems means that our educational systems need to be flexible in steadily changing to accommodate both changes in computer capabilities and in human needs.

This is a worldwide challenge. The education-related research done in one part of the world needs to be appropriately interpreted, disseminated, and used to help improve education in other parts of the world. AGATE's goal is to expand the current work of IAE to help accomplish this task.

Part 1: Preface and Five Chapters About the 4^{th} R

Preface to Part 1

> "Education is a human right with immense power to transform. On its foundation rest the cornerstones of freedom, democracy and sustainable human development." (Kofi Annan; Ghanaian diplomat, seventh Secretary-General of the United Nations, winner of 2001 Peace Prize; 1938-.)
>
> "The purpose of education, finally, is to create in a person the ability to look at the world for him/herself." (James Baldwin; American novelist, playwright, and civil rights activist; 1924-1987.)
>
> "It isn't enough just to learn—one must learn how to learn, how to learn without classrooms, without teachers, without textbooks. Learn, in short, how to think and analyze and decide and discover and create." (Michael Bassis; American educator and author; 1946-.)

This short book is based on six *IAE Newsletters* published during late 2016 and early 2017 (*IAE Newsletter*, 2017). Part 1 consists of a Preface and six chapters about changing education so that it includes a **4th R** of **R**easoning/Computational Thinking. These chapters are slightly revised versions of the six newsletters. Part 2 provides some supplementary materials from nine *IAE Blog* entries (*IAE Blog,* 2017).

The book's intended audience is preservice and inservice teachers at the PreK-12 levels, as well as all people interested in improving education at these levels. The emphasis is on defining and securing widespread acceptance of a **4^{th} R** in the traditional list of **R**eading, '**R**iting, and '**R**ithmetic.

The **4^{th} R** is named **R**easoning, and it stands for Computational Thinking. **R**easoning/ Computational Thinking makes use of one's brain and Information and Communication Technology (ICT)–especially Artificial Intelligence–to represent and solve problems. My recommendation is that this **4^{th} R** should be thoroughly integrated into the traditional **3 Rs** and throughout the curriculum.

Part 1 presents a rational for thoroughly integrating the **4th R** throughout the curriculum and in all aspects of preservice and inservice teacher education. It assumes that all readers of this book are familiar with the **3 Rs**. These have been foundational content of schooling for a very long time. The **3 Rs** are both important disciplines of study in their own right, and also very important components of the various disciplines that make up PreK-12 education.

I believe that a good education is a birthright of all children. This point of view has been strongly supported by the United Nations (UN) since its inception (United Nations, 1948). The 1948 United Nations Declaration of Human Rights states in Article 26:

> (1) Everyone has the right to education. Education shall be free, at least in the elementary and fundamental stages. Elementary education shall be compulsory.

> Technical and professional education shall be made generally available and higher education shall be equally accessible to all on the basis of merit.
>
> (2) Education shall be directed to the full development of the human personality and to the strengthening of respect for human rights and fundamental freedoms. It shall promote understanding, tolerance and friendship among all nations, racial or religious groups, and shall further the activities of the United Nations for the maintenance of peace.
>
> (3) Parents have a prior right to choose the kind of education that shall be given to their children.

Education still remains one of the UN's highest priorities. Quoting from the UN Secretary General (Ki-moon, 5/19/2015):

> Education must do more than produce individuals who can read, write and count. It must nurture global citizens who can rise to the challenges of the twenty-first century. At any age, people can learn. Let us give them the chance, so that we can all create a new future.

Chapter 1 introduces the **4th R** as both a discipline of study–Computational **R**easoning/Thinking (Information and Communication Technology)–and as a new fundamental component of the other disciplines that students study in PreK-12 education.

Chapter 2 presents Robert Branson's upper limit hypothesis that only a major paradigm shift, such as extensive use of Information and Communication Technology in education, can propel our education results to new, higher levels.

Chapter 3 lists some of the problems our world faces in the 21st century. Information and Communication Technology is both a source of some of these problems and an aid to addressing many of them.

Chapter 4 proposes some approaches to improving education in order to help prepare students to become adults that have the knowledge and skills needed to help address major problems our world faces.

Chapter 5 outlines some of my philosophy of computers in education and encourages readers to develop and implement their own philosophy.

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Chapter 1

Adding a 4th R to the 3 Rs of Education

Based on *IAE Newsletter:* Issue 198, November 30, 2016.
See http://i-a-e.org/newsletters/IAE-Newsletter-2016-198.html.

> "The only person who is educated is the one who has learned how to learn and change." (Carl Rogers; American psychologist; 1902-1987.)
>
> "Nothing could be more absurd than an experiment in which computers are placed in a classroom where nothing else is changed." (Seymour Papert; South African/American mathematician, computer scientist, and educator; 1928-2016.)

Reading, 'riting, and 'rithmetic (math) are both **disciplines of study** and **tools** that are useful across all curriculum areas. In the early 1970s, when computers began to be widely available, Art Luehrmann and other computer-oriented educational leaders strongly recommended that all students should become Computer Literate (Moursund, 2016b). Many suggested that all students should learn some computer programming and that all should learn to make effective use of some basic computer tools.

Clearly, Computer Science is an important discipline in its own right and computers are also a powerful aid to representing and solving problems throughout the curriculum. That is, Information and Communication Technology (ICT) is both a discipline of study and a broad-based tool, just as are the 3Rs.

More recently, the term **Computational Thinking** has come into common use (Moursund, 2016a). This term can be thought of as describing our current insights into Computer Literacy (Carnegie Mellon, n.d.):

> **Computational thinking** is a way of solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computer science. Computational thinking is thinking in terms of abstractions, invariably multiple layers of abstraction at once. Computational thinking is about the automation of these abstractions. **The automaton could be an algorithm, a Turing machine, a tangible device, a software system—or the human brain.** [Bold added for emphasis.]

The Wikipedia provides the definition:

> **Computational Thinking** (CT) is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer—human or machine—can effectively carry out.

Please reread the two definitions. Pay careful attention to the emphasis on computer brains and human brains working together. That is a unifying theme in this and subsequent chapters of the book.

Computational Thinking is a "mouth full" and it seems to me it would be difficult to convince our educational systems that all students should be learning the 3Rs as well as Computational Thinking. Hmmm. How about learning the 3Rs and Computational **R**easoning? **Aha! A 4th R!**

However, lots of people have thought about adding a **4th R** to the 3Rs. My 11/9/2016 Google search of the expression *4Rs in education* produced more than 280,000 results. Considerable browsing led me to the conclusion that people writing about the **4Rs** in education tended to be interested in variations of **R**esponsibility, **R**espect, **R**esourcefulness, and **R**esponsiveness. In some cases, one of these terms was added to the conventional 3Rs. These suggested changes to the 3Rs miss the point that each of the 3Rs is both a discipline of study and a fundamental cognitive tool.

The remainder of this chapter and the rest of the book focuses on my definition of the **4Rs.**

Information and Communication Technology (ICT)

Computer technology first became commercially available in the early 1950s. During the ensuing 65 years, the price to performance ratio of computer hardware has decreased by a factor of more than a billion. Moreover, computer software has been steadily improved. Today's PreK-12 students take for granted such things as computerized toys and games, Smartphones, the Internet and Web, robots, and artificial intelligence. Us "older folks" can compare the world of today's youth with the world we grew up in. In terms of ICT and other technology, a short summary is: **What a difference!**

We all recognize that not all of the change is for the better. Moreover, there are huge worldwide differences between the "haves" and the "have-nots" in terms of access to ICT.

One such change that we have all seen is an increasing worldwide competition for employment and a major change in the nature of employment. Many middle class jobs have disappeared (Moursund, April, 2014; Moursund, 10/9/2012). Moreover, many of today's white-collar jobs require skills in using computers as an aid to solving problems, answering questions, and accomplishing tasks.

The next section looks to the future and addresses the question, "What technological developments will have the greatest impact on our future?"

Artificial Intelligence Today

Here is a recent answer from Kevin Kelly, the founding executive editor of *Wired* magazine, and a former editor/publisher of the *Whole Earth Review* (Kelly, 10/26/2016):

> By far, the greatest impact in the coming decades will be due to artificial intelligence [AI]. **It will equal or exceed the scale of changes brought about by the industrial revolution.** That revolution was ignited by our invention of artificial power—steam power, motors, electricity—which greatly amplified and extended the natural power of muscles. Up until then, the only way to make things was to employ animal or human muscle.
>
> Once we harnessed artificial power and delivered it as a commodity on a grid, we could build skyscrapers, railways, factories, and the entire world of modernity. This

> artificial power transformed everything in our lives, from business, to education, to the military, to science, and beyond.
>
> With the coming of artificial intelligence, we are going to repeat that revolution. Instead of merely harnessing 250 virtual horses as we speed down the highway in our car, we are going to add 250 virtual minds and make it a self-driving car.
>
> As we deliver this AI as a commodity on the grid so that anyone can purchase as much AI as they want, we will begin to cognify everything that we formerly electrified. **Cheap, ubiquitous, ever-improving AI will transform everything in our lives. It will be a second industrial revolution.** [Bold added for emphasis.]

Kevin Kelly emphasizes the steadily growing importance and capabilities of artificial intelligence. This is an area of research and development in which thousands of researchers are building on the previous research and development of their colleagues and previous workers in this field. I like to think of a new AI-based tool as an aid to human capabilities than can be mass produced and distributed quickly and widely.

Often it requires only a modest amount of time and effort to learn to make effective use of such new tools. For example, consider natural language translation by computer. From time to time, I receive an email message written in a language that is foreign to me. I copy it, then paste it into a free service such as *Google Translate.* I get an immediate translation that typically serves my needs.

AI is different from "human" intelligence. Thus, humans and computers bring somewhat different cognitive abilities to solving problems and accomplishing tasks. Humans and computers working together can often out-perform either working alone.

From the Industrial Age to the Knowledge Age

In terms of education, ponder the following question, "If a computer can solve or greatly help in solving a problem, answering a question, or accomplishing a task, what do we want students to learn about dealing with the problem, question, or task?"

You are aware that the same type of question can be applied to the tools developed during the Industrial Age. We have had well over two hundred years to answer this question for steam engines and subsequent inventions such as: trains and steamships; electrical power, telegraph and telephone; radio and television; gas powered and electric powered cars; airplanes and space shuttles; and worldwide trade and travel. All of these except space travel were developed before electronic digital computers first became available.

Many argue that our current PreK-12 educational systems are still best described as **Industrial Age.** But the world has moved on. The **Information Age** officially began in 1956, when the number of white-collar jobs in the United States first exceeded the number of blue-collar jobs (Moursund, 2016c). In the Information Age, a steadily increasing proportion of employment involves working with data, information, knowledge, and so on.

Figure 1 explores Arthur C. Clarke's Cognitive Understanding Scale (Clarke, n.d.). This chart is intended to suggest that it takes an increasing level of understanding and insight to move up the scale. I believe Clarke developed this scale as an aid to communicating about various levels of human insight and understanding.

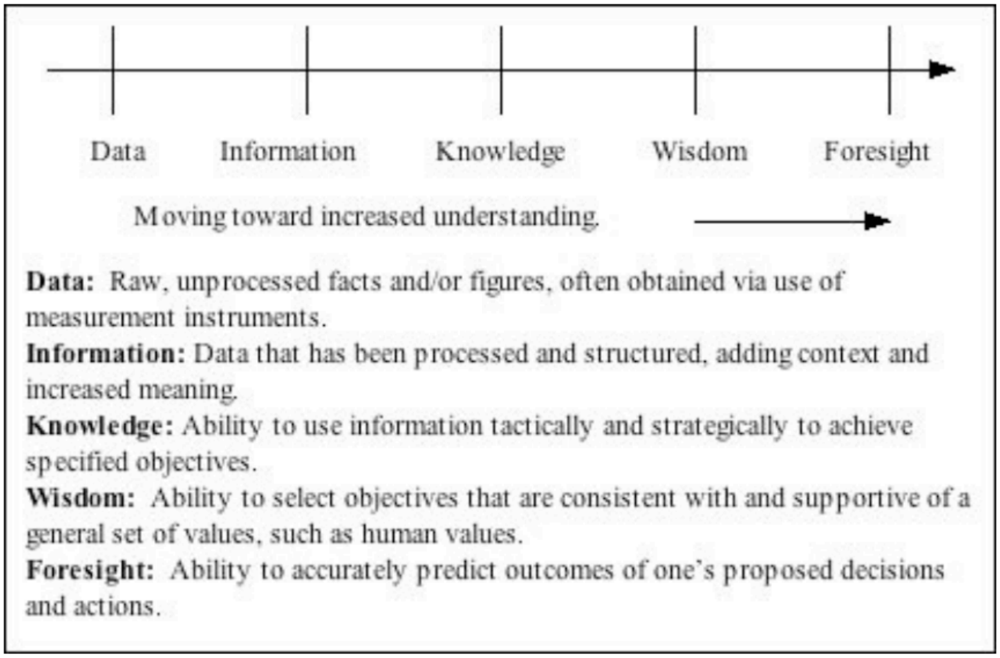

Figure 1.1. Arthur C. Clarke's Cognitive Understanding Scale.

The first electronic digital computers were called data processing machines. They could take over many of the tasks of humans who used calculators and other aids to do data processing.

Soon it became clear that computers could store and process *information*. Indeed, the discipline of Computer Science began to be called Computer and Information Science.

> **This is an aside.** If you want to stretch your brain a little, think about what it might mean to have a cognitive understanding of data and data processing. It might help to consider a child memorizing and following a step-by-step set of instructions to do addition, subtraction, multiplication, and division of integers. Even if the algorithms being used are memorized with little or no understanding, the child has some understanding of what it means to add numbers and to do other arithmetic.
>
> The ability to add, subtract, etc., numbers is built or programmed into computers. A relatively inexpensive computer can carry out a billion calculations per second with no errors. But, the computer does not have even a child-like understanding of the meaning of these data processing tasks. Moreover, the computer does not "know" what problem is actually being solved. Is it processing a payroll, a day's receipts from sales by a chain of stores, or data from a scientific experiment?

In some sense, over the years, the performance of computers has moved up the Clarke scale. We are now at the level that computers are becoming somewhat adept at processing knowledge. However, even though Computer and Information Science has made considerable progress in Artificial Intelligence (Machine Intelligence), our current computer systems are quite weak in what we humans call cognitive understanding. While computers are becoming better and better in accomplishing tasks that humans use cognitive understanding to solve or attempt to solve, computers still use machine intelligence rather that human-like cognitive intelligence.

We are now well into the **Knowledge Age**, which began in the early 1990s. Currently, there are huge disparities among the precollege educational systems of the world in terms of how well they are taking advantage of the technology and steadily accumulating human knowledge of this new Knowledge Age (Moursund, 2016b).

Educational Change Agents

The term **change agent** usually applies to a person who is trying to make a change in an organization. I use the term more broadly, as I include computers and other tools as change agents.

The **Knowledge Age** is building on the **Information Age,** which built on the **Industrial Age,** which built on the **Agricultural Age.** We currently have a vast range of physical and cognitive tools, and the combined capabilities of both are rapidly increasing. Robots provide an excellent example of combining Industrial Age machinery and Knowledge Age tools.

But wait, there's more! Consider the progress that is occurring in cognitive neuroscience, health and medicine, the behavioral sciences, and our understanding of how poverty, bullying, and social unrest affect learning. Also consider the fact that the world is facing a wide range of problems (Moursund, November, 2016). Many of these problems, such as population pressures, lack of fresh water, and rising sea levels, are growing rapidly.

I hope it is clear to you that our educational systems need to appropriately accommodate the growing host of change agents, and that these change agents are themselves rapidly changing. I believe that the foundations of a good modern education now lie in the **4 Rs** described at the beginning of this chapter. It is very important to keep in mind that the **4th R** (Computational **R**easoning) strongly impacts the first 3 (conventional) Rs.

Integrating the 4th R into Education

An obvious challenge to integrating the **4th R** into education is the cost of the needed hardware, software, and connectivity. But, the economically developed nations are well along in meeting that challenge. The cost is modest relative to the total costs of education in these economically developed nations.

The huge educational challenge will be to fully integrate ICT capabilities and uses into the teaching, learning, and use of the current 3Rs. As students learn the conventional 3Rs starting in PreK or earlier, the **4th R** comes into play. Their teachers need to be familiar with appropriate roles of ICT throughout the PreK curriculum as well as in the everyday life of students outside of school.

This same challenge applies to teachers at all grade levels. We expect teachers at all levels and in all subject areas to have an appropriate level of reading, writing, and arithmetic knowledge and skills. By the time a person obtains teacher certification, the person has been studying and making use of Reading, Writing, and Arithmetic for about 17 or 18 years of schooling (kindergarten through a bachelor's or master's degree). The task of bringing all current teachers and all new teachers up to this same level of **4th R** knowledge is indeed daunting!

Let's use writing, one of the current 3Rs, as an example. We have long included use of graphic images as part of writing for books, magazines, and journal articles. But, "ordinary" people could not take a photograph and integrate it into their written letters and other writings. Now, children can easily accomplish this task of adding images as they write using a computer.

In writing using a word processor, one can easily take advantage of aids such as spelling and grammar checkers, a wide variety of type faces and sizes, nicely formatted tables of data, and so on. So, our educational systems now face the challenge of teaching students topics such as design, layout, use of various fonts, and use of graphics in desktop publication. Moreover, when writing for online publication, one can also make use of video, as well as touch sensitive buttons and other links. This is another huge educational challenge, and it is certainly not beyond the learning capabilities of even relatively young students.

Nowadays, tables and collections of data are generated using spreadsheet and database software. However, it is by no means easy to learn to make effective use of spreadsheets and databases. These are powerful aids to representing and solving a wide range of problems, and many people skilled in their uses make their living applying such knowledge and skills. So, this constitutes another challenge to implementing the new **4th R.**

You can see the gist of this conversation. The **4th R**—which includes all aspects of the discipline of Information and Communication Technology—is both a major area of study in its own right and is a powerful change agent in each of the traditional 3 Rs.

ICT-based Aids to Learning the 4 Rs and Other Curriculum Content

The development of reading, writing, and arithmetic created a need for formal schooling and certainly changed the world. For the 5,200 years since these tools were first developed, our educational systems have gradually become better at teaching the 3 Rs. However, this progress seems to have nearly plateaued perhaps 20 years ago (Moursund, October, 2016a).

Through the work of Benjamin Bloom and others, we have long known that a knowledgeable and skilled individual tutor is a powerful aid to learning (Moursund, August/September, 2000). For many years, educators have been working on developing computer-assisted learning systems that incorporate some of the characteristics of an individual tutor. We now have a growing number of Highly Interactive, Intelligent Computer-assisted Learning (HIICAL) systems. While these have not yet reached the level of highly skilled individual tutors—they have surpassed many of the skills of teachers working with classes of 20 to 40 or more students (Moursund, 9/11/2011). We can look forward to the time that HIICAL-based units of instruction and full courses span the curriculum. Learning to learn from HIICAL systems is a key component of a modern education.

Remember that HIICAL is steadily improving. Also, HIICAL systems can make use of information stored on the Web, voice input, voice output, computerized language translation, and so on.

Moreover, good HIICAL systems are both tutor and tool. That is, the software needed in a good HIICAL system can solve or help to solve a very wide range of problems. This is a key idea, so let's carry it a little further. We are used to the idea of learning to read and then reading to learn. We are also used to the idea of the Web as a gigantic online library that can help in solving a very wide range of problems. Thus, think of the Web as both a tool and an aid to learning, much as we think of learning to read and then reading to learn.

Final Remarks

We are well along in moving from the Information Age into the Knowledge Age. In the future, artificial intelligence and other computer-based aids to posing, representing, and solving problems will greatly supplement the physical and cognitive capabilities of humans. This ongoing change will require ongoing changes to all levels of our educational systems.

Our educational systems can be greatly improved through the thorough integration of the newly defined and expanded **4Rs of reading, 'riting, 'rithmetic, and reasoning.** Our educational systems will also be improved by integrating the routine use of HIICAL into the curriculum at all levels.

I suspect that most people do not understand the magnitude of the staff development challenges faced by current teachers and the changes that will need to occur in our preservice teacher education programs. Our current educational systems are based on curriculum content, pedagogical processes, and assessment that are thoroughly intertwined with a 3Rs-based educational system and largely ignore the **4th R.**

The **4th R** greatly adds to and changes the current 3Rs. In addition, it is both a large content area in its own right, and it is a major change agent in curriculum, instruction, and assessment. I believe the **4th R** will produce more change in education than all of the changes we have seen since the current 3Rs became such a powerful force in our educational systems many hundreds of years ago.

The magnitude of this challenge suggests we need a major change in inservice education and continuing professional development for all teachers. The task of being a professional teacher must include substantially more time and resources for staff development than our schools currently provide. Learning on the job must become a much larger part of being a professional teacher.

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Chapter 2

Upper Limits of Education

Based on I*AE Newsletter:* Issue 195, October 15, 2016.
See http://i-a-e.org/newsletters/IAE-Newsletter-2016-195.html.

> "It isn't enough just to learn—one must learn how to learn, how to learn without classrooms, without teachers, without textbooks. Learn, in short, how to think and analyze and decide and discover and create." (Michael Bassis; American educator and author; 1946-.)

More than ten years ago, I read and later wrote about Robert K. Branson's article, Why Schools Can't Improve: The Upper Limit Hypothesis (Branson, 1987). See my paper, Developing a Philosophy of Computers in Education (Moursund, 7/23/2005). In brief summary, Branson's article (now 30 years old) presents the case that, in 1987, schools in the U.S. were about as good as they were going to get without use of the new computer technologies that were emerging.

Quoting from Branson's1987 article:

> The first purpose of this paper is to question whether there is a significant discrepancy between the current levels of productivity and quality of American schools and the levels required to serve the society well. The second purpose questions whether the current approach, or the approaches of blue ribbon commissions are likely to produce significant improvements. A third purpose sets forth the hypothesis that the current school operations model cannot be improved by the recommendations offered by the National Commission. **The fourth purpose is to suggest that some form of technological intervention must be made before any substantial increases are made in productivity.** [Bold added for emphasis.]

Remember, this is a 1987 statement. The computer industry was well established by then. Many schools were making instructional use of computers. However, the Smartphone and tablet computers were nearly 20 years in the future! You can get glimpses of computers in education at that time by reading my International Council for Computers in Education (ICCE) editorials (Moursund, D., 1986-1987).

Branson's fourth point (highlighted above) relates to the idea that Malcolm Gladwell called the **tipping point**. Gladwell's book, *The Tipping Point: How Little Things Can Make a Big Difference,* provides a number of examples of how changes in technology have produced tipping points that have caused many companies to go bankrupt (Gladwell, 2002). His key point is that new technologies often present a major challenge to companies that are doing well using the older technologies and ways of doing business. New and more nimble companies may well capture the customers served by the older, better-established companies.

Branson supported both research-based incremental improvements and the need for a paradigm shift. Quoting from Branson's later 2001 article (Branson, May, 2001):

The conclusion to be presented and defended is that education cannot get better until it uses the results of programmatic research and development (R&D) to make incremental changes in the current processes. Educators cannot avoid the difficult and deliberate R&D work that other industries must do to make fundamental improvements.

Upper Limit Theory

Branson uses the word **hypothesis** in his ß1987 article. I tend to use the term **theory** in discussing the same ideas. In a "pure" science, a theory (hypothesis) is proposed, and then scientists go about the task of trying to prove or disprove the theory. Their goal is to have results that are solid enough, sound enough, reliable enough (choose your own words) so that others can build on them with confidence. Newton's theory (laws) of motion published in 1687 was very useful, but eventually gave way to results from Einstein's general theory of relativity published in the early 1900s. Einstein's earth-shaking theory is still being tested now, more than a hundred years later.

My recent Google search of the expression *upper limit OR limits theory* produced over 60 million results. The term is used in many different areas of performance. For example, how fast can a human run the 100-meter dash? The world record time for the 100-meter dash has decreased over the past hundred years from about 10.60 seconds to 9.58 seconds (Wikipedia, n.d.). This is due to some combination of a broader range of participants drawn from much of the world, better training, better shoes, better tracks, and so on. A "scientific" analysis of this data might suggest that 9 seconds is an upper limit.

Of course, with appropriate technology, it is quite easy for a person to travel 100-meters in less than 9 seconds. (Just think about automobile drag racers that can cover a quarter mile in less than 4 seconds.)

Figure 1 illustrates an incremental, *continuous improvement* model. Although the remainder of this article is specifically talking about education, this figure is applicable in many different areas of performance. Over a long period of time, incremental improvements are made. The effects are small from year to year, but tend to occur in a cumulative manner. Thus, the total effect increases over the years.

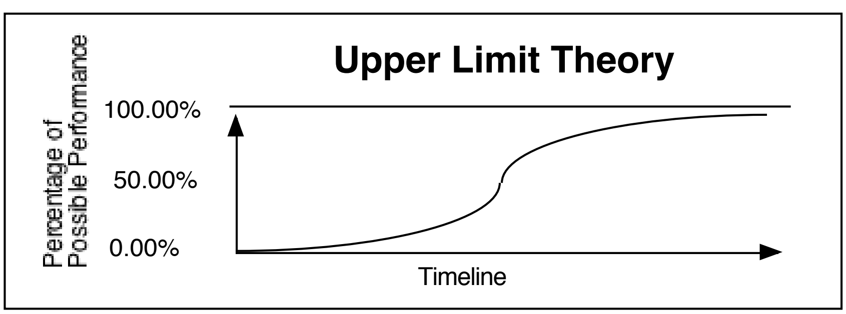

Figure 2.1. Continuous improvement model and upper limit theory.

Eventually, the new improvements begin to have a smaller and smaller overall effect. Whatever performance is being improved gets closer and closer to being as good as it can be—that is, unless there is a major breakthrough.

Our educational system employs a continuous, incremental improvement model. Now, 30 years since Branson's 1987 article, we can look back over a great many years of national data on K-12 education and see that little progress is occurring in the overall quality of student performance in areas such as reading, writing, science, and math. Branson argued that our educational system was performing at approximately the 95% level of possible performance by the mid 1960s. All of our efforts to improve our educational system since then have had little effect on performance in reading, writing, science, and math.

Branson's 1987 article argues that a paradigm shift—based on computer technology—would propel education to much higher levels of achievement. Figure 2 helps to illustrate the idea of a major paradigm shift. A paradigm shift is like starting anew from the level that has previously been achieved.

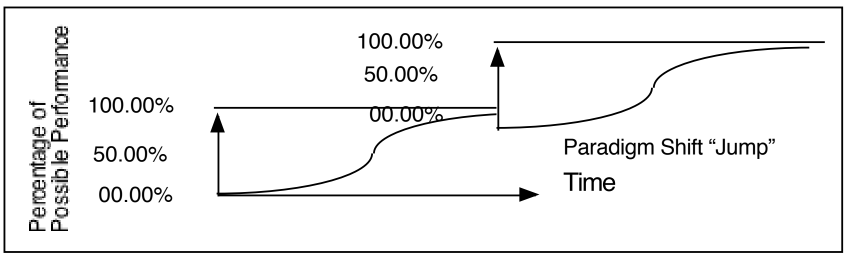

Figure 2. Paradigm shift, opening room for more incremental change.

Malcolm Gladwell's book provides examples of such paradigm shifts in business and industry. Here is a computer-related example. Before the invention of the transistor, vacuum tubes were an essential component of electronic equipment. Vacuum tubes (much like incandescent light bulbs) were relatively large, fragile, had a short life, and produced a lot of heat. Such tubes were gradually improved over time since their invention in the early1900s. However, it seemed likely that they were approaching their upper limit in the 1940s, just as electronic digital computers were beginning to be developed.

The early computers were machines that used many thousands of vacuum tubes. In essence, the developing computer industry was stymied by the power consumption and heat of the best tubes that could be produced. You may find it both instructional and amusing to read a little bit about the 18,000 vacuum tube ENIAC computer built in the United States during 1943-45 (Computer History Museum, n.d.).

The invention and development of transistors was a tipping point—a major paradigm shift in electronics. Beginning after the invention of the transistor in 1947, vacuum tubes gave way to transistors. Now, about 70 years later, it may well be that you own a laptop or desktop computer that contains more than a billion transistors. Try to imagine such a machine containing a billion vacuum tubes, each the size of your thumb and each giving off 25 watts of heat. At 10 cents per kilowatt-hour of electricity, the hourly cost of running such a machine would be about $2.5 million! And, this does not include the cost of the needed air conditioning.

Perhaps you don't own a desktop or laptop computer, but do own a Smartphone. The newer Smartphones contain more than two billion transistors. The number of neurons in a human brain is estimated at 186 billion. Intel predicts that by 2026 they will be producing a computer chip containing as many transistors as the number of neurons in a human brain (Henderson, 1/6/2014).

How would you like to be a billionaire? The chances are that you own electronic equipment that contains transistors that are equivalent to several billion dollars worth of vacuum tubes from the 1940s. In today's dollars, such vacuum tubes may have cost in the $5 to $10 range. So, a person why buys a modern cell phone or tablet computer is buying the equivalent of billions of dollars worth of the types of vacuum tubes that existed before transistors were invented.

Final Remarks

The 100-meter dash makes use of very precise measures of distance and time, and precise rules on drug use, equipment, track surfaces, wind speed, and so on. Our educational system lacks precision, both in what it is trying to accomplish and how accomplishments are measured. Moreover, the "rules of the game" have changed over time, now being quite flexible in allowing use of technology such as books, audiovisual materials, drugs (for example, Ritalin for students with ADHD and anxiety), ICT, and so on. So, the analogy between the 100-meter dash and Branson's observation about possible upper limits in educational achievement is quite a stretch.

Our schools have considerable experience in measuring how well students at various grade levels can read and do math. But, we do not have such data for the **4th R.** Reading and math are slowly changing areas. So, data gathered over the years tends to be useful in the near future. However, since the **4th R** depends on use of technology that is changing rapidly, we cannot expect to develop grade level performance measures that will stand the test of time.

We all know what modern electronic technology has done for the communication and entertainment industries. It seems like an understatement to say that electronic technology has revolutionized these industries. In addition, we routinely hear news about how robots are "taking over" middle class jobs. We are getting used to voice input to computers and voice output from computers (Weise, 9/29/2016).

Here is a very important "fact" to understand. Machine interfaces (the way that humans interact with the machines) are designed so that the machines are both relatively easy to learn to use and relatively easy to use. A typical five-year-old can learn to use a tablet computer, a cell phone, a digital camera, and a wide variety of computer games. There is a strong parallel between this type of learning and the other informal learning that is going on for young children. **It is not school-based learning.**

Think of this from a formal schooling point of view. What can/do children learn from their routine, everyday lives outside of school? What do children learn from the 180 or so school days per year? Here are three questions for you to ponder:

1. How can the overall education of children be improved by modifications to their informal (outside of school) forms of education?
2. How can computer technology and other school-related paradigm shifts make school time more productive?

3. What should our informal and formal educational systems be doing to effectively deal with the continuing progress in artificial intelligence? Perhaps someday computers will be more intelligent than humans. Computer scientists call this the **singularity** (Moursund, 5/16/2015 and 3/4/2015). This singularity would represent a paradigm shift in computer intelligence.

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Chapter 3

We Face Many Local, National, and Global Problems

Based on *IAE Newsletter:* Issue 197, November 15, 2016.
See http://i-a-e.org/newsletters/IAE-Newsletter-2016-197.html.

> "The future is here. It's just not widely distributed yet." (William Gibson; American-Canadian writer who coined the term "cyberspace" in his short story "Burning Chrome" and later popularized the concept in his debut novel, *Neuromancer;* 1948-.)
>
> "The secret of change is to focus all of your energy, not on fighting the old, but on building the new." (Socrates; Greek philosopher; circa 469 BC-399 BC.)

Past, Present, and Future Problems

For a child, life is full of new things. That's just the way it is. For those of us adults who have been around for a number of years, each day brings some new things, but there is also a lot of "same-o, same-o."

We all know that today's children are tomorrow's adults, and so they need to be introduced to the major problems they will face as adults. Many of these problems are global. And, problem solving is a core component of each discipline that students study in school.

Each of the **4Rs** is both a discipline of study and a tool useful across many other disciplines. The **4th R** (Reasoning; computational thinking) focuses on processing information. A computer is an information processing machine—a machine designed for the input, storage, processing, and output of information. One can form an analogy between a computer (brain) and a human brain. Thus, many researchers study the discipline of information processing both from the point of view of what human brains can do and what computer "brains" can do. What are the problem-solving capabilities and limitations of human brains and computer brains? Such a question is an important aspect of students learning and using the **4th R.**

This chapter lists and briefly discusses some of the global problems that I believe should be addressed in precollege education. This is not intended to be a comprehensive list. Rather, it is intended to illustrate the breadth and complexity of the world that we want our children to learn about.

One Historical Example

My father was born in 1901. Cars using internal combustion engines existed by then, but it was years before one first made it to his small town in Texas.

Think about some of the things you know about cars and trucks, gasoline and diesel fuel, highways, traffic accidents, and learning to be a safe and responsible driver. Think about the world's oil production and distribution systems, wars motivated by gaining or maintaining access to oil, air pollution, and so on. Suppose you were a teacher a hundred years ago, but had relatively good foresight about what was to come in the world of ground transportation. What would you want your students to learn about this area?

While you are pondering this question, it may occur to you to ask the same question about ocean liners and airplanes. The internal combustion engine certainly was a world changer. Some of the changes have been for the better, and some have been quite bad. Hold these thoughts in mind as you think about some of the problems and changes our world (and schools) currently face.

World Problems

My recent Google search of the expression *world problems* produced well over 800 million results. Google provided me with links to articles such as the following:

- Fifteen Major Current Environmental Problems (CFF, n.d.).
- The Ten Biggest Problems in the World According to the European Union (Jardine, 10/7/2011). This article was written before Great Britain decided to withdraw from the European Union. However, the EU economic situation was number three in the list.
- Ten Most Critical Problems in the World Today (Loudenback, 8/23/2016).
- Top Ten Third World Problems (PEI Staff, 2016).
- The World's Biggest Problems (WBP, 2016).

I found it interesting to read and compare a number of different lists. There are considerable overlaps in the lists I examined.

I built my own list, and I hope you will build a personal list. By "personal," I mean that items in your list are ones that you feel strongly enough about so that you are willing to expend some of your time, energy, and other resources to help address the problems.

Part of Dave Moursund's List

Here is part of my list, with the items in alphabetical order.

- Accountability and transparency at individual, corporate, organization, and government levels. (I want to know what **they** are doing for us and to us.)
- Big and little brother and sister are watching you. (Privacy is rapidly disappearing.)
- Climate change: global warming and changing weather patterns. (**We humans** have messed up the world's climate and weather. Now we are trying to do something about this problem situation.)
- Cognitive Neuroscience, especially as it applies to education and to quality of life.
- Education for all, with special emphasis on worldwide education for disadvantaged people and women. Also, education to understand and appropriately be involved in dealing with the problems in this list.
- Energy, with special emphasis on sustainable, non-polluting energy. (Will progress in science and technology substantially help in solving the world's energy problems?)

- Food, water, clothing, shelter, and other basics. (These are part of Abraham Maslow's hierarchy (McLeod, 2016). Fresh water is a major and growing problem.)
- Gender inequalities.
- Instructional uses of Information and Communication Technology (ICT). (This is a yin and yang situation discussed in detail in the next chapter.)
- Medical care. (How to provide all people with basic and more advanced medical care.)
- Pollution of air, land, and water.
- Population growth and an aging population.
- Quality of life. (Related topics include poverty, jobs and decent-paying jobs, and huge economic inequalities.)
- Racism and religious bigotry.
- Shrinking world. (Think in terms of transportation, communication, and competition for jobs.)
- Sustainability and species extinction. (Conspicuous consumption is a related topic.)
- Terrorism at local levels; large-scale conflicts (war); refugees.
- Weapons of mass destruction.

As you think about these problems, pick out one or more that really concerns you. For these, ask yourself what you personally are doing to help address the problems and what you think our schools should be teaching students about them.

I have selected two items from my list for further discussion in the remainder of this chapter. A third item, Information and Communication Technology ICT), is discussed in chapter 4.

#1: Climate Change

I live quite near the Pacific Ocean. A rising ocean, a massive earthquake, or a huge storm could devastate the region in which I live. The same can be said for 20 percent or so of the world's (human) population. I have no reason to believe that humans cause earthquakes along major fault lines, but I am absolutely convinced that humans are a major contributor to rising oceans and substantial changes in the weather.

While each of us can do a little to help, this is a global problem. I have found it interesting to follow the machinations of individuals, companies, nations, and the whole world as they have come to grips with the seriousness of this problem. I am quite concerned that, so far, we are doing "too little, too late."

The human race has survived and prospered through people learning to cooperate with each other in small groups, such as families, clans, and small tribes. We are not nearly so successful at city, state, national, and international levels.

It is pleasing to note that the Paris Accord on climate change has received enough votes to go into effect beginning November 4, 2016 (United Nations, 11/4/2016).

Formal and informal education, travel, and opportunities to get to know the "others" can all help. Schools provide an environment in which people from all kinds of backgrounds can learn to work together toward common goals. Schools in the United States (and in many other parts of the world) have vast opportunities for improvement in such endeavors. In terms of Upper Limit Theory, we have by no means reached our upper limits.

One very powerful approach to problem solving is to break a big problem into smaller, more manageable pieces. Climate change, and many of the other global problems, lend themselves to actions by individuals and small groups at the local level. Perhaps the following quote comes to your mind: "Think globally, act locally." I believe such thinking should be thoroughly integrated into the education of our children.

#2. Quality of Life

Our world currently is making considerable progress in improving the average level of quality of life of its people. But, there are huge disparities. I see this all of the time where I live and as I travel. I am deeply saddened when I read about homeless and hungry school-age children in my city, state, and nation. I am constantly exposed to evidence of huge quality of life disparities throughout the world.

Our world has the resources and capabilities to greatly improve the average quality of life of all of its people. Indeed, it has considerable progress during the past century. This problem requires a combination of thinking and acting at the local community, city, state, nation, and international levels. There is plenty for all of us to do.

At a local school level, ponder these questions:

- Why should any children come to school hungry, without adequate clothing and school supplies, and having spent a night without adequate shelter?
- Why should any children leave school at the end of the day facing a night without appropriate food and shelter?
- Why should any children be fearful of serious bullying, injury, or death as they travel to and from school, or spend time in school?
- Why should any students receive less than a good education due to inadequate school staffing and facilities?

You may want to add to the list. Each of us can learn about your local community. Each of us can begin to think and act locally to help address such problems. And, each of us can support governments that are committed to addressing such problems at city, state, national, and global levels.

What You Can Do

Think about your current **4th R** knowledge and skills. How do they compare to your level of knowledge and skills in the other three Rs? Discuss this same question with your students, children, colleagues, and so on. By doing so you will be making a contribution to helping the **4th R** become an everyday component of the daily lives of yourself and others.

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Chapter 4

Some Approaches to Improving Education

Based on *IAE Newsletter:* Issue 196, October 31, 2016.
See http://i-a-e.org/newsletters/IAE-Newsletter-2016-196.html.

> "The principal goal of education in the schools should be creating men and women who are capable of doing new things, not simply repeating what other generations have done." (Jean Piaget; Swiss philosopher, natural scientist, and educator, well known for his 4-stage theory of cognitive development; 1896-1980.)

> "Once you have learned how to ask relevant and appropriate questions, you have learned how to learn and no one can keep you from learning whatever you want or need to know." (From *Teaching As a Subversive Activity* by Neil Postman and Charles Weingartner, 1969.)

Improving Our Schools

I often am annoyed when I hear someone say our school-based educational system is not as good as it should be, and then proceed to tell me one or more changes they believe should be made in order to improve it. I am reminded of the quote:

> "There is always an easy solution to every human problem—neat, plausible, and wrong." (Henry Louis "H.L." Mencken; American journalist, essayist, editor; 1880-1956.)

There are certainly a very large number of areas in which changes could be made. These changes might be made in goals, curriculum content, pedagogy, assessment, computer facilities available to students, textbooks and other curriculum materials, teacher education, teacher working conditions, teacher pay, school building facilities, class size, number of counselors/advisors available to students, school breakfast and lunch programs, reducing poverty, head-start programs, after-school programs, length of school day, starting time of the school day, number of school days in a year, and so on and so on. In terms of improving education, all of these are interrelated and any change affects different stakeholders (students, teachers, school administrators, parents, tax payers, etc.) in different ways.

The book you are now reading suggests the addition of a **4th R** to the basics of education. When I (and many others) make such a suggestion, I am aware of what H. L. Mencken said about simple solutions to complex problems. However, the **4th R** is neither a simple nor an easy solution. Rather, it represents a difficult, complex change that will take much effort over many years to implement.

That is, education is a **very complex, multivariable endeavor**. Moreover, students and the world they live in are changing. For example, in the economically advanced nations of the world, children grow up with Smartphones, Web and Internet access, Social Networking, and computer games. These outside-of-school experiences certainly have a significant educational impact on our students.

This chapter cannot explore each of the huge number of possible change areas. Many have been tried and not one has proven to be a "magic pill." Indeed, that is not surprising, since education is such a complex system. For example, you know that the education of a child begins even before birth. Children have learned a great deal before they begin to attend school. How will the proposed **4th R** changes accommodate the huge differences in young students entering a PreK-12 school system?

For practice, let us focus on just one possible area of school change—the goals of education. Off the top of your head, pick one goal of education that you believe could/should be changed, and that the change would lead to an improvement in our educational system.

With that goal in mind, explore the following types of questions:

1. Can you, with confidence, name the current generally accepted goals of education in your country and school district? If you are going to propose a change, a good starting point might be to know the current goals. For a relatively stable and generally accepted set of goals of education in the U.S., see the article by David Moursund and Richard Ricketts (Moursund & Ricketts, 2013).
2. Why did you select the particular goal you proposed to be changed? What evidence do you have that the changes you propose will actually improve the generally accepted set of goals? How would you measure the improvements?
3. How would you and others go about implementing the changes you propose? For example, will others support the changes, are the changes possible to implement, what will the change cost, how long will change take, and so on?
4. What are some possible major flaws in what you are proposing? Can you give good arguments both for and against your proposed changes?

You know that we each have our own ideas about effective goals for education. Our current educational system represents a compromise among a large number of stakeholder groups. This system has many and diverse goals, many ways of helping students achieve these goals, and many ways to measure progress toward achieving goals. In total, education is a very complex and challenging human endeavor.

Consider just the issue of goal setting. People have their own ideas as to what constitutes a good education. Parents and other childcare providers each implement their own individual ideas as they care for and help to educate children. Teachers and other educators have their own ideas of what the goals should be, and how to implement them. Similar statements hold for the wide range of other stakeholders. In brief summary, setting goals, designing and implementing ways to achieve these goals, and measuring how well we are succeeding are not exact sciences. Education is not a factory-like manufacturing process.

Information Age and Knowledge Age

The Information Age in the United States began in 1956 when the number of white-collar jobs first exceeded the number of blue-collar jobs (Moursund, 2016a). The Knowledge Age in the United States began in 1991 when the U.S. spending for information technology hardware and software first exceeded the spending for Industrial Age capital goods.

For background information, see the article Learning, Technology, and Education Reform in the Knowledge Age by Bernie Trilling and Paul Hood (Trilling & Hood, May-June, 1999). Figure 4.1 below is from Trilling and Hood's article. It lists seven key human concepts (components, activities) of the Knowledge Age. Some of these can be done without the use of computers, while others are done by computers and humans working together.

Seven C's	Component Skills
Critical Thinking-and-Doing	Problem-solving, Research, Analysis, Project Management, etc.
Creativity	New Knowledge Creation, "Best Fit" Design Solutions, Artful Storytelling, etc.
Collaboration	Compromise, Consensus, Community-building, etc.
Cross-cultural Understanding	Across Diverse Ethnic, Knowledge, and Organizational Cultures
Communication	Crafting Messages and Using Media Effectively
Computing	Effective Use of Electronic Information and Knowledge Tools
Career and Learning Self-reliance	Managing Change, Lifelong Learning, and Career Redefinition

Figure 4.1. The seven C's: Knowledge Age survival skills.

Spend some time reflecting on the components of this 1999 table. Especially look for components relating to the 4th R. Do you think that our current PreK-12 educational systems are doing well in the Seven C's?

Some of My Education-related Beliefs

I tend to think about improving education in very general terms. During my long career as a teacher and writer, I have developed a simple set of beliefs that have served me well in my educational endeavors. These beliefs help me to analyze and understand our current educational system and proposed changes in curriculum content, pedagogy, and assessment.

I believe:

1. A unifying purpose of education is to help people improve the quality of their lives.
2. Learning is a natural (inherent, built-in) ongoing and lifelong process for all people. Schooling should stress learning to learn, and becoming an intrinsically motivated and independent learner.

3. All people have the right to a lifetime of rich and varied informal and formal learning opportunities. Schooling should be designed to help each person to develop and use his or her cognitive, physical, social, and emotional skills.
4. Each person is unique. Thus, we should be cautious about designing and implementing schooling content, pedagogy, and assessment processes and goals that "pretend" all students are nearly alike.
5. Problem solving is an underlying, unifying theme in all education. Through informal and formal education and experiences, people increase their abilities to solve the types of problems, accomplish the types of tasks, and make "considered" decisions in their work, play, interactions with other people, and other aspects of their everyday lives.

You undoubtedly have your own set of education beliefs. Our beliefs tend to be embedded in how we teach and in our own personal approaches to learning. Moreover, both you and I are likely aware that our beliefs do not provide enough detail to design a good educational system.

Problem Solving and Expertise

Of my five beliefs listed above, I have spent the most time and effort on problem solving (Moursund, 2014). Problems and problem solving include:

- Question situations: recognizing, posing, clarifying, and answering questions.
- Problem situations: recognizing, posing, clarifying, and solving problems.
- Task situations: recognizing, posing, clarifying, and accomplishing tasks.
- Decision situations: recognizing, posing, clarifying, and making good decisions.
- Using higher-order critical, creative, wise, and foresightful thinking to do all of the above. Often the results are shared, demonstrated, or used as a product, performance, or presentation.

Gaining an increased level of expertise in problem solving is an important goal in the study of any academic discipline. Quoting again from Moursund (2014):

> Each academic discipline or area of study can be defined by a combination of general things such as:
>
> - **The types of problems, tasks, and activities it addresses.**
> - Its accumulated accomplishments such as 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. 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, employable in the discipline; d) an expert; and e) a world-class expert.** [Bold added for emphasis.]

Thus, I believe that instruction in any area of study should be designed to help students move up an expertise scale such as the one given in Figure 2. I developed this scale many years ago and have found it quite useful in my teaching. I also find it useful as I observe myself while learning a new game or task.

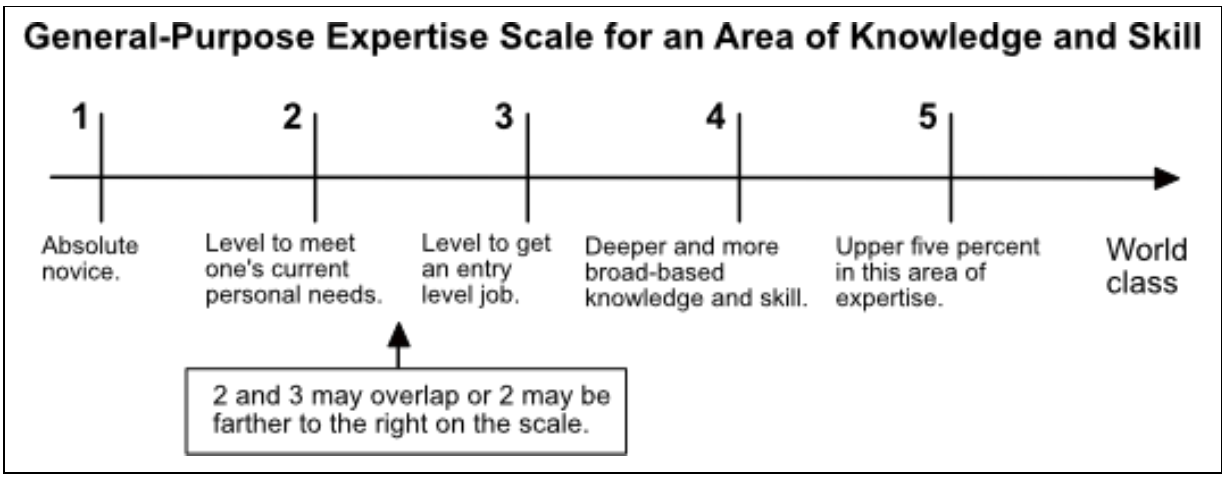

Figure 4.2. Expertise scale. It is not a uniform or linear scale.

Much is known about how to help students gain increased expertise in problem solving. Moreover, problem solving can be taught in a manner that cuts across disciplines—a manner in which there is considerable transfer of learning, both from one discipline to another and over time. Thus, while my comments about problem solving do not suggest specific goals for the various disciplines of study, they provide one approach to measuring the overall quality of education of students. **How well can students apply their knowledge, skills, and readily available cognitive and physical aids to solve the problems they encounter in their lives?**

Final Remarks

During the Industrial Age, people learned how to design, manufacture, and distribute better “widgets.” They also developed and implemented the idea of education for the masses. The educational systems that we now have are a legacy of a mass production approach developed during the Industrial Age.

Of course, educational goals and processes in content, pedagogy, and assessment have changed over the years to better accommodate changing needs of students and the world.

However, current rates of change in education are not keeping up with changes in our world. The Industrial Age has given way to the Information Age, and in the United States and a number of other countries we are in the Knowledge Age. The **4th R** is an essential component of the Knowledge Age.

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Learning to Do and Doing to Learn

Based on I*AE Newsletter:* Issue 201, January 15, 2017.
See http://i-a-e.org/newsletters/IAE-Newsletter-2017-201.html

Education has many goals. One of its fundamental and unifying goals is to help learners gain knowledge and skill that will be useful to them as they deal with problems and tasks they currently face or are likely to encounter in the future (Moursund, 4/19/2015). *Learning to learn* and *learning to make effective use of one's learning* cut across all disciplines of study.

I think of learning in terms of *Learning to Do* and then *Doing to Learn.* For example, students first *learn to read* and then they *read to learn.* This idea is fully integrated into our school system. In the United States, the expectation is that students will learn to read well enough by the end of the third grade so that reading across the curriculum can become a useful aid to their future learning across the curriculum. Long ago when I was in middle school (junior high school), the general plan was that more than half of school learning would come via reading.

A lot has changed since then. Not only do we have interactive computerized reading materials, we also have greatly improved video aids to learning. In some sense, reading has expanded to be reading and using other visual aids to obtaining information.

This *IAE Newsletter* considers the **4 Rs** (**R**eading, '**R**iting, '**R**ithmetic/math, **R**easoning/computational thinking) and explores some of its *Doing to Learn* aspects. See my free book, (Moursund, December, 2016). My goal is to help make schooling more relevant to students (Moursund, 8/7/2014).

Reading and Writing

In this section I explore *learning* to read and write and then *doing* reading and writing to gain greater skill in reading and writing.

Reading and writing are human inventions—tools that one can learn to use. Over thousands of years, people have worked on the task of how to effectively help children learn to read. Nowadays, parents and other child caregivers are strongly encouraged to start this instruction for infants, and to continue reading to and reading with their children up through the first few grades of school.

As children begin preschool, they receive group instruction in reading. For most students, group instruction provided by schools is reasonably effective, but not as effective as one-on-one instruction provided by a parent, caregiver, or tutor.

Instruction in writing may also be initiated at home by parents and other child caregivers. However, very young children lack the hand-eye coordination that writing using pencil/pen and paper requires. But wait! Now quite young children can access a tablet computer or child-oriented toy that has a keyboard. A keyboard overcomes the hand-eye coordination problem and facilitates very early learning of writing.

Moreover, the tablet computer or educational toy a child is playing with can provide oral instruction and various types of feedback. While not the same as (not as good as) a one-on-one human teacher, clearly we can now make use of components of the 4th R at the preschool level to help a child get started in reading and writing. Teachers—even at the preschool level—now have to deal with some children who have had this early computer-assisted instruction aid to learning reading and writing.

A learner progresses in learning reading and writing by *doing* reading and writing. An essential aid to this progress is feedback. Consider a child who is not hearing impaired. The child can provide self-feedback. Learner-appropriate reading material contains words and content ideas that are part of the learner's oral language. The child ask: "Does what I have just read make sense to me?" Computer-assisted instruction can also provide feedback. Such a learning aid instruction can read individual words, sentences, or the whole passage to a learner.

In summary, reading and writing are powerful aids to communication, writing, and thinking. Computers can now play a significant role in reading and writing instruction as well as in using one's reading and writing skills.

Arithmetic (Math)

To parallel the discussion of the previous section, I will use the vocabulary *learning to math* and *mathing to learn.* We all have personal experience in learning to do arithmetic and other aspects of mathematics. Math is a required component of schooling typically up through three years of high school mth and continues to be required of many students even in the first year of their college undergraduate work. At all levels of instruction, teachers and their instructional materials attempt to in include uses of the math they are teaching. Math is taught both as a discipline in its own right and as a tool that is useful in doing things outside of the school classroom math environment.

My observation is that most math instruction is weak in the area of *mathing to learn* math and non-math disciplines. Part of the difficulty is that "real world" applications of math tend to be above the math knowledge and skills a student has acquired by the time such challenges occur. For example, consider pie charts (circle graphs) that illustrate and make use of parts of a whole. These are visually and somewhat intuitive to second graders. But actually creating pie charts requires math content taught at the fourth and fifth grades. Contrast this with the ease of use of software designed for the task. A second grader can learn to use this software. The computer technology is used to invert the order of the traditional pie chart curriculum. My colleague James Fey developed the idea of an inverted curriculum in the early 1980s (Fey, 1984; Moursund, 1/11/2015).

Learning 4th R Tools and Using 4th R Tools to Learn

In this section I use the expressions *Learning to ICT* and *ICTing to Learn.* This is hugely important to education. For a simple example, consider a film camera and a digital camera. Film is relatively expensive and usually takes several days to get commercially developed. A digital photograph costs nothing (once one has a digital camera) and is available instantly. Even a preschool child can use a digital camera, such as one built into a Smartphone. Think about learning to take digital photographs and taking digital photographs to learn about photography and in the study of many other subject areas.

In addition, there are a variety of computer-assisted instruction programs designed to help teach photography. These are learning by doing computer simulations that provide an excellent environment for learn by doing and making use of feedback from one's own eyes (CameraSim n.d.; Canon, n.d.).

For a more dramatic example, see Virtual Reality in the Science Lab (Moursund, 6/5/2016). This IAE Blog entry begins with a *learn by doing* quotation:

> "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead give them a tool, the use of which will lead to new ways of thinking." (Richard Buckminster Fuller; American engineer, author, designer, inventor, and futurist; 1895-1983.)

The emerging Maker Culture and Maker Movement provide good examples of learning by doing. Computer technology empowers students of all ages to use their talents invent and make new things (Wikipedia, n.d.). Quoting from that source:

> The maker culture is a contemporary culture or subculture representing a technology-based extension of Do It Yourself (DIY) culture that intersects with hacker culture (which is less concerned with physical objects as it focuses on software) and revels in the creation of new devices as well as tinkering with existing ones. The maker culture in general supports open-source hardware. **Typical interests enjoyed by the maker culture include engineering-oriented pursuits such as electronics, robotics, 3-D printing, and the use of Computer Numeric Control tools, as well as more traditional activities such as metalworking, woodworking, and, mainly, its predecessor, the traditional arts and crafts.** The subculture stresses a cut-and-paste approach to standardized hobbyist technologies, and encourages cookbook re-use of designs published on websites and maker-oriented publications. **There is a strong focus on using and learning practical skills and applying them to reference designs.** [Bold added for emphasis.]

Final Remarks

Information and Communication Technology is providing powerful aids to both learning and doing. Many of these aids can be used by relatively young students, and many suggest needed restructuring of both the content and the order of the traditional curriculum.

All teachers face questions such as "Why do I have to learn this?" and "What's it good for?" I believe we educators can help answer such questions by developing curriculum that has an increased emphasis on doing—students making use of what they are learning. The 4th R can be smoothly integrated into curriculum content, instructional processes, and assessment at all grade levels. This can be done in a manner that em[powers students—helps them to solve problems and accomplish tasks that they consider relevant.

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Chapter 6

A Personal Philosophy of Computers in Education

Based on I*AE Newsletter:* Issue 199, December 15, 2016.
See http://i-a-e.org/newsletters/IAE-Newsletter-2016-199.html

> "Mankind owes to the child the best it has to give." (United Nations Declaration of the Rights of the Child, 1959.)
>
> "Imagine a school with children that can read or write, but with teachers who cannot, and you have a metaphor of the Information Age in which we live." (Peter Cochrane; United Kingdom engineer, technologist, and entrepreneur; 1950-.)
>
> "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead give them a tool, the use of which will lead to new ways of thinking." (Richard Buckminster Fuller; American engineer, author, designer, inventor, and futurist; 1895-1983.)

This current chapter explores the idea that each educator has a personal philosophy of education. For today's educators, it is important that this philosophy include the appropriate roles of Information and Communication Technology (ICT)—and especially the **4th R**—in education. This chapter draws heavily from a talk I gave in 2006, and I have been working on the topic ever since (Moursund, February, 2006). My thinking continues to evolve.

The Quotations Given at the Beginning of this Chapter

I like to collect and use poignant quotations that are representative of my beliefs (Moursund, 2016b). The three quotations given above provide some insight into my current philosophy of Computers in Education. Think about some ideas that occur to you as you ponder each quotation. Doing so will help you to gain insight into your current personal philosophy of education and computer technology in education.

Walt Disney's Magic Kingdom popularized the song *It's a Small World* written by Richard M. Sherman and Robert B. Sherman. Here is a small piece of the song:

It's a world of laughter
A world of tears
It's a world of hopes
And a world of fears
There's so much that we share
That it's time we're aware
It's a small world after all

Probably the tune is now going through your head. If not, you can listen to the tune at http://www.niehs.nih.gov/kids/lyrics/smworld.htm. Want to learn more about Disneyland? Short video clips are available at http://www.gofox.com/vacations/dlexplore.php?explore=Clips. Does it seem a little strange to you that a person can be reading an article from a computer screen, click on a piece of the article, and almost immediately be listening to a tune or viewing video clips that help the article to communicate more effectively? Probably not strange to you, and almost undoubtedly not strange to the many children throughout the world now growing up in this online environment. For these children, it is the new norm—the world has indeed become "a small world".

I strongly believe today's modern education must fully incorporate the steadily growing capabilities of ICT and the Web. I think of the Web as a library of the accumulated work of humankind. In the words of Albert Einstein:

> "A hundred times every day I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving." (Albert Einstein; German-born theoretical physicist and 1921 Nobel Prize winner; 1879-1955.)

Perhaps Einstein was exaggerating, but his statement raises an important idea. In our day-to-day activities we depend on and build on the previous work of others. For example, a few minutes ago I turned on my computer. It draws electricity from a huge electrical generation and distribution system. The hardware and software of my computer represent the works of thousands of researchers, developers, and distributors. I think it is a good idea to thoroughly integrate this sense of our indebtedness to countless others into our educational systems.

Developing a Personal Philosophy of Education

Many years ago, some of my Computers in Education graduate students told me about a course they were taking, one in which they were required to develop a personal philosophy of education. They said it was one of the most useful assignments they had ever been asked to do. I remember sort of laughing at the time—who needs to write down a philosophy of education? Or, perhaps it was an embarrassed laugh. I had never given thought to my own philosophies of teaching math, computer science, and computers in education.

I have gradually matured over the years and now realize the value of that assignment. Consider two very different philosophies of computers in education that I recently encountered while talking with two of my friends. The first said his philosophy of education is that teaching and learning are personal, human things. He believes that the heart of teaching and learning is the face-to-face interaction among students and teachers. In his opinion, distance education (online education via computer) has inherent weaknesses because a computer is not a human being.

The second friend said that computers are an extension to the human brain—a tool designed to supplement and extend the capabilities of a human brain. Much in the way that we integrate into our curriculum and daily lives the tools that aid our physical capabilities, we need to also integrate into our curriculum and daily lives the tools that aid our cognitive capabilities. We have certainly done that with reading and writing.

I believe there is considerable merit in both of these views. What are your own thoughts, and how have they evolved over time? This is a key question. Presumably, many of your actions and deeds are based on your personal philosophy. As the world changes, does your personal philosophy evolve? Are you flexible in your thoughts and deeds? Or you "stuck in a rut"?

Over the years, I have listened to many educators express their own philosophy of computers in education by saying, “Computers are here to stay”. I cringe when I hear that statement, because it typically is followed by a quite shallow statement of the person’s insights into the many possible and effective applications of computers in education.

For such people, I wonder about their philosophy of education in other areas of study. Have you ever heard a person say, “My philosophy of mathematics in education is that mathematics is here to stay”? How about other statements such as “reading and writing are here to stay” or “history is here to stay”?

Surely, we can expect more than that from education professionals! I hope you agree with me that such superficial statements are not particularly useful in guiding a teacher in performing everyday tasks of curriculum development, teaching, and assessment, in addition to interacting with students, parents, colleagues, and so on.

I have for many years argued that ICT has the potential to greatly improve our educational systems. Not only are computers here to stay, they will eventually revolutionize both the content and the processes of education. The remainder of this chapter is designed to help all educators (including parents, teachers, school administrators, and teachers of teachers) understand that they need to develop a forward-looking philosophy of ICT in education that is designed to prepare today’s students for their futures.

Keep in mind the fact that children tend to build their own philosophies from those of the adults they interact with. One characteristic of a good (human) teacher or parent is being a good (human) role model.

Your Beliefs

I am an old timer in the field of Computers in Education, having spent more than 50 years working in this discipline (Moursund, 2002; Moursund, 2016a). Over these years, I have gradually developed a personal philosophy that helps to guide me in my teaching, writing, consulting, and presentations. I want to share some of my ICT ideas and philosophy with you, and I strongly encourage you to examine/develop your own personal philosophy of computers in education.

You undoubtedly have beliefs about education based on your upbringing, education, and life experiences. Here are some of mine:

I believe:

- A good education is an appropriate balance between developing “people-oriented” knowledge and skills, and learning to make effective use of the tools people have developed to augment and increase our physical and cognitive capabilities. We solve problems and accomplish tasks through using a combination of the capabilities of people and the capabilities of the tools that people have developed.
- The **4th R** of Information and Communication Technology (ICT) and other technology-based change agents can be used to make major improvements in the world’s (and our country’s) educational systems. This **4th R** is as important as the first three Rs.

- All of the our world's children deserve the opportunity to gain a high-quality education that includes learning to make effective use of routine access to the communication facilities and knowledge base provided by the Internet and Web.
- Artificial Intelligence (including computerized robots and other tools) is a very powerful change agent. A modern education helps to prepare students for a life in which such computerized tools perform or help to perform more and more of the jobs that human workers are currently performing. They will also play an increased role in our avocations and other aspects of our everyday lives.

I can easily expand my list of education-related beliefs. Over the years, in my professional career, I have developed habits of mind that incorporate these beliefs. I hope that you will make your own list of education-related beliefs, giving special attention to the **4th R** role of ICT in education. As you develop and come to understand the ramifications of your list, I hope that you will build your beliefs into a philosophy of education that will effectively serve both yourself and the students you help to educate.

Final Remarks

A person's life is shaped by both nature (one's genes) and nurture (informal and formal education; life experiences). For a newborn, most life experiences are new—they present opportunities to learn new things. Soon, however, an infant develops a knowledge and experience base, and this continues to grow throughout a lifetime. While a child's perceived world continues to change from day to day, gradually there is less "new" and more "same o', same o'".

As most adults age, there is a gradual decrease in ability and/or desire and willingness to cope with change. Thus, for example, we see children mastering the learning of a second or third natural language, and learning to make relatively sophisticated use of new computer technologies, while many adults struggle in such endeavors.

A forward-looking educational system helps a student to learn and to develop habits of mind that will support lifelong learning. These habits of mind need to include a personal philosophy of lifelong learning to meet one's changing personal needs as one becomes and remains a responsible, contributing adult in our changing world.

Parents, guardians, and teachers serve as role models for children. I strongly encourage you to examine your personal philosophies of dealing with change as part of the role model you are setting for children and others.

How well do you know and understand your own philosophy of education? Remembering that we are all lifelong teachers and lifelong learners, what do you do as a teacher to help others to develop a philosophy of education and habits of mind that will best serve them and our world?

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Part 2: Appendices

Preface to Part 2

Since its inception, IAE has published more than 300 *IAE Blog* entries (*IAE Blog,* 2017). This Appendix consists of eight *IAE Blog* entries that I believe supplement and help to explain various ideas covered in chapters 1-5. I have made small corrections and additions to the original versions of these blog entries.

The first Appendix provides an overview of problem solving and creative problem solving, background information that will be useful to many readers of this book.

The second Appendix discusses reinventing our educational systems. Fully integrating the **4th R** into our schools, from the PreK level through graduate school, would certainly constitute a reinvention!

The third Appendix focuses on Quality of Life. For me, this is a very important topic. In the same sense that I consider a good education to be a birthright, I believe that a decent quality of life is also a birthright.

This is not to say that I believe that each person will obtain the same (good) education and that each person will have the same (good) quality of live. However, I strongly believe that a good education tends to contribute to a person's quality of life. Thus, as we work to improve education, we need to think carefully about how the changes we propose will contribute to the quality of life of students, staff, parents, and others.

The fourth Appendix explores virtual reality (VR). VR is already here. It is beginning to be a powerful force in entertainment, and it certainly has the capabilities of being a powerful aid to education.

The fifth Appendix proposes the possibility that computers will eventually become more intelligent than humans. What will it do to the quality of life of humans if this actually happens? We know that some aspects of this have already occurred. For me, the GPS provides an excellent example. I have a very poor sense of direction and my GPS "gets me there" with much less difficulty than I can manage alone.

The sixth Appendix presents the issues of information underload and overload. ICT adds to our information overload, but also helps us to better deal with this overload. The **4th R** must address the issue of what do we want students to memorize and what do we want them to be able to "look up", understand, and effectively use in a timely fashion.

The seventh Appendix discusses the idea that each teacher—indeed, all of us—might benefit by having a personal, computerized *digital filing cabinet* designed and organized to fit our own individual information storage and retrieval needs.

The eighth Appendix discusses some of the changes that Information and Communication Technology has brought to mathematics. The blog draws on an article by Keith Devlin, a leading math educator. It presents the argument that ICT should be integrated into the math and other curriculum areas starting at the earliest levels of formal schooling. It also stresses the need for lifelong learning if one wants to "keep up" in any discipline of study.

The ninth and last Appendix provides links to many valuable sources of information. It has been specifically designed for use by teachers.

References and Resources

IAE Blog (2017). *Information Age Education Blog* entries. Retrieved 2/5/2017 from http://i-a-e.org/iae-blog.html.

Appendix 1: Assessing and Teaching Creative Problem Solving

Most of the content of Appendix 1 has been previously published in the two sources given below.

> Moursund, D. (9/6/2014). Assessing and Teaching Creative Problem Solving. *IAE Blog.* Retrieved 12/5/2016 from http://i-a-e.org/iae-blog/entry/creative-problem-solving.html.
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> Moursund, D. (2016). Problem Solving. *IAE-pedia.* Retrieved 12/5/2016 from http://iae-pedia.org/Problem_Solving.

Background Information

Throughout my professional career I have been interested in studying and teaching about problem solving. Most of the content of this appendix is from the first reference given above. However, this background information about problems solving section is from the second reference.

A Discipline of Study

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

- The types of problems, tasks, and activities it addresses.
- Its accumulated accomplishments such as 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. 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, employable in the discipline; d) an expert; and e) a world-class expert.

What Is a Problem?

Here is a definition of "problem" that fits well in many different disciplines. 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, the telecommunication system, computers, friends, teachers, and so on. There may be specified limitations on resources, such as rules, regulations, guidelines, and time lines 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.

We use the term *problem situation* to refer to a problem-like situation in which one or more of the four components listed above are missing.

Problem solving includes:

- Question situations: recognizing, posing, clarifying, and answering questions.
- Problem situations: recognizing, posing, clarifying, and then solving problems.
- Task situations: recognizing, posing, clarifying, and accomplishing tasks.
- Decision situations: recognizing, posing, clarifying, and making good decisions.
- Using higher-order critical, creative, wise, and foresightful thinking to do all of the above. Often the results are shared, demonstrated, or used as a product, performance, or presentation.

In many problem-solving situations, Information and Communication Technology (ICT) and computerized tools are resources of the type mentioned in #3 of the four-part definition. These resources have grown more powerful over the years. That is one reason why the **4th R** is so important. I strongly believe we must integrate teaching the use of computers in problem solving thoroughly into the basic fabric of academic courses across the curriculum.

Item #4 in the definition of a problem is particularly important. Unless you have ownership—through an appropriate combination of intrinsic and extrinsic motivation—you do not have a problem. Motivation, especially intrinsic motivation, is a huge topic in its own right.

For example, you glance at the headlines in your local newspaper and see that a drought in a particular country in Africa is causing widespread hunger. Hundreds of thousands of people are on the verge of starvation.

This hunger and starvation situation meets the first three components of the definition of a problem. Moreover, the story touches your heart. But what—if anything—can or will you do about it? It is one thing for a problem situation to touch your heart. It is another situation entirely for you to make a decision to commit some of your resources such as time and money to do something about helping to solve the problem.

Now, think about the types of "problems" that we assign students in school. Many students look at the tasks assigned as homework and mentally respond, "I couldn't care less. These are just make-work busy work—a hoop that I am supposed to jump through." That is, these students have no ownership of the problem.

A good teacher creates learning situations in which students are willingly engaged in working on problems and tasks that they believe to be personally relevant and important.

Creative Problem Solving

(Note: This section is quoted from Moursund (9/6/2014) listed at the beginning of this Appendix.)

Informal and formal education—along with personal drive and a number of other factors—enter into how well people develop and use their natural curiosity and creativity (Moursund, 12/24/2010). Each of us can help our self and the people with whom we interact to become better at creative problem solving. Quoting from the Wikipedia:

> **Creativity** is a phenomenon whereby something new and valuable is created (such as an idea, a joke, an artistic or literary work, a painting or musical composition, a solution, an invention etc.).

This is a very broad definition. When I think a thought and express it orally or in writing, this is an act of creativity. The thought doesn't have to be new to others or to the whole world. Similarly, when I am faced by a problem that is a challenge to me and I manage to solve the problem, I consider this to be an act of *creative problem solving*.

Thus, we are all creative problem solvers. Through informal and formal education and practice, we become better at it.

The 2014 PISA Assessment

The most recent Program for International Student Assessment (PISA) was designed to measure 15-year-olds in math, science, and reading. In addition, it was designed to measure *creative problem solving.*

Quoting Holly Yettich from the article U.S. Students Score Above Average on First PISA Problem-Solving Exam (4/1/2014):

> U.S. 15-year-olds scored above average on a first-of-its-kind international assessment that measured creative problem-solving skills.
>
> …
>
> The assessment, which was the subject of an Organization for Economic Cooperation and Development (OECD) report released Tuesday, **defined creative problem-solving as the ability to "understand and resolve problem situations where a method of solution is not immediately obvious."**
>
> …
>
> U.S. performance was especially strong on tasks designed to measure interactive problem solving, which requires students to find some of the information they need on their own. [Bold added for emphasis.]

After reading Yettich's article, I did a search of my own IAE-published writings for the term *creativity*. I was somewhat surprised to see that I have used that term in 27 of my *IAE Blog* entries. In addition, I have recently added a section on creativity to my Brain Science entry in the *IAE-pedia* (Moursund, 2014a).

There is considerable literature on teaching creative problem solving. My 9/3/2014 Google search of the expression *teaching creative problem solving* produced nearly 4 million results. At every level of education, teachers integrate creative problem solving into the courses they teach. Many schools teach separate courses on creative problem solving (coursea, 2014).

Teaching Creative Problem Solving

Each discipline of study focuses on solving problems and accomplishing tasks within a limited area. The problems and tasks in the fine and performing arts are different from the problems and tasks in the sciences or in the humanities/social sciences.

A student studying in a particular discipline is faced by the challenge of the huge and steadily growing accumulation of knowledge and skills in that discipline. One approach to studying a discipline is to study some of the problems that it has already solved. This approach includes developing some "basic skills" within the discipline. The study of discipline-specific basic skills types of problems can provide students with a beginning level of understanding of how the discipline deals with some of its most important problems and tasks.

Another approach is to learn for understanding and to practice on challenging problems that stretch one's current knowledge and skills within a discipline. The goal is to move beyond basic skills—to learn to deal with novel, challenging problems within the discipline.

A curriculum driven by high-stakes testing tends to take the former approach, and a curriculum designed to teach understanding and creative problem solving tends to take the latter approach. Both of these approaches are important, and students have varying levels of strengths, weaknesses, and personal preferences in these two general approaches to learning.

Each discipline of study has its own approaches to teaching creative problem solving. (See http://iae-pedia.org/Problem_Solving.) Thus, for example, suppose that you are interested in teaching math. Both physical and virtual math manipulatives are a powerful aid to teaching and learning math. Within this environment it is possible for teachers to pose problems that challenge a wide range of students and that encourage creative problem solving (Kelly, July, 2006; Lepi, September, 2014).

The steadily increasing capabilities of computer-based information retrieval systems tends to decrease the advantages of becoming very good at rote memorization and to increase the value of creatively attacking and solving novel problems.

Higher-order and Lower-order Skills

Benjamin Bloom (1956) chaired a committee that developed the taxonomy that bears his name and also edited the first volume of the 1956 text, *Taxonomy of Educational Objectives: The Classification of Educational Goals.* (See http://en.wikipedia.org/wiki/Bloom%27s_taxonomy.) In the initial publication, the cognitive domain was divided into Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. The first three levels are considered to be "lower order" and the second three are considered to be "higher order." While the definitions have been somewhat modified over time, the basic ideas have held up well. (See http://www.nwlink.com/~donclark/hrd/bloom.html.)

Benjamin Bloom and his colleagues were bothered by the fact that much of the college teaching at their time focused on lower-order skills. Nowadays, there is a strong trend toward placing increasing emphasis on higher-order skills at both the precollege level and in higher education.

I am particularly interested in approaches to teaching and learning for creative problem solving that are useful in many different disciplines. The next four sub-sections provide examples I have frequently used in my own teaching.

Assess Your Students' Insights

Think about a group of students that have varying levels of expertise (varying levels of knowledge and skill) in an area in which you will be teaching them a sequence of lessons (Moursund, 2014b). What problems, tasks, and questions will the students learn to successfully deal with through the unit of study? You are particularly interested in improving their creative problem-solving knowledge and skills. In what follows, I use the term "problem solving" to include solving problems, accomplishing tasks, and answering questions.

A good starting point is to assess their current level of knowledge and skills. Ask your students to spend a few minutes writing down two types of problems, tasks, and questions about this area of study:

1. Problems (problems, tasks, questions) that they think they can solve, but ones they consider to be "hard." For example, you can encourage them to pose problems that they can solve but that they believe some/many of their classmates cannot solve.
2. Problems (problems, tasks, questions) that they would like to be able to solve by the end of the unit of study.

Have students share some of their examples in small groups. While they are doing this, wander around the classroom and listen to their ideas. Then have a whole class discussion in which you draw on students' ideas and integrate these into your goals for the unit of study.

Posing Researchable (Possibly Answerable) Questions

In my university-level teaching, I wanted my students to understand and make use of the concept of a researchable (possibly answerable) question. Here are two general, and somewhat overlapping, categories of such higher-order questions:

1. A question that is possibly answerable by research and analysis based on the current accumulated and reasonably accessible knowledge of the human race.
2. A question that is possibly answerable through the design and implementation of a research study designed to add new knowledge to the accumulated human knowledge. Typically such research begins with a literature search making use of the Web and other readily available resources.

This type of question posing activity can be carried out with students at any school level. As students progress in school, they can become better at posing and learning how to answer higher-order questions.

Wait Time

When you are about to ask your class a question, first think about how much time you will wait before you take an answer. This is called **wait time.** The types of questions that lead to an immediate popping up of hands are almost always lower-order.

Substantial research on **wait time** has been available for many years. Quoting from Mary Budd Rowe (1986):

> This paper describes major outcomes of a line of research begun nearly 20 years ago by the author on a variable called wait time. To put it briefly, when teachers ask questions of students, they typically wait 1 second or less for the

> students to start a reply; after the student stops speaking they [teachers] begin their reaction or proffer the next question in less than 1 second. If teachers can increase the average length of the pauses at both points, namely, after a question (wait time 1) and, even more important, after a student response (wait time 2) to 3 seconds or more, there are pronounced changes (usually regarded as improvements) in student use of language and logic as well as in student and teacher attitudes and expectations.

In my own teaching of teachers, I frequently ask a question and then orally analyze the extent to which it is higher-order before I accept an answer. This wait time and analysis helps my students gain insights into what I call higher-order questions, and it gives them time to think about an answer.

Group Brainstorming

Brainstorming in groups is an activity designed to encourage higher-order, "divergent" thinking. Quoting from the Wikipedia:

> **Brainstorming** is a group or individual creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its member(s). The term was popularized by Alex Faickney Osborn in the 1953 book *Applied Imagination.* Osborn claimed that brainstorming was more effective than individuals working alone in generating ideas, although more recent research has questioned this conclusion. See: http://en.wikipedia.org/wiki/Brainstorming - cite_note-DiehlStroebe61-1.

Here is information supporting the last sentence quoted above. Quoting from an article in *The New Yorker* titled Groupthink (Lehrer, 1/30/2012):

> The underlying assumption of brainstorming is that if people are scared of saying the wrong thing, they'll end up saying nothing at all. The appeal of this idea is obvious: it's always nice to be saturated in positive feedback. Typically, participants leave a brainstorming session proud of their contribution. The whiteboard has been filled with free associations. Brainstorming seems like an ideal technique, a feel-good way to boost productivity. **But there is a problem with brainstorming. It doesn't work.** [Bold added for emphasis.]
>
> …
>
> Brainstorming didn't unleash the potential of the group, but rather made each individual less creative. Although the findings did nothing to hurt brainstorming's popularity, numerous follow-up studies have come to the same conclusion. Keith Sawyer, a psychologist at Washington University, has summarized the science: "Decades of research have consistently shown that brainstorming groups think of far fewer ideas than the same number of people who work alone and later pool their ideas."

What You Can Do

Develop a personal definition of creative problem solving that fits well into your professional and personal life. As you go through a day, stop occasionally to reflect on the types of problems you are dealing with at that time, and the creativity you are using to deal with these problems. What do you do in an "ordinary" day to improve your own creative problem-solving skills? Then think about what you are doing to help others—such as your students and colleagues—to reflect on and improve their creative problem-solving skills.

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Appendix 2: Reinventing Our Educational System

Moursund, D. (8/26/2016). Reinventing Our Educational System. *IAE Blog.* Retrieved 11/30/2016 from http://i-a-e.org/iae-blog/entry/reinventing-our-educational-system.html.

Many people working to improve our educational system appear to be looking backward. They fix on measures of success that were deemed worthy in the past, and strive to have our schools perform still better in meeting these measures.

However, the world is changing, and many of these past measures of success are becoming less important for today's children. Tony Wagner is one of my favorite authors currently writing about needed changes. Quoting from a 2010 *IAE Newsletter* (Moursund & Sylwester, June, 2010):

> Tony Wagner (2008) is a professor in the Harvard Graduate School of Education and co-director of the Change Leadership Group. In his work, he distinguishes between students gaining competencies (knowledge) in various disciplines and students developing habits of mind.
>
> …
>
> Throughout his book, Wagner stresses seven Survival Skills that he feels need to be major drivers in a modern education.
>
> A1. Critical thinking and problem solving.
>
> A2. Collaboration across networks and leading by influence.
>
> A3. Agility and adaptability.
>
> A4. Initiative and entrepreneurism.
>
> A5. Effective oral and written communication.
>
> A6. Accessing and analyzing information.
>
> A7. Curiosity and imagination.

Notice that none of these is discipline specific. Wagner argues that each discipline-specific course should be a vehicle for helping students to develop these **interdisciplinary habits of mind.**

In a *TEDx Talk,* Wagner emphasized that knowledge is now a commodity, What the World Cares about Is Not What You Know, But What You Can Do with What you Know." (Wagner, April, 2012). In his talk, he emphasizes the seven points A1-A7 above.

Still more recently, the article Mindshift (8/25/2015) contains a few minor modifications in Wagner's list. In this Mindshift list that follows, I have added my current insights.

To be successful lifetime learners, young people need to learn to:

B1. Formulate good questions.

Moursund comment: Problem posing is the first step in A1 given above. Notice the shift in emphasis from having students answer questions posed by teachers and others, to having students pose question of personal interest—questions in which they have some ownership. Ownership is a key idea in education. See my *IAE-pedia* article on Problem Solving (Moursund, 2015).

B2. Communicate in groups and lead by influence.

Moursund comment: This is a variation on 2A given above. Solving problems and accomplishing tasks often involves collaboration of a group and leaders who can influence others to work together toward a common goal. Nowadays, this routinely involves electronic communications and use of (collaborating with) computers. The idea of collaborating with an artificially intelligent machine adds a new dimension to problem solving.

B3. Be mentally agile and adaptable.

Moursund comment: Among other things, this requires being open to change and to learning to make effective use of the growing human knowledge and the tools for using this knowledge. Students need to learn the capabilities and limitations of their brains working alone, working in groups, and working with the aid of computers. See my book on *Brain Science for Educators and Parents* (Moursund, August, 2015).

B4. Take initiative and be entrepreneurial.

Moursund comment: Each of us has capabilities that we can learn to use to improve our own lives and the lives of others. Using a very broad definition of being entrepreneurial, these are entrepreneurial activities. I personally like to think about the idea of using one's own initiative and entrepreneurship to help improve quality of life for one's self and others.

B5. Have effective written and oral communication skills.

Moursund comment: The Internet and Web provide us with new tools for oral, written, and graphical communication. Our educational system is being slow to appreciate and make use of how readily children adapt to and enjoy using these new tools.

B6. Know how to access and analyze information.

Moursund comment: See the sequence of *IAE Newsletters* on Credibility and Validity of Information (Moursund & Sylwester, 2014-2015).

B7. Be creative and imaginative.

Moursund comment: Young children have a great deal of creative ability and wild imaginations. Our current educational system is weak in fostering and building on this innate creativity and imagination. See chapter 6 of my book, *Brain Science for Educators and Parents* (Moursund, August, 2015).

What You Can Do

You undoubtedly have heard about the idea of a military-industrial complex. Quoting from the Wikipedia:

> The term is most often used in reference to the system behind the military of the United States, where it gained popularity after its use in the farewell address of President Dwight D. Eisenhower on January 17, 1961.

We now have a very large and powerful **commercial-political educational complex** that is becoming increasingly commercialized and is highly resistant to the type of changes proposed by Tony Wagner. However, a large and important component of education is informal (determined by parents and students) and another large and important component is still determined by individual teachers. Parents, teachers, and individual students can be guided by Wagner's ideas. Think carefully about what you are currently doing and what you can continue to do in this very important endeavor!

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Appendix 3: Improving Worldwide Quality of Life

Moursund, D. (2/12/2016). Improving Worldwide Quality of Life. *IAE Blog*. Retrieved 11/25/2016 from http://i-a-e.org/iae-blog/entry/improving-worldwide-quality-of-life.html.

I have discussed Quality of Life (QoL) in two previous *IAE Blog* entries (Moursund, 2/5/2016; Moursund, 12/24/2014).

While we each have our own ideas on how to measure and improve our own quality of life, considerable progress has occurred in developing global measures and goals. A Social Progress Index has been developed. Quoting from the Social Progress Index website (n.d.):

> MEASURING NATIONAL PROGRESS – To truly advance social progress, we must learn to measure it, comprehensively and rigorously. The Social Progress Index offers a rich framework for measuring the multiple dimensions of social progress, benchmarking success, and catalyzing greater human wellbeing. The 2015 version of the Social Progress Index has improved upon the 2014 version through generous feedback from many observers and covers an expanded number of countries with 52 indicators.

Michael Green is part of the team that has created the Social Progress Index, a standard to rank societies based on how they meet the needs of citizens. Quoting from his recent *TED Talk,* How We Can Make the World a Better Place by 2030 (Green, October, 2015):

> Do you think the world is going to be a better place next year? In the next decade? Can we end hunger, achieve gender equality, halt climate change, all in the next 15 years?
>
> Well, according to the governments of the world, yes we can. In the last few days, the leaders of the world, meeting at the UN in New York, agreed on a new set of Global Goals for the development of the world to 2030.… [These] goals are the product of a massive consultation exercise. The Global Goals are who we, humanity, want to be.

United Nations Global Goals

Quoting from the Preamble to the UN Global Goals, How We Can Make the World a Better Place by 2030 (UN Global Goals, 8/12/2015):

> This Agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom. We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development.
>
> All countries and all stakeholders, acting in collaborative partnership, will implement this plan. We are resolved to free the human race from the tyranny of poverty and want and to heal and secure our planet. We are determined to take the bold and transformative steps that are urgently needed to shift the world on to a sustainable and resilient path. As we embark on this collective journey, we pledge that no one will be left behind

How to Achieve the UN Global Goals

The first part of Michael Green's 2015 *TED Talk* discusses a previous set of UN goals. Quoting from his talk:

> Back in 2001, the UN agreed to another set of goals, the Millennium Development Goals. And the flagship target there was to halve the proportion of people living in poverty by 2015. The target was to take from a baseline of 1990, when 36 percent of the world's population lived in poverty, to get to 18 percent poverty this year.
>
> Did we hit this target? Well, no, we didn't. We exceeded it. This year, global poverty is going to fall to 12 percent. Now, that's still not good enough, and the world does still have plenty of problems. **But the pessimists and doomsayers who say that the world can't get better are simply wrong.** [Bold added for emphasis.]

This is huge progress. But with the current (December, 2016) world population in excess of 7.3 billion, the 12% figure represents well over 800 million children living in poverty. Each country has its own definition of what constitutes living in poverty. In the United States, the National Center for Children in Poverty estimates that in 2016, about 20% of American children were living in poverty (NCCP, 2016).

At the Millennium Summit in September, 2000, the largest gathering of world leaders in history adopted the UN Millennium Declaration, committing their nations to a new global partnership to reduce extreme poverty and setting out a series of time-bound targets, with a deadline of 2015, that have become known as the Millennium Development Goals. Quoting from (UN, n.d.):

> The Millennium Development Goals (MDGs) are the world's time-bound and quantified targets for addressing extreme poverty in its many dimensions-income poverty, hunger, disease, lack of adequate shelter, and exclusion-while promoting gender equality, education, and environmental sustainability. They are also basic human rights-the rights of each person on the planet to health, education, shelter, and security.

The remainder of Michael Green's *TED Talk* analyzes the steps needed to meet the year 2030 goals. He begins by discussing poverty. It remains a major worldwide problem, but further progress in reducing poverty is only a small part of what needs to be done to achieve the 2030 goals. Quoting again from his talk:

> We have countries that are underperforming on social progress, relative to their wealth. Russia has lots of natural resource wealth, but lots of social problems. China has boomed economically, but hasn't made much headway on human rights or environmental issues. India has a space program and millions of people without toilets. Now, on the other hand, we have countries that are over performing on social progress relative to their GDP. Costa Rica has prioritized education, health and environmental sustainability, and as a result, it's achieving a very high level of social progress despite only having a rather modest GDP. And Costa Rica's not alone. From poor countries like Rwanda to richer countries like New Zealand, we see that it's possible to get lots of social progress, even if your GDP is not so great.

Final Remarks

Despite the bad news that pervades our daily news media, the world is making good social progress in working for a better Quality of Life (QoL). Michael Green emphasizes the value of having well-defined goals and measures of how well the world is doing at the global and national levels to achieve these goals. Quoting the Cheshire Cat from Louis Carroll's *Alice in Wonderland*:

> "If you don't know where you are going, any road will get you there."

What You Can Do

Here is a group activity that can be used with a classroom group of students, a grade-level group, a school, and so on. Develop a long-range set of goals for improving the quality of life of a group of people. For example, at the secondary school level the task might focus on goals for a school, neighborhood, or community. The project requires developing and agreeing on a set of quality of life, developing measurable goals, doing research on past progress in achieving the goals, and carefully analyzing/planning how to achieve the goals.

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Appendix 4: Virtual Reality Science Lab

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> "The medium is the message." (Herbert Marshall McLuhan; Canadian philosopher of communication theory and a public intellectual; 1911-1980.)
>
> "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead give them a tool, the use of which will lead to new ways of thinking." (Richard Buckminster Fuller; American engineer, author, designer, inventor, and futurist; 1895-1983.)
>
> "Nothing could be more absurd than an experiment in which computers are placed in a classroom where nothing else is changed." (Seymour Papert; South African/American mathematician, computer scientist, and educator; 1928-2016.)

I am very interested in what is "coming down the pike" of technology innovations that may greatly improve our educational system. I recently viewed a *TEDx Talk*, This Virtual Lab Will Revolutionize Science Class, that literally blew my mind (Bodekaer, October, 2015).

My short *IAE Blog* entry cannot begin to capture the current and emerging capabilities of relatively inexpensive virtual reality to make major improvements in the quality and effectiveness of science education. However, here are a few of the highlights of Bodekaer's short video. I assume that you will take the time to view the video.

First, the virtual lab incorporates a Smartphone for each user. Since the annual worldwide production of Smartphones is now over a billion (one per every seven people on earth) the availability of this part of the hardware is no longer a major issue. Remember, today's Smartphone has as much compute power as the multimillion dollar super computers from 25 to 30 years ago.

Second, the Smartphone is inserted into a relatively inexpensive headset that easily slips on and off one's head. In the presentation, some of the audience members were provided with the equipment and seemed to quickly adjust to it.

Third, the virtual lab provides users with access to a very modern science lab with many millions of dollars of equipment. For example, there is a gene sequencer, an electron microscope, and the ability to miniaturize oneself and move around the inside of an object at the level of individual molecules.

Fourth, the virtual lab includes built-in computer-assisted instruction and access to online instructional and research articles.

Fifth, the virtual lab has a "built-in" virtual teacher, but a human teacher can supplement and/or fill this role. That is, a student functioning in this virtual reality laboratory can be interacting with a human (live) teacher who is functioning in the same lab.

While functioning in this virtual laboratory, a student can learn to use the "real" equipment needed to carry out experiments traditionally done with the actual equipment in a physical lab—but not have to deal with the dangers and expenses of using such equipment in the physical lab.

This aspect of learning to do science laboratory work is not much different from the now routine use of computer simulations by researchers and developers in their everyday work. In essence, the virtual experiments and the computer simulation-based real experiments are in many cases nearly identical. Thus, it is possible for today's students to do cutting edge research via use of a virtual lab and computer simulations.

Research and Development in Materials Science

The previous section mentioned computer simulations as now being a routine tool of researchers in the sciences. A *Scientific American* article by Gerbrand Ceder and Kristin Persson describes how the computer has changed the entire field of materials science (Ceder & Persson, 11/19/2013). Quoting from the article:

> In 1878 Thomas Edison set out to reinvent electric lighting. To develop small bulbs suitable for indoor use, he had to find a long-lasting, low-heat, low-power lighting element. Guided largely by intuition, **he set about testing thousands of carbonaceous material**s—boxwood, coconut shell, hairs cut from his laboratory assistant's beard. After 14 months, he patented a bulb using a filament made of carbonized cotton thread." [Bold added for emphasis.]

Engineered materials such as chip-grade silicon and fiber-optic glass underpin the modern world. Yet, as illustrated by Thomas Edison's work, designing new materials has historically involved a frustrating and inefficient amount of guesswork.

Streamlined versions of the equations of quantum mechanics—along with supercomputers that, using those equations—can virtually test thousands of materials at a time. This is eliminating much of that guesswork involved in developing new materials. In essence, computerized simulations using the mathematics of quantum mechanics produces a huge increase in the speed of certain types of trial and error in the materials sciences.

Researchers are now using this method, called high-throughput computational materials design, to develop new batteries, solar cells, fuel cells, computer chips, and other technologies.

In Summary

Quoting again from Bodekaer's *TEDx* presentation:

> We basically set out to create a fully simulated, one-to-one, virtual reality laboratory simulator, where the students could perform experiments with mathematical equations that would simulate what would happen in a real-world lab. But not just simple simulations—we would also create advanced simulations with top universities like MIT, to bring our cutting-edge cancer research to these students. And suddenly, the universities could save millions of dollars by letting the students perform virtual experiments before they go into the real laboratory. And not only that; now, they could also understand—even on a molecular level inside the machine—what is happening to the machines. And then they could suddenly perform dangerous experiments in the labs as well.

> But we didn't stop there, because we had seen just how important meaning is for the students' engagement in the class. So we brought in game designers to create fun and engaging stories. For instance, here in this case, where the students have to solve a mysterious CSI murder case using their core science skills.

The developers of this virtual reality system engaged a team of researchers to study 160 college students from Stanford University and Technical University of Denmark. This study provided what I would call "promising" evidence of greatly increased student learning. Moreover, when the virtual reality students had a real human teacher to interact with in the virtual laboratory, learning results were further improved.

Final Remarks

In the preceding paragraph I used the term "promising" because a single research study is inadequate in providing "solid" evidence of the effectiveness of a complex innovation. A number of companies are working on virtual reality systems and beginning to sell their products to the general public. In that sense, this provides strong evidence that virtual reality has now arrived. It is proving to be a marketable entertainment product.

Bodekaer's *TEDx Talk* provides an example of how virtual reality can be used in education, both in higher education and at the precollege level. A computerized version of the tools students need to learn to use can become the teacher. This idea is discussed in chapter 4 of my book, *Technology and Problem Solving: PreK-12 Education for Adult Life, Careers, and Further Education* (Moursund, 9/13/2015).

The following statement summarizes my view of the future of teaching machines: **The tool is the teacher.** I believe this is a paradigm shift that is beginning to occur in education. It will take years of curriculum development, teacher education, and work on convincing our educational systems that this is a good way to go. However, there is much that you can do now.

What You Can Do

As a teacher and/or parent, think carefully about the essence of what is illustrated in the virtual lab educational system described above. It represents a huge change from our current immersion of students in a "traditional" oral, pencil-and-paper, and print materials approach to learning and using one's learning. This current approach has a long history of being relatively "authentic," since students were being prepared to function as adults in a similar world. For a summary of key ideas in authentic instruction and assessment, see Mueller's Authentic Assessment Toolbox (Mueller, n.d.).

However, over recent decades, our traditional education has steadily become less authentic. Your current students are facing an adult life in a world that is substantially different than it was when you were a child. What you can do is to routinely provide examples of this difference as you interact with your students and/or your children. Draw on both their knowledge and your own knowledge of tools such as digital cameras, handheld calculators, Smartphones, video games (these provide good examples of computer simulations), computerized toys (these provide examples of robots and computerized machinery), Web and search engines, Internet, GPS, voice input/output to a variety of devices, and so on.

You and your students/children already use these new technologies effectively in everyday life outside of school. **It's time to bring these tools into the classroom!**

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Appendix 5: Education for the Coming Technological Singularity

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> "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; American social writer and philosopher; 1902-1983.)
>
> "It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change." (Charles Darwin; English scientist and naturalist; 1809-1882.)
>
> "Intelligence is the ability to adapt to change." (Stephen W. Hawking; British theoretical physicist and cosmologist; 1942-.)
>
> "The secret of change is to focus all of your energy, not on fighting the old, but on building the new." (Socrates; Greek philosopher; circa 469 BC-399 BC.)

This is the second of a two-part *IAE Blog* entry about our rapidly changing technology. The previous entry introduced the idea of a **technological singularity** (Moursund, 2/25/2015). The term technological singularity refers to some time in the future when computers become much "smarter" than people.

Right now the rate of technological change is both large and rapidly increasing. We have artificially intelligent computer systems that are more capable than humans in certain limited areas, and we have artificially intelligent robots that are taking over many jobs previously performed by human workers. However, we still seem far away from a time in which computer intelligence and capabilities exceed human intelligence and capabilities over the broad range of human endeavors.

Remember, the current estimated life expectancy of today's precollege students is about 80 years. So, our current K-12 educational system is preparing students for what they will do during the 60 or more years after they leave high school. Think back over the changes our world has seen in the past 60 years. Now try to imagine what would constitute a good education for a future of 60 years of rapidly accelerating change. The next two sections provide my current insights and recommendations about this question.

Educational Implications: Foundational Ideas

This *IAE Blog* entry is motivated by the (possibly coming) technological singularity, and our current high and accelerating pace of technological change. Our educational system is currently facing many other challenges, and they are not going away!

First, consider the current balance between a "past-oriented" and a "future-oriented" education. When the world was changing only slowly, a past-oriented education served us well. Adults could easily adjust to the very small number of Science, Technology, Engineering, and Mathematics (STEM) changes that occurred during their lifetime.

This slowly evolving educational system served humanity well even as reading, writing, and arithmetic were developed and very, very slowly were introduced to the masses. Most of the world's population remained illiterate for thousands of years after the development of these three "basics" of today's education.

Reading, writing, and arithmetic, along with oral communication skills, remain essential today. However, the technology-enhanced environment in which we perform these activities has changed. A modern and future-looking educational system prepares students to function well in our current "connected and computerized" world, and also lays a foundation that will help our future adults adjust to continuing rapid technological progress.

Second, consider aids to teaching and learning. Books were (and still are) a tremendous aid, as were audio and video recording and playback systems. All of these, and much more are available in today's state-of-the-art teaching machines. Such teaching machines are interactive and make effective use of modern technological aids to learning and doing reading, writing, arithmetic—and **thinking, problem solving, and communication.** *Technology and Problem Solving: PreK-12 Education for Adult Life, Careers, and Further Education* is a free short book that provides an overview of such teaching machines (Moursund, 2015).

Third, consider the idea of learning to work with computer technology rather than compete with it. What can human beings do well that computers cannot do or can only do quite poorly? We need to help all of our students better understand the intrinsic human characteristics that make us so different from computers.

We are a very long way from having computers that have the knowledge and skills of a caring, loving, human with well-developed and routinely used good "people skills." An increasing number of future jobs will go to job seekers who have well-developed "human" strengths and who can employ these strengths when working with robots and general-purpose computer systems.

Educational Implications: Specific Recommendations

This section contains my current specific recommendations to students, parents, and others who are concerned about today's students getting a modern education.

To begin, think about **what distinguishes people from the machines and tools humans have developed** as aids to their physical and mental capabilities. Perhaps words such as compassion, empathy, loyalty, tenderness, and spirituality come to mind. Perhaps you think about sharing feelings such as love, joy, happiness, sadness, fear, and anger. Some people have love-hate relationships with their car or computer, but these are not reciprocated from the tools back to the people.

Here are some specific recommendations:

- Develop your "people" and communication skills. Become fluent in face-to-face, written, and computer communication skills. If you have the opportunities to do so, become bilingual and bicultural. Become a "people person" and a "citizen of the world."
- Focus your education on gaining higher-order, creative thinking, understanding, and problem-solving knowledge and skills in whatever areas you decide to study.
- Learn about current and near-term capabilities and limitations of computers and robots. Plan your education and develop your abilities so that you do not end up in head-to-head competition with computers and robots in areas that they are already quite good at and are getting better (Moursund, 2/11/2015; Boehm, 2/8/2014).

- Make very sure that you learn to make effective and fluent use of Information and Communication Technology (ICT), both in general use and in the discipline areas you choose to study. Remember, the combination of a human brain and a computer brain can often outperform either one working alone (Moursund, 2014).
- If you are "really into" computers, continue to develop your computer knowledge and skills, but also work toward gaining a high level of expertise in one or more other career fields. This will help prepare you for many of the new jobs that are being developed that require a combination of ICT and "traditional" knowledge and skills.
- Develop learning skills and habits of mind that will serve you throughout your lifetime. For example, learn about persistence along with the concepts of intrinsic motivation, reflection, and instant gratification. (Moursund, 1/28/2014.)
- Identify your specific physical and mental strengths and weaknesses as a learner and "doer" in each area that you study. Develop and exploit your strengths, and work to overcome your weaknesses.
- This final recommendation is specifically for students. Think about what you want in your future. What informal and formal education do you need to help ensure that you will achieve a decent quality of life? Remember the quote, "All work and no play makes Jack a dull boy." Make sure that you gain knowledge and skills that support possible avocations, hobbies, and other non-vocational aspects of your future.

How Fast Is Technology Changing?

The following chronological list captures billions of years of "intellectual" change. I find it helps me to think about the very slow pace of change for billions of years, and the increasingly rapid current and likely future pace of change.

1. Life on earth started with in the first simple cells and their genetic coding of information using RNA and later DNA. This began about 3.6. billion years ago. Within a hundred million years, multi-celled life forms developed. A DNA molecule stores the equivalent of about 1,000 books of data.
2. Over the next three billion years, more complex life forms developed. Life forms developed with a precursor to a brain of gradually increasing complexity to store and process information. By a half-billion years ago a basic ganglia structure existed in some animals, and this is considered to be a start of a brain. It provided information storage that supplemented the DNA storage, and eventually evolved into our current mammalian brain.
3. The first primate-like animals developed about 65 million years ago. They were a product of well over three billion years of evolution. It was a mere 200,000 years ago that anatomically modern humans with our current brains developed. The storage capacity of a human brain is probably in the range of two million to two billion books. Our brains both store and process information. We both learn and forget.
4. A mere 5,200 years ago, writing and reading were developed by humans as aids to storing and retrieving information. We finally had long-term information storage that could easily be shared among many people and relatively accurately passed on from generation to generation. Libraries could grow in size and additional libraries could be built.

5. Less than 80 years ago, electronic digital computers were developed as aids to storing, processing, and retrieving information. A single "run" of the Large Hadron Collider produces about 30 petabytes of data—the equivalent of about 30 billion books. Today's fasted supercomputers can perform more than 100 million billion arithmetic computations per second. (Compare that number with how long it takes you to do a multiplication or division of two multidigit numbers.)

Photography, telephones, television, electronic storage and playback devices, and computers are all predecessors to today's Smartphone. The first commercially available telephone combining the concepts of intelligence, data processing, and visual display screens into telephones became available in 1993. Both in 2013 and in 2014, total worldwide production of Smartphones was about 1 billion per year—that is, about one for every seven people on earth in each of these two years.

The "smartness" of Smartphones is quite impressive and increasing year to year. Some of the smartness features are a Global Positioning System, a voice input and output system, and access to increasingly smart Web search engines. Some of the artificially intelligent smartness is built into a Smartphone, and some comes from access to and use of the steadily growing accumulation of human knowledge stored on the Web and in other digital libraries. That is, the Smartphones that people are buying right now continue to increase in capability and intelligence through progress in improving the smartness of devices outside of computers and improving the capabilities of the global communications network.

Final Remarks

Here are two quotes that capture the essence of this *IAE Blog* entry:

> "We must welcome the future, remembering that soon it will be the past; and we must respect the past, remembering that it was once all that was humanly possible." (George Santayana; Spanish citizen raised and educated in the United States, generally considered an American man of letters; 1863-1952.)
>
> "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; American social writer and philosopher; 1902-1983.)

What You Can Do

> "When you teach, you learn twice." (Seneca; Roman philosopher and advocate of cooperative learning; 4 BC-65 AD.)

Your knowledge, skill set, and insights make you different from every other person. As you interact with other people, you are both a teacher and a learner. As a teacher, you can help shape the future lives of many people.

Select a couple of the bulleted items in the Specific Recommendations section that seem particularly important to you. Bring these ideas up in discussions with your colleagues and students. Especially, share them with your students and engage them in thinking about how the ideas are being integrated into their current education. Listen carefully to—and learn from—their insights into what they believe would improve the education they are receiving.

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Appendix 6: Information Underload and Overload

Moursund, D. (3/1/2016). Information Underload and Overload. *IAE Blog.* Retrieved 11/30/2016 from http://iae-pedia.org/Information_Underload_and_Overload.

> "Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it." (Samuel Johnson; British author and father of the English dictionary; 1709-1784.)
>
> "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; British science fiction author, inventor, and futurist; 1917-2008.)

I have recently substantially revised and updated my *IAE-pedia* entry, Information Underload and Overload (Moursund, 2016a). This has proven to be a popular article, with more than 50,000 hits to date. Since I first wrote this document in 2009, the total amount of information available on the Web and from other sources has grown remarkably. Indeed, quoting from the new version of the entry:

> Reading, writing, and arithmetic (math) became formal subjects in schools more than 5,000 years ago. Since then there has been a steady increase in the accumulated knowledge of the human race. The pace of this increase has been increasing. Quoting from the article, Knowledge Doubling Every 12 Months, Soon to be Every 12 Hours (Schilling, 4/19/2016):
>
> > Buckminster Fuller created the "Knowledge Doubling Curve"; he noticed that until 1900 human knowledge doubled approximately every century. By the end of World War II knowledge was doubling every 25 years. Today things are not as simple as different types of knowledge have different rates of growth. For example, nanotechnology knowledge is doubling every two years and clinical knowledge every 18 months. But on average human knowledge is doubling every 13 months. **According to IBM, the build out of the "internet of things" will lead to the doubling of knowledge every 12 hours.** [Bold added for emphasis.]

Information Overload, Underload, and Appropriate Load

It is easy to see why so many people experience *information overload*—too much information. I certainly see it when I do a Web search and get a hundred thousand results.

Information underload refers to the situation where we don't have ready access to information needed to help us solve problems and accomplish tasks that we face.

I have now added a new short section on *Information Appropriate Load* to this updated *IAE-pedia* entry (Moursund, 2016a):

> Consider an Information scale with one end labeled *Overload* and the other end labeled *Underload.* Let's label the middle of the scale *Appropriate Load.* This

reminds me of the Goldilocks story in which the bowls of porridge were too hot, too cold, and just right; the beds were too hard, too soft, and just right.

For a particular person faced with a particular information need, there might be too much information available, too little information available, or an appropriate (for the person) amount of information available. Moreover, the information might be written at a level that is way over the person's head, way under the person's reading and understanding levels, or appropriate to the person.

Educators are familiar with this situation. A dictionary with a quite limited number of words, and containing illustrative pictures and simple definitions, is appropriate to a student just learning to read. Books for students at different grade levels have readability levels appropriate to average students at those grade levels.

Now, think about this situation from the point of view of the creators of the Wikipedia. They envisioned a collection of articles (information) that would eventually exceed that in any current print encyclopedia and that articles would be authored by many different writers. What readability level should it have? What background knowledge of the subject of a particular article should the writer of the article assume the readers will have?

Every writer faces the challenge faced by authors of Wikipedia entries. Every educational system faces the challenge of meeting the information needs of a very wide range of students with different interests, background knowledge, and reading/viewing skills.

Retrieving Just the Information One Needs

Part of the information underload problem is that often one cannot find the needed information, even in cases where it exists. The various Web search companies and many other groups are working on this problem. Quoting again from the updated entry, what is emerging is a three-pronged approach:

1. Increase the breadth and depth of information available of the Web. Develop more intelligent search engines that order the search results in a manner that better fits the needs of people using the Web. Currently Google is the most widely used of such search engines.
2. Develop answer engines that are designed specifically to produce answers to problems (including questions) posed by users. Two important examples of this are:
   - **WolframAlpha.** See https://www.wolframalpha.com/. This is a computational knowledge engine. This is an online service that answers factual questions. It comes in a limited free version and a (not free) professional version. Among other things, the system "knows" a lot of math and can solve a wide range of such problems.
   - **IBM's Watson.** See http://www.ibm.com/watson/. Watson gained fame by defeating two past champions in the TV question and answer program Jeopardy in 2011.
3. Make use of user-specific search, answer, and teaching engines. (To a large extent, this is still the future of search engines.) Such a system would "know" a

great deal about what the question poser knows and would provide information and answers that are individualized to that person. Moreover, such a system views a question as a "teachable moment" and uses it to provide not only the desired information but also appropriate instruction to help the question poser learn more about the topic area.

Final Remarks

A good, modern education acknowledges and makes use of the information available to today's students. It prepares students to make use of and build on this accumulated knowledge of the human race. Moreover, it assumes that it is preparing students for adult life in a world in which computer-based aids to learning and using information are readily available in daily life, on the job, and in further lifelong education.

What You Can Do

As I have mentioned many times in my writing and presentations, I consider each person to be both a lifelong learner and a lifelong teacher. The rapidly changing face of information storage, retrieval, and use provides an excellent opportunity for each of us to be a learner and a teacher. I hope that you will do so and thoroughly enjoy these activities.

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Wolfram Alpha (n.d.). Wolfram Alpha Computational Knowledge Engine. Retrieved 11/30/2016 from https://www.wolframalpha.com/.

Appendix 7: Personal Digital Filing Cabinet for Every Teacher

Moursund, D. (10/1/2013). A Personal Digital Filing Cabinet for Every Teacher. *IAE Blog.* Retrieved 11/30/2016 from http://i-a-e.org/iae-blog/entry/a-personal-digital-filing-cabinet-for-every-teacher.html.

In the past couple of weeks, *Information Age Education* has made substantial progress in editing and updating its *IAE-pedia.* I believe the entry on Digital Filing Cabinets is one of the more important entries in the *IAE-p edia* (Moursund, 2016a).

The idea is very simple. We now have quite good technology that makes it easy for each preservice and inservice teacher to accumulate a personal library of "good stuff." I call such a collection a *Personal Digital Filing Cabinet.*

All teachers accumulate materials that they find useful in their teaching. It is now convenient to have quite a bit of such material available in electronic digital form so it can be easily accessed, edited, copied, and shared. Here are two key ideas of such a personal library:

1. As you develop this library and make extensive use of it, you gain personal ownership of and familiarity with the content. In some sense it becomes an extension of your brain. Browsing though your collection can help you to retrieve a memory that you have temporarily forgotten.
2. You can readily share your personal library with professional colleagues, students, parents of your students, and others. This facilitates the development of a lifelong habit of listening to education-related needs of others and providing them with content that you are comfortable in sharing and that you feel is relevant to their needs.

Notice that such a personal library is quite different from the concept of the very extensive electronic "impersonal" libraries such as the Web. Your Personal Digital Filing Cabinet contains materials that you have personally studied and used. It is information that you consider to be "tried and true." Moreover it can gain in value over time. Each time you access a document, you can add a comment that explains what you were looking for and whether the article was helpful. You can add thoughts on possible other uses of the document, and other places in your Personal Digital Filing Cabinet that you have found useful when searching on the topic you currently have in mind.

A Bit of History

I first started thinking and writing about the idea of preservice and inservice teachers having a personal digital library of teaching/learning materials years before the World Wide Web developed by Tim Berners-Lee in 1990-1991 became available. At that time, I was particularly interested in math education and I envisioned that a student entering a teacher education program could be provided with a free CD-ROM containing a reasonably extensive library of math content and math education materials.

Of course, in those days most preservice and inservice teachers had a personal print library of books, "handouts," course notes, and so on that they had accumulated and were building. But I envisioned giving every preservice and inservice teacher a CD with a relatively large electronic library of books, lesson plans, assessment instruments, state math standards, and similar documents. These would be specifically related to the math content, instructional processes, and assessment they were studying and using. I strongly believed that this would help to improve math education.

Suggestion to Teacher Education Programs

One of the things I would like to see happen is for each teacher education institution or program of study to develop a Digital Filing Cabinet that is aligned to its courses, programs of study, and other college/university coursework relevant to preservice and inservice teachers. For example, it may be that preservice elementary teachers take a Math Methods course from the College of Education and one or more Math for Elementary Teachers courses from the Mathematics Department. Each of these types of courses needs to be covered in the DFC (Moursund, 2016b).

On a larger scale, I would like to see the teacher education programs in each state collaborate in developing a Digital Filing Cabinet for the state. Preservice and inservice teachers in a state have a lot in common, and they can benefit from having a Digital Filing Cabinet that reflects the various programs of study and the curriculum standards of the state.

Personal DFCs for Each K-12 Student

Here is an idea that I believe many teachers and their students will find useful. Each student can be building a Personal DFC—adding to it year after year from what they are studying and learning in their formal schooling and informal education.

While such a collection is not a portfolio, it can certainly have some portfolio-like characteristics. It is becoming common for grade school students to begin to develop portfolios of their schoolwork and other activities. The process includes selecting representative samples of one’s work and writing a critical analysis of the work. This is an important aspect of learning to self-assess and learning to take responsibility for one’s education.

A student's Personal DFC provides a historical record of what the student has been taught in school and has studied/learned both inside and outside of school. It can contain information about the books studied and personal likes and dislikes at the time. Besides its personal historical record, it can provide help in reviewing and relearning what one has learned in the past.

What You Can Do

Analyze the progress you are making (or, the lack of progress) in having a Personal Digital Filing Cabinet relevant to your own professional career. If you feel your current progress is inadequate to your lifelong learning and professional needs, make a decision to do something about this—and, then do it!

Explore the extent to which the PDFC ideas from this article have been implemented in your professional circles. If progress is occurring, contribute to it. If the idea of a PDFC seems to be totally inadequate or missing in your preservice, inservice, and professional circles, take the initiative and start something.

References and Resources

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Moursund, D. (2/1/2017). Keith Devlin's Thoughts About a Modern Mathematics Education. *IAE Blog*. Retrieved 2/5/2017 from http://i-a-e.org/iae-blog/entry/keith-devlin-s-thoughts-about-amodern-mathematics-education.html.

Keith Devlin has long been a world class math educator. This *IAE Blog* entry discusses his recent article, All the Mathematical Methods I Learned in My University Math Degree Became Obsolete in My Lifetime (Devlin, 01/01/2017). Quoting Devlin:

> When I graduated with a bachelor's degree in mathematics from one of the most prestigious university mathematics programs in the world (Kings College London) in 1968, I had acquired a set of skills that guaranteed full employment, wherever I chose to go, for the then-foreseeable future—a state of affairs that had been in existence ever since modern mathematics began some three thousand years earlier. **By the turn of the new Millennium, however, just over thirty years later, those skills were essentially worthless, having been very effectively outsourced to machines that did it faster and more reliably, and were made widely available with the onset of first desktop- and then cloud-computing.** In a single lifetime, I experienced first-hand a dramatic change in the nature of mathematics and how it played a role in society. [Bold added for emphasis.]

Now, in 2017, we can look back and ask what progress undergraduate math education has made in light of the observation by Devlin and many others. During this time, computer hardware, software, and connectivity have continued to make rapid progress. This progress has greatly changed how colleges graduates solve the problems and accomplish the tasks in the disciplines they have studied. Of course the amount of change varies considerably from discipline to discipline.

Just for the fun of it, I examined the current requirements in the undergraduate math program of study at Kings College London. From the material I found on the Web, it is clear that this is a very challenging and rigorous program of study. But, I saw no mention of computers in the program description, nor any requirements in the field of Computer and Information Science. Clearly, the faculty in this program believes that rigorous math is good math, and rigorous math is what a good bachelor's degree in math is all about.

The bachelor's degree in mathematics at my alma mater, the University of Oregon, requires far less courses in mathematics than does the Kings College London, but requires more breadth of study outside of mathematics. In addition, it offers a joint Math/Computer Science degree (University of Oregon, 2016). Quoting from this document:

> Are you fascinated by the challenges and excitement of computer and information science? Do you also have a consuming interest in mathematics? With this major, you can explore the realm of computer and information science while developing a mathematics anchor. If you want to gain knowledge in both fields, but don't initially want to specialize in either, this may be the major for you.
>
> The knowledge you gain in this major is hugely practical in the real world. Computer science offers the challenge and excitement of a dynamically evolving

> science, the discoveries and applications of which affect every aspect of modern life. **You will choose classes from areas such as programming languages, modeling and simulation, human-computer interaction, and artificial intelligence.** [Bold added for emphasis.]

The Fourth R: Reasoning/Computational Thinking

Reading, writing, and arithmetic (math)—the three Rs—are considered to be the basics of education. At the PreK-12 level, students are required to take year after year of coursework in these areas. If students go on to college, they typically are required to take additional coursework in one or more of these areas. Indeed, a great many students entering college do so poorly on placement exams that they are required to start their college work with remedial courses that do not carry credit toward their degree (ACT, 2015). Quoting from the ACT article:

> The ACT (2015) provides data annually on the percentages of students going on to college who were "qualified" in English, Reading, Mathematics, Science, and All Four Subjects. The site referenced above provides data for the past five years. During that time, the percentage qualified in all four areas went from 25% to 28%. English, Reading, and Math showed modest declines, and science showed a modest increase. In summary, the situation has not improved much over the past five years, and over 70% of students entering college need to take remedial coursework in one or more of the basic subject areas.

We live at a time when a **fourth R** (**R**easoning/Computational Thinking) has emerged. The **4th R** makes use of both human brain and computer brain to answer questions, represent and solve problems, and accomplish tasks.

In earlier chapters of the book you are currently reading, I strongly recommend that the **4th R** be thoroughly integrated throughout the PreK-12 curriculum in each discipline area students study during their many years in school. In higher education, I recommend that the **four Rs** be treated equally, and thoroughly integrated into each course students take. The emphasis on each of the **four Rs** should, of course, be appropriate to the specific discipline a course is covering.

My major thesis is that it takes years and years of study and use to develop an appropriate modern level of competence in each of the four Rs. Currently there are two major movements approaching this in computer education. The first is to teach some computer programming to all precollege students, and the second is to require some computer science coursework at the college level.

Both of these approaches have merit, and each has strong supporters. However, both are weak in that they do not focus on integrating Information and Communication Technology (ICT) knowledge and skills into the new knowledge and skills the students are gaining as they progress through their PreK-12 and further education. This integration requires that all teachers have the computer knowledge and skills appropriate to the level and disciplines they teach, and that all curriculum content reflect this "modern" use of ICT.

Kelsey Sheehy's article, Computer Science Transitions from Elective to Requirement, presents some of the ICT progress being made in higher education (Sheehy, 4/3/2012). She quotes Geoffrey Bowker, professor of informatics at the University of California—Irvine:

> "Yes, [computer science] absolutely should be [required]," says Geoffrey Bowker, professor of informatics at the University of California—Irvine. All aspects of our personal lives and our work lives are affected by computers. We need to know about the tools that we're working with."
>
> …
>
> "Getting a flavor of science is great," he says. "**But computer science is not a flavor; it's a staple.**" [Bold added for emphasis.]

Bowker's point is consistent with my point of view. ICT is both a discipline of study and a tool useful across the curriculum. It is a "staple" in a modern education.

What You Can Do

No matter what your current level of informal and formal education, you are living at a time of very rapid pace of change in your world. This is likely to affect your own future and the future of many people you care about. Think carefully about what you are going to do to help yourself and others to deal with these changes. Perhaps start with an analysis of what you are currently doing. If you are not fully satisfied with your analysis, start to become more proactive. Set some learning and teaching goals for yourself. Then, "Make it so."

References and Resources

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CCSS (n.d.). Common Core State Standards initiative. Retrieved 1/28//2017 from http://www.corestandards.org/Math/Practice/.

Devlin, K. (01/01/2017). All the mathematical methods I learned in my university math degree became obsolete in my lifetime. The Huffington Post. Retrieved 13122017 from http://www.huffingtonpost.com/entry/all-the-mathematical-methods-i-learned-in-my-university_us_58693ef9e4b014e7c72ee248.

Devlin, K. (n.d.). Keith Devlin at Stanford University. Retrieved 1/18/2017 from http://web.stanford.edu/~kdevlin/.

Moursund, D. (12/23/2016). The Fourth R. Eugene, OR: Information Age Education. Download the Microsoft Word file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/289-the-fourth-r/file.html. Download the PDF file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/290-the-fourth-r-1/file.html. Access the book online at http://iae-pedia.org/The_Fourth_R.

Sheehy, K. (4/3/2012). Computer science transitions from elective to requirement. US News. Retrieved 1/29/2017 from http://www.usnews.com/education/best-colleges/articles/2012/04/03/computer-science-transitions-from-elective-to-requirement-computer-science-transitions-from-elective-to-requirement.

University of Oregon (2016). Joint mathematics and computer science degree program. Retrieved 1/30/2017 from http://uocatalog.uoregon.edu/arts_sciences/mathematicsandcomputerscience/.

Appendix 9: Lists of Free Online Educational Resources

Moursund, D. (8/21/2016). Lists of Free Online Educational Resources. *IAE Blog.* Retrieved 11/25/2016 from http://i-a-e.org/iae-blog/entry/iae-lists-of-free-online-educational-resources.htm.

Six Examples of Recently Updated IAE Resource Lists

The following are brief discussions of some of the recently updated *IAE-pedia* documents. The IAE Resources section at the end of this *IAE Blog* entry includes the complete list with Web addresses.

Fair Use

Moursund, D. (2016). Fair Use. *IAE-pedia.* Retrieved 7/17/2016 from http://iae-pedia.org/Fair_Use.

What do teachers and students need to know about fair use of Web materials? The Internet has raised new issues of intellectual property rights. Many teachers and students are confused about their rights to make teaching and learning uses of these materials.

Free Educational Videos

Moursund, D. (2016). Free Educational Videos. *IAE-pedia.* Retrieved 8/17/2016 2016 from http://iae-pedia.org/Free_Educational_Videos.

Thomas Edison was one of the world's greatest inventors. However, some of his forecasts for the future now seem quite amusing. Here is one of my favorites:

> "Books will soon be obsolete in the schools.... Scholars will soon be able to instruct through the eye. It is possible to touch every branch of human knowledge with the motion picture." (Statement by Thomas A. Edison, 1913.)

Today's children routinely use interactive computer educational and entertainment materials that (I assume) are far beyond Edison's wildest imaginations. The Free Educational Videos document contains brief discussions about and links to a large number of these materials.

Free IAE Math Education Materials

Moursund, D. (2016). Free Math Education Materials. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_IAE_Math_Education_Materials.

A number of the most popular IAE publications are about math education. The Free Math Education Materials document provides brief discussions about and links to a large number of IAE books, *IAE-pedia* pages, blog entries, and newsletters that focus on math education. One unifying theme is improvements in math education being made possible by the use of Information and Communication Technology.

Free Science Education Software

Moursund, D. (2016). Free Science Education Software. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Science_Software.

Computers are now an integral component of learning and "doing" science. The Free Science Education Software document provides brief introductions to a number of sites that specialize in developing and disseminating software of particular use in K-12 education.

Free Open Content Libraries

Moursund, D. (2016). Free Open Content Libraries. *IAE-pedia.* Retrieved 6/27/2016 from http://iae-pedia.org/Free_Open_Content_Libraries.

The development of reading and writing more than 5,000 years ago made it possible and desirable to accumulate information in a form that could be preserved over many years and widely disseminated. Historically, such materials were stored in "hard copy" form. However, the development of photography, audio recordings, video recordings, and then electronic digital storage and retrieval have greatly changed the nature of libraries.

A number of the great libraries of the world are making good progress in digitizing their holdings. The totality of these materials that can be accessed online is still growing rapidly.

Free Open Source Online Databases

Moursund, D. (2016). Free Open Source Online Databases. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Open_Source_Online_Database.

A database is a collection of information that is organized so that it can easily help to solve problems and accomplish tasks. A database may be as simple and short-lived as a handwritten shopping list, and as large as the Web. Yes, the World Wide Web is a database, and you certainly want all of your students to become experienced in making effective use of this database.

Final Remarks

Most of the PreK-12 educational systems of the world have yet to comprehend the improvements that are possible as the routine full use of Information and Communication Technology (ICT) is integrated into the curriculum. Teacher access to the vast array of free educational resources now available on the Web can support the implementation of more powerful uses of ICT in the curriculum.

Imagine an educational system in which every student is growing up with rapid voice, keyboard, and touch screen input to access the steadily growing accumulated knowledge of the human race. Also consider what artificially intelligent systems can do in terms of answering questions and solving problems.

As such ICT capabilities continue to improve, students are becoming more skilled in using them at home and in other non-school locations. **It is increasingly imperative that our educational systems keep pace with and provide some leadership in what the students are learning on their own.**

What You Can Do

Reread the Final Remarks. A great many schools and students now have good enough access to the Web to be learning its capabilities and limitations as they apply to each subject area they are studying. Students themselves, along with teachers, parents, and others, have the capability of making this happen right now. **I hope you are doing your part!**

IAE Resources

Lists of Free Online Resources

Moursund, D. (2016). **Fair use.** *IAE-pedia.* Retrieved 7/17/2016 from http://iae-pedia.org/Fair_Use.

Moursund, D. (2016). **Free educational videos.** *IAE-pedia.* Retrieved 8/17/2016 2016 from http://iae-pedia.org/Free_Educational_Videos.

Moursund, D. (2016). **Free IAE math education materials.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_IAE_Math_Education_Materials.

Moursund, D. (2016). **Free math education videos.** *IAE-pedia.* Retrieved 7/17/2016 from http://iae-pedia.org/Free_Math_Education_Videos.

Moursund, D. (2016). **Free math software.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Math_Software.

Moursund, D. (201f). **Free open content libraries.** *IAE-pedia.* Retrieved 6/27/2016 from http://iae-pedia.org/Free_Open_Content_Libraries.

Moursund, D. (2016). **Free open source and open content educational materials.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Open_Source_and_Open_Content_Educational_Materials.

Moursund, D. (2016). **Free open source online databases.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Open_Source_Online_Databases.

Moursund, D. (2016). **Free open source software packages.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Open_Source_Software_Packages.

Moursund, D. (2016). **Free science education software.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Science_Software.

Moursund, D. (2016). **Free science education videos.** *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Free_Science_Education_Videos.

Free Online IAE Books

Free books by Dave Moursund. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/David_Moursund_Books.

Free books by Bob Albrecht. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Robert_Albrecht#Free_Books_by_Bob_Albrecht.

Free books co-authored by Dave Moursund & Bob Sylwester. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/IAE_Newsletter#Free_IAE_Books_by_David_Moursund_and_Robert_Sylwester.

Moursund's Collections of Quotations

Math education quotations. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Math_Education_Quotations.

Quotations collected by Dave Moursund. *IAE-pedia.* Retrieved 8/17/2016 from http://iae-pedia.org/Quotations_Collected_by_David_Moursund.

Digital Filing Cabinets

Digital filing cabinet: Overview. IAE-pedia. Retrieved 8/17/2016 from http://iae-pedia.org/Digital_Filing_Cabinet:_Overview.

Digital filing cabinet: Secondary school history. IAE-pedia. Retrieved 11/30/2016 from http://iae-pedia.org/Digital_Filing_Cabinet:_Secondary_School_History.

Digital filing cabinet: Math education. IAE-pedia. Retrieved 8/17/2016 from http://iae-pedia.org/Digital_Filing_Cabinet:_Math_Education.

Popular Free Online IAE Books

Moursund, D. (February, 2016). ***Math methods for preservice teachers.*** Eugene, OR: Information Age Education. PDF: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/283-math-methods-for-preservice-elementary-teacher-1/file.html. Microsoft Word: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/282-math-methods-for-preservice-elementary-teacher/file.html. HTML: http://iae-pedia.org/Math_Methods_for_Preservice_Elementary_Teachers.

Moursund, D. (August, 2015). ***Brain science for educators and parents.*** Eugene, OR: Information Age Education. PDF: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/271-brain-science-for-educators-and-parents-1/file.html. Microsoft Word: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/270-brain-science-for-educators-and-parents/file.html. HTML: http://iae-pedia.org/Brain_Science.

Moursund, D. (2/28/2015). ***Technology and problem solving in PreK-12 education for adult life, careers, and further education.*** Eugene, OR: Information Age Education. PDF: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/267-technology-and-problem-solving-in-prek-12-education-1.html. Microsoft Word: http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/266-technology-and-problem-solving-in-prek-12-education.html. HTML: http://iae-pedia.org/Technology_and_Problem_Solving.

Sylwester, R., & Moursund, D., eds. (2012). ***Creating an appropriate 21st century education.*** Eugene, OR: Information Age Education. PDF: http://i-a-e.org/downloads/doc_download/243-creating-an-appropriate-21st-century-education.html. Microsoft Word: http://i-a-e.org/downloads/doc_download/242-creating-an-appropriate-21st-century-education.html.

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