

Increasing the IT Developmental Level and Maturity of Your Students

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This document is the basis of my talk prepared for the NCCE conference on March 17, 2005. It is more formal and longer—more “scholarly academic”—than the talk. When I write, I generally leave out jokes and snide comments that underlie some of my thought and feelings. My writing tends to fill in a number of the details that get left out of a talk.

Abstract	2
Problem Solving & the Problems Addressed in This Paper.....	3
Some General Background Information	4
Information Explosion.....	4
Decision Explosion.....	4
Jean Piaget.....	5
Benjamin Bloom.....	5
Brain and Mind Science	6
Human Intelligence	7
Artificial Intelligence	8
Computer as Auxiliary Mind/Brain.....	8
Academic Disciplines.....	9
Discipline-Specific Maturity.....	10
Communication Maturity	11
Interdisciplinary Maturity	11
Cognitive Development Theory	12
Children and Media	13
ICT Developmental Scale	14
ICT Sensorimotor and Preoperational.....	15
ICT Concrete Operations	16
ICT Formal Operations	16
Final Remarks and Recommendations.....	17
References	17

Abstract

The presentation covers some of my understanding of current progress in Brain Science, Information and Communication Technology (ICT), and the Science of Teaching and Learning. Some of the unifying themes in this document include:

1. Understanding that expertise in ICT is based on a combination of ICT Content Knowledge and ICT Maturity;
2. Understanding and teaching to the Information and Communication Technology (ICT) cognitive developmental levels of learners;
3. Understanding the idea of an ICT system as an auxiliary mind/brain, or as an extension of a person's mind/brain.

ICT **content** includes knowing how to use a variety of ICT hardware and software tools. ICT **maturity** includes learning to learn ICT, learning to recognize, understand, pose, and solve ICT-related problems, and developing fluency in reading and writing in ICT. In all disciplines, we need to help students gain an appropriate balance between content knowledge and maturity. One of the reasons for this is that content knowledge tends to be forgotten much more rapidly than the various aspects of maturity.

In ICT, as in any discipline, we can easily create learning environments that are developmentally too low or too high for our students. It is important to know the ICT developmental level of our students and to provide curriculum and instruction that is appropriate to it.

An ICT system can be thought of as an auxiliary mind/brain. The human/ICT interface is gradually being improved, and the “intelligence” and capabilities of ICT systems are rapidly improving. We need an educational system that includes a strong focus on people and ICT systems learning to work together to solve problems and accomplish tasks.

Increasing the IT Developmental Level and Maturity of Your Students

Problem Solving & the Problems Addressed in This Paper

I like to write and talk about the new things that I am learning. This past year I have become increasingly interested in brain and mind science as they relate to the field of Information and Communication Technology (ICT) in education. As I learn new things, I relate them to what I already know and what I believe is really important. I am a firm believer in constructivism and teaching in a manner that facilitates each student's constructivist processes.

For me, the discipline of ICT is about solving problems and accomplishing tasks. In our everyday lives we encounter a wide range of problems to be solved and the tasks to be accomplished, and where ICT can make a significant contribution. For example:

- The problem to be solved might be one of pure entertainment. I want to be entertained, and I want to play a game that I find intrinsically and extrinsically motivating, that grabs and holds my attention, and that causes my dopamine to flow so that I feel good.
- The problem to be solved might be to help my students learn. I want powerful aids to teaching and learning that are proven effective in helping my students to learn more, better, and faster, and that increases their long-term retention.
- The problem to be solved might be one of communicating with my friends. I want to be able to talk to my friends, share pictures with them, and to include them as a routine part of my everyday life.
- The task to be accomplished might be to do the needed research and write a detailed report that meets the needs of my employer.
- The task to be accomplished might be to refinance my home loan, or to do appropriately fiscal planning for my children's college education and my retirement.

I view ICT as an extension of reading, writing, and arithmetic—as a powerful, general-purpose aid to solving the types of problems I encounter in my life. In this document I use the term problem solving to include:

- Posing, clarifying, and answering questions;
- Posing, clarifying, and solving problems;
- Posing, clarifying, and accomplishing tasks (including producing products, doing performances, and giving presentations);
- Posing (generating) and testing hypotheses; conjecturing and then verifying (prove, disprove, show it is undecidable) conjectures.
- Posing, clarifying, and making decisions;
- Using higher-order, critical, logical, well-reasoned, and wise thinking to do all of the above (Moursund, 2004a).

Perhaps you have noticed the emphasis on “posing” in the above list. Learning to pose (state, recognize, identify, clarify) meaningful and important problems, questions, and tasks is a central part of each academic discipline. From an ICT point of view, we want students to be skilled in

posing ICT-related problems and questions in each discipline they study. More generally, we want to help our students get better at a full range of uses of ICT in problem solving across the entire curriculum.

Pay special attention to the last item in the bulleted list. If you are familiar with Piaget's cognitive developmental scale, you likely recognize that the last item is similar to Formal Operations, the highest level on the Piagetian scale. In some of my previous articles I have been critical of the ICT progress our educational system is making. We educators are spending far too much time on lower-order aspects of ICT in education, and far too little time on the higher-order aspects (Moursund, 2002).

Some General Background Information

Formal school-based education can trace its history back to the development of reading and writing more than 5,000 years ago. During the past 5,000 years there has been a large accumulation of theory and practice knowledge about teaching and learning (Bransford et al., 1999). Thus, preservice and inservice teachers face a large and steadily growing learning challenge as they work to increase their professional (**content** and **maturity**) knowledge and skills.

Information Explosion

Depending on whom you happen to want to quote, you can find assertions that the totality of human knowledge is doubling every three years, or every five years, or every ten years. In any case, we are living during a time of very rapid growth in the totality of human knowledge. The growth rate is particularly high in science and technology. This growth completely overwhelms a "memorize and regurgitate" type of education.

Moreover, complexity continues to increase. The types of problems that ordinary people tend to face in their everyday lives are becoming more complex. For example, think about your health and diet with respect to rapid increases in medical knowledge and options.

ICT provides powerful aids to the storage, processing, retrieval, and communication of information. It also aids in automating or greatly simplifying the process of solving many problems. The increasing capabilities of ICT systems are both a major contributor to the information explosion and a major aid to coping with problems of information explosion.

Decision Explosion

Recently I thought about a possible restatement of the information explosion or information overload situation. Rather than think about information overload, think about "decision overload." As the totality of human knowledge increases, an ordinary person is faced by more decisions and the decisions are more complex. For example, suppose I have a cold. Just think about the range of options I have available to select from in a typical drugstore or supermarket. Compare this decision-making situation with that faced by adults a hundred years ago.

Suppose I think about my weight and health. I need to make some decisions. I am overwhelmed by the range of choices I have available. This comes from watching television and seeing ads in other media.

Indeed, the media is a big source of my decision overload. There are problems throughout the world. What should I do? There are traffic accidents, burglaries, shootings, etc. throughout the US. What should I do? There are announcements of new research in medicine, new medicines,

and new medical procedures nearly every day. What should I do? I need to make decisions about my retirement money. What should I do?

As a professor, I face the decision of what to include in my courses. With the rapid pace of change in information and communication technology, what can I teach that will be of lasting value to my students?

From my point of view, the essence of the problem is not information overload. Rather, it is a steady increase in the decision-making problems that an individual faces in everyday life. The essence of the problem is the rapid pace of change in the world.

Jean Piaget

Each teacher education program provides a balance of theory and practice. We want teacher to understand key underlying aspects of educational research, and we want teachers to translate this theory into actual classroom practice. The research work of Piaget (1896-1980) and those who have built on this research provides an excellent example.

The astute reader will notice that I have not given a reference for Piaget. A few minutes ago I did a Google search on Piaget, and obtained 630,000 hits. You can view this situation as part of the information explosion, or information overload. Or, you can view it as me being faced by a decision of what one or two references on Piaget to include in this document. My solution is to pass the problem on to you. If you want specific information on Piaget, I assume you will look at some of the materials that are available on the Web and make a decision as to which might be most useful to you. I refuse to make this decision for you. Moreover, I hope that you will pick up on this idea, and incorporate with the students you teach. Part of increasing maturity in a discipline is gaining increased competence and confidence in one's own decisions about what information resources to use.

Piaget's developmental theory came from observations that as children grow older, they can do and can learn to do a variety of things that they had not previously been able to do. Many teachers certainly understood this at an intuitive level many years before Piaget came on the scene. Piaget proposed and explored a four-level cognitive developmental scale: sensorimotor, preoperational, concrete operations, and formal operations. This cognitive developmental theory now plays a significant role in the design of curriculum content, instruction, and assessment.

Piaget and many others have recognized that a student's progress up the Piagetian cognitive development scale may differ considerably from discipline to discipline. This means that it is appropriate to have a Piagetian-type cognitive development scale for each discipline. A later section of this document contains a Piagetian-type cognitive development scale for ICT.

Benjamin Bloom

Many other researchers have addressed related issues. Probably you know about Bloom (1913-1999) and what is now called Bloom's Taxonomy (Bloom's Taxonomy, 1956). Bloom's research focused on learning, especially learning by college students. About 50 years ago he reported on the fact that much of college education focused on lower-order knowledge and skills. Since then it has become clear that this is a problem at all educational levels. Nowadays, there is a strong push for schools to increase their emphasis on the higher-order levels (analysis, synthesis, and evaluation). State and national assessments of precollege students are placing increasing emphasis on problem solving.

Computer systems tend to be good at lower-order knowledge and skills. For example, a computer system has no trouble storing a 100,000-word dictionary, giving definitions and correct spelling when requested to do so. Computers are really good at such “non thinking, memorize and regurgitate” activities.

Indeed, I sometimes use as a definition (to promote debate in my classes and talks): “If a computer can do XXX, then XXX is lower-order.” The reason for this is to emphasize what computers can do better than people, and what people can do better than computers. I believe we currently spend far too much of our school time having students learn to do things that computers can do much better than people. The issue is really one of lower-order versus higher-order. The issue is preparing students to live, work, and play in a computer-rich environment. I believe we need to focus more of our formal education on helping students learn to do things that computers are not good at, and learning to work effectively with computers to solve problems and accomplish tasks.

Brain and Mind Science

Brain Science and Mind Science have a long history, and clearly these disciplines are important to education. Computer people tend to talk about the brain as “wetware” (that is, somewhat akin to hardware) and the mind as software (somewhat akin to systems and applications programs). A different way to look at this is that psychology can be viewed as a study of the mind (mind science), while cognitive neuroscience is a science of the brain.

A hundred years ago, psychologists were making significant progress in studying human intelligence and IQ. They were doing mind science, and teachers were learning to make use of mind science results. They were also laying foundations for the Exceptional Education components of our current educational system. Studies of the cognitive capabilities and limitations of very low IQ and very high IQ people help us to understand some important aspects of teaching and learning.

While reading the previous paragraph, did you mentally review your knowledge and understanding about IQ and the history of IQ? I just did a Google search on *history of IQ*, and obtained 920,000 hits. A search of *IQ* gave me over five million hits. This situation is another example of information explosion—or, it is an example of where you, personally, get to make a decision. Your mental review may lead you to decide that your current knowledge about the history of IQ and the general topic of IQ suffices to meet your needs. If you decide you need to know more, you can browse some of the “hits” and decide which ones might fit your specific needs. This is a higher-order cognitive activity.

Over the past couple of decades, progress in science and technology has led to the development of a variety of brain scanning tools. These tools make it possible to study what is going on inside a brain as it works to solve problems and accomplish tasks. And, of course, you all have some understanding of the progress in genome research, gene therapy, cloning, and related areas.

Perhaps you are also aware of progress that is occurring in developing and using drugs that enhance performance of a brain. Caffeine and Prozac are examples of such drugs. Some of the drugs being developed in research on Alzheimer’s significantly increase brain performance of people who do not have Alzheimer’s.

This research is at the cutting edge. I just did a Google search on brain-enhancing drugs and got only 942 hits. One of the hits caught my attention, and in it I learned about a drug named modafinil. A Google search on that drug produced 228,000 hits. Quoting from

<http://www.modafinil.com/>, "... is a memory-improving and mood-brightening psychostimulant. It enhances wakefulness and vigilance, but its pharmacological profile is notably different from the amphetamines, methylphenidate (Ritalin) or cocaine. Modafinil is less likely to cause jitteriness, anxiety, or excess locomotor activity - or lead to a hypersomnolent 'rebound effect' - than traditional stimulants. Subjectively, it feels smoother and cleaner than the amphetamines too. The normal elimination half-life of modafinil in humans is between 12 - 15 hours. So it's worth fine-tuning one's dosage schedule accordingly.

The previous paragraphs in this section contain a number of examples of information explosion that impinges on the everyday professional lives of teachers and many other people. You are undoubtedly aware of the roles and problems of drugs in amateur and professional sports. Can you imagine what will happen as an increasing variety of cognitive-enhancer drugs become available? Will schools and teachers have to do drug testing on their students when the students are taking tests? How can you tell if some of your students are on modafinil?

Here is a less dramatic (less frightening) example. Teachers, psychologists, and doctors have long understood that an appreciable number of students have great difficulty in learning to read. Work on dyslexia goes back about 150 years. More than a hundred years ago there was some understanding that dyslexia seemed to be related to certain parts of the brain not functioning correctly.

But now we can actually "see" what parts of the brain are most active when dyslexic and non-dyslexic children are reading. We now understand some of the gene differences between dyslexic and non-dyslexic people. Such research has led to the development of instructional interventions that can significantly change a learner's brain. It is beginning to look like appropriate intervention can actually cause a significant rewiring of a brain—in essence, "cure" dyslexia. Some of this intervention is being implemented using highly interactive, intelligent, computer-assisted learning (HIICAL). (See Moursund, 2001).

Attention Deficit/Hyperactive Disorder (ADHD) is another area that lends itself to a HIICAL intervention. It is now understood that "attention" is based on several components of the brain, and significant differences in performance are somewhat dependent on some specific genes that have been identified (Murray, 2003).

Perhaps you can see the pattern. The tools of brain/mind science are allowing researchers to better understand various learning difficulties. HIICAL and drugs are being developed to help deal with some of these learning difficulties.

Human Intelligence

A person's intelligence is comes from a combination of nature (genes) and nurture. For many years, psychologists studying the human brain/mind have tried to measure its capabilities. Quite a bit of this work has focused on defining intelligence and measuring a person's intelligence.

The concept that intelligence could be or should be tested began with a nineteenth-century British scientist, Sir Francis Galton. Galton was known as a dabbler in many different fields, including biology and early forms of psychology. After the shake-up from the 1859 publishing of Charles Darwin's "The Origin of Species," Galton spent the majority of his time trying to discover the relationship between heredity and human ability (History of I.Q., n.d.).

Intelligence can be divided into two major components or factors: fluid intelligence (Gf) and crystallized intelligence (Gc).

The first common factor, **Gf**, represents a measurable outcome of the influence of biological factors on intellectual development (i.e., heredity, injury to the central nervous system), whereas the second common factor, **Gc**, is considered the main manifestation of influence from education, experience, and acculturation. (Healy & McNamara, 1996).

While a person's level of fluid intelligence tends to peak in the mid 20s, growth in crystallized intelligence may continue well into the 50s. Since decline in fluid intelligence over the years tends to be relatively slow, a person's total cognitive capabilities can remain high over a long lifetime. Current research indicates that for the brain/mind, as well as the rest of the body, "use it or lose it." (See Goldberg, 2005.)

I am particularly interested in the combination of a person's intelligence with an ICT system's intelligence. Through appropriate education of a person and programming of an ICT system, the person and ICT system can "learn" to work well together. Each brings different capabilities and limitations to a problem-solving task. Together, the human/ICT system team can solve problems and accomplish tasks that neither can do alone. This learning to work together is an important aspect of increasing ICT maturity.

Artificial Intelligence

Artificial intelligence (AI) is a branch of the field of computer and information science. It focuses on developing hardware and software systems that do things that would require intelligence if done by people (Moursund, 2004b). Note that this type of definition does not require the ICT systems to use human-type knowledge, skills, and understanding to solve problems and accomplish tasks. Some AI researchers attempt to build ICT systems that emulate human brains and bodies. Others take a more pragmatic approach, often focusing on problem-solving approaches that are completely different from those that a human uses. For example, the computer system that beat the world's reigning chess champion in 1987 could examine and analyze 3 million different chess board positions per second. This is at least a million times as fast as the fastest humans can do.

The theory and practice of AI is leading to the development of a wide range of artificially intelligent tools. These tools, sometimes working under the guidance of a human and sometimes without external guidance, are able to solve or help solve a steadily increasing range of problems. Over the past 50 years, AI has produced a number of results that are important to students, teachers, our overall educational system, and to our society.

Some of the futurists in the field of AI see a time (within the lifetimes of many readers of this document) when AI systems will be more intelligent than humans. You do not have to believe this forecast—but certainly you understand that ICT systems are growing in capability, and that they currently surpass humans in some (limited) areas. Our educational system faces the problem of the extent to which we help students learn to compete with AI systems versus the extent to which we educate students to work with AI systems.

A similar challenge also faces teachers themselves. We already have a number of examples of HIICAL systems that can outperform human teachers in limited areas.

Computer as Auxiliary Mind/Brain

Although you may not know the name Douglas Engelbart, you are certainly familiar with the computer mouse that he invented. More than 50 years ago, well before he invented the mouse, Engelbart began to work on the idea of computer as an auxiliary mind/brain (Bootstrap Institute,

n.d.). Of course, science fiction addressed this topic much earlier, and the first computers were called electronic brains. But Engelbart has spent a lifetime working in this discipline. Some unifying ideas quoted from the Bootstrap Institute Website include:

Our world is a complex place with urgent problems of a global scale.

- The rate, scale, and complex nature of change is unprecedented and beyond the capability of any one person, organization, or even nation to comprehend and respond to.
- Challenges of an exponential scale require an evolutionary coping strategy of a commensurate scale at a cooperative cross-disciplinary, international, cross-cultural level.
- We need a new, co-evolutionary environment capable of handling simultaneous complex social, technical, and economic changes at an appropriate rate and scale.
- The grand challenge is to boost the collective IQ* of organizations and of society. A successful effort brings about an improved capacity for addressing any other grand challenge.

This quoted material summarizes the idea of computers (whose capabilities are expanding exponentially) being used as an aid to increasing the collective intelligence of the human race in an effort to address global problems of immense proportion. In a recent interview Engelbart was asked how much progress has occurred in this endeavor. He replied that on a scale of 1 to 10 (with 1 being the low point), we are now at 1.8. I interpret this to mean that during your lifetime, and the lifetime of your students, and the lifetime of your students' children, and so on, we will continue to move up this scale.

Academic Disciplines

Our PreK-12 curriculum introduces students to a number of different academic disciplines. Some of these disciplines are approached via sequence of courses—a multiyear strand. Other disciplines or sub disciplines are only briefly touched upon in our Prek-12 curriculum.

An academic discipline can be described or characterized by an appropriate discussion of components such as:

1. The types of problems, tasks, and activities the discipline addresses.
2. Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, producing products, and so on.
3. Its accumulated accomplishments, results, achievements, products, performances, scope, power, uses, and so on.
4. Its history, culture, and language (including notation and special vocabulary), and ways of representing, archiving (storing, retrieving, sharing) its results.
5. Its methods of teaching and learning.
6. Relationships between the discipline and other disciplines.

Each of the major disciplines that is approached as a multi-year strand in our K-12 curriculum has considerable depth and breadth. It is possible to spend a lifetime gaining a high level of expertise in just a small component of one of these disciplines. For example, science is a multi-year strand, but a researcher can spend a lifetime working in a small piece of science, such as quantum physics.

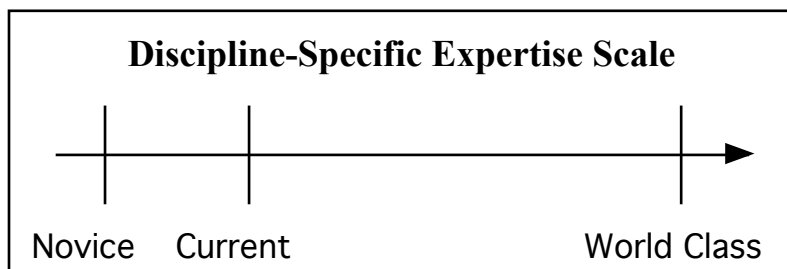


Figure 1. Expertise scale.

Thus, curriculum designers and teachers need to think very carefully what aspects of a particular discipline should be emphasized within a discipline-specific curriculum strand. Nowadays it is common to establish standards that we would like students to meet within various disciplines such as language arts, math, science, and social science. Standards have been developed in many other disciplines, including ICT (ICTE NETS, 1998).

For the most part, these standards focus on content and not on maturity. While is sometimes not clear whether a topic is mainly discipline specific content oriented or mainly discipline specific maturity oriented, you may find it helpful to select a discipline you know well and analyze the list of six discipline components listed above. For each component, see if you can extract some content aspects and some maturity aspects.

One way to think about content versus maturity is to think about some course you have taken in the past. Perhaps high school geometry is a good example. Unless you are a math teacher, the chances are that you do not remember very many theorems and proofs from your high school geometry course. What do you remember that you feel is of lasting value? Perhaps you remember that in geometry you learned to work with very precise definitions, that there were theorems, and that you learned to prove some theorems. The ideas of precise definition, theorems, and proofs are independent of any specific examples, They are part of your current level of math maturity.

Discipline-Specific Maturity

Math people have long talked about the idea of a student having (or, not having) math maturity. They are not talking about specific courses the student has taken or specific math content that the student has learned. Rather, they are talking about aspects such as a student understanding the math that s/he has studied and solving math-related problems s/he has not previously encountered. They are talking about theorem proving, precise mathematical communication, mathematical logic and reasoning, knowing how to learn math, problem posing, transfer of learning (being able to use one's math knowledge and make math connections over a wide range of disciplines and in novel settings), and interest (including intrinsic motivation) in math (Moursund, 2005).

I find it interesting to talk to teachers about what they think their students will remember and be able to do a year or more after completing a course. This conversation typically includes asking the teacher to do some introspection about his or her own education. The result of such a conversation is that the teacher gains a considerable better understanding of the need to teach for increased maturity

Each discipline can be analyzed in a manner that helps to differentiate between content and maturity. Thus, for example, we can explore the idea that as students take a history course, we want them to learn some history content and we want them to increase their history maturity.

Here are three examples of maturity aspects of history education.

1. Consider studying history from a causality point of view. The idea is to gain increasing ability to analyze historical events from a cause-effect point of view.
2. Consider making use of primary resources and multiple sources of information. The idea is to gain increasing ability to find and analyze historical information.
3. Consider the idea of generating and testing historical hypotheses. This is akin to using scientific method in learning and “doing” history.

At the current time, our educational system tends to stress content that can be assessed by traditional forms of testing. This approach to assessment and education encourages teachers teaching to the test, students learning (and memorizing) specifically for the test, and students then forgetting most of what has been covered in a course.

Communication Maturity

Reading is much more than decoding the words in a sentence. It is a process of building meaning and understanding. That is, reading is a constructive process. Reading in the sciences and mathematics is particularly difficult. Part of the reason is that these disciplines make use of an extended symbol set, part is because the vocabulary tends to be challenging, and part is the precision in communications. ICT writing draws heavily from science and math. In addition, it has some of its own vocabulary and symbols. For example, K has a different meaning in ICT from its meaning in science; a Mac is a type of computer, not a type of hamburger.

An important aspect of gaining increasing expertise and maturity in a discipline is gaining increasing precision and fluency in reading, writing, speaking and listening. Another important aspect is gaining increasing skill in retrieving information about the discipline. Many teachers are weak in their ICT communication skills. They have difficulty in providing a teaching and learning environment that helps their students develop precision and fluency they need to gain an increasing level of ICT maturity.

Interdisciplinary Maturity

The discipline or professional of teaching is challenging because of its depth and breadth. If you are an elementary school teacher, you understand the challenge of having adequate content knowledge, content-pedagogical knowledge, and maturity in each of the many disciplines you teach. If you teach at the secondary school level, you have focused your leaning in a smaller number of content areas, but you are expected to have considerable depth of content knowledge, pedagogical knowledge, and maturity within this smaller number of disciplines.

No matter what you teach, you understand the concept of reading and writing across the curriculum. You know that math is an important aid to representing and solving problems in whatever disciplines you teach. You understand that reading and writing poetry is a lot different

than reading and writing math. You understand reading a novel is a lot different than reading a science textbook.

ICT is a discipline that shares many commonalities with reading, writing, and math. Thus, no matter what disciplines and grade levels you teach, you are faced by the challenge of “ICTing across the curriculum.”

Consider the discipline of ICT in Education and your own preparation in this discipline area. You know that to be an effective teacher in a discipline, you need content knowledge and skills, pedagogy knowledge and skills, and maturity. Look back through the list of six aspects of a discipline given in the previous section. Analyze your level of expertise in the discipline of ICT in Education. What are your components of greatest strength, and what are your components of relative weakness?

Cognitive Development Theory

Piaget’s four-level cognitive development scale is given in Figure 2. Let’s discuss some of the more recent insights into (improvement on) this theory, and possible ways that ICT may affect this theory.

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

Figure 2: Piagetian cognitive development scale.

The highest level of Piaget’s scale is general, broad-based formal operations that can be applied over the full range of one’s activities. It requires critical, higher-order thinking, as well as working with abstract symbols and representations of problems (Huitt and Hummel, 2003).

Most people tend to think of students moving steadily up the Piagetian scale as they move towards and through adolescence. However, the reality is that this upward movement is highly dependent on formal and informal education, and only about 35% of students in our country reach broad-based formal operations by the time they finish high school (Huitt and Hummel, 2003).

My analysis of this situation suggests that many secondary school courses are being taught over the heads of typical high school students. My recent book (Moursund, 2005) provides a number of examples from the mathematics curriculum. I believe it is possible to find important examples in each discipline. For example, some of the key ideas in the teaching of history are helping students understand causality, develop and test historical hypotheses (somewhat akin to scientific method being applied to the study of history), and read, analyze, and understand primary resources. This type of learning and activity is at a Formal Operations level on the Piagetian cognitive developmental scale.

It is useful to view the Piagetian cognitive development scale within specific disciplines or areas of intelligence. This is somewhat akin to viewing intelligence in the way that Howard Gardner (and many people earlier than Gardner) does—as a number of different areas in which one has intelligence (Gartner, n.d.). In terms of cognitive development, a person might be at formal operations in their use of language but not in their use of math, or vice versa. A person may meet the Piagetian criteria to be at formal operations in many disciplines, but still not be at formal operations in ICT.

We can think of ICT in several different ways:

1. As a general aid to informal and formal education in each academic discipline—designed in a manner to help a student move toward Formal Operations within that discipline.
2. As part of the content of each discipline. Within each discipline we need to consider what aspects of the combined ICT/discipline content are important to moving up the developmental scale.
3. As a discipline in its own right. If we want students to be moving towards Formal Operations within this discipline, then we need to ensure that they receive appropriate informal and formal education within this discipline.

Children and Media

In the past, there has been substantial research done on children and media such as radio and television. In recent years the has broadened into other media such as computers and electronic games. The National Science Foundation has funded a Children's Digital Media Center. (See CDMC.) Its goal is to “shed light on how entertainment media impact the development of youth and then disseminate that information to policy makers and businesses.” The recent work of this five-university center has led to the publication of a number of quite useful papers. For example, notice the bolded part in the abstract quoted below.

Calvert, Sandra et al. (2005). Age, ethnicity, and socioeconomic patterns in early computer use: A national survey. Accessed 3/5/05: http://cdmc.georgetown.edu/papers/age_ethnicity_and_socioeconomic_patterns.pdf

Parents were interviewed about the media habits of their 6-month to 6-year-old children. For children who had used computers, linear increases in computer usage occurred across this age range with a shift from using a computer on a parent’s lap at about age 2 1/2 to autonomous computer and mouse use at about age 3 1/2. There were almost no gender differences in early computer patterns. Families with higher incomes and higher education levels were more likely to own computers and to have Internet access from home. Latino families were least likely to own a computer; Latino and African American families were less likely than Caucasian families to have Internet access at home. **Parents perceived computers favorably for children’s learning. No relationship was found between the frequency with which children play computer games and**

the likelihood that they can read, but increased non game computer use was associated with increased likelihood of reading. [Bold added for emphasis.]

ICT Developmental Scale

Figure 3 contains an ICT cognitive developmental scale based on the ISTE NETS for students. There is a strong parallel between this scale and the Piagetian cognitive development scale. I consider this scale to be a work in progress, and I will undoubtedly make changes to it in the future. However, I feel that in its current form it is already quite useful.

Stage "Title"	Age and/or Education Levels	Brief Discussion
Stage 1. Piagetian Sensorimotor.	Age birth to 2 years. Informal education provided by parents, and other caregivers.	Infants use sensory and motor capabilities to explore and gain increasing understanding of their environments. ICT has brought us a wide range of sound and music-producing, talking, moving, walking, interactive, and developmentally appropriate toys for children in Stage 1. These contribute both to general progress in sensorimotor growth and also to becoming acquainted with an ICT environment.
Stage 2. ICT Preoperational.	Age 2 to 7 years. Includes both informal education and increasingly formal education in preschool, kindergarten, and first grade.	During the Piagetian Preoperational stage, children begin to use symbols, such as speech. They respond to objects and events according to how they appear to be. They accommodate to the language environments they spend a lot of time in. ICT provides a type of symbols and symbol sets that are different from the speech, gestures, and other symbol sets that have traditionally been available. TV and interactive ICT-based games and edutainment are a significant environmental component of many children during Stage 2. During this stage children can develop considerable speed and accuracy in using a mouse, touch pad, and touch screen to interact and problem solve in a 3-dimensional multimedia environment displayed on a 2-dimensional screen.
Stage 3. ICT Concrete Operations.	Age 7 to 11 years. Includes informal education and steadily increasing importance of formal education at grades 2-5 in elementary school.	During the Piagetian Concrete Operations stage, children begin to think logically. In this stage intelligence is demonstrated through logical and systematic manipulation of symbols related to concrete objects. Operational thinking (mental actions that are reversible) develops. ISTE has established NETS-Student that includes a statement of what students should be able to do by the end of the fifth grade. During the ICT Concrete Operations stage children: <ul style="list-style-type: none"> • Learn to use a variety of software tools such as those listed in the 5th grade ISTE NETS-Student, and begin to understand some of the capabilities and limitations of these tools. (They do logical and systematic manipulation of symbols in a computer environment.) • Learn to apply these software tools at a Piagetian Concrete Operations level as an aid to solving a wide range of general curriculum-appropriate problems and tasks.
Stage 4. ICT Formal Operations.	Age 11 and beyond. This is an open ended developmental stage, continuing well into adulthood. Requires ICT knowledge, skills, speed, and	During the Piagetian Formal Operations stage, thought begins to be systematic and abstract. In this stage, intelligence is demonstrated through the logical use of symbols related to abstract concepts. Formal Operations in ICT includes functioning at a Piagetian Formal Operations level in specific activities such as: <ol style="list-style-type: none"> 1. Communicate accurately, fluently, and with good understanding using the vocabulary, notation, and content of ISTE NETS-S for the 12th grade. 2. Given a piece of software and a computer, install and run the software, learn to use the software, explain and demonstrate some of the uses of

	<p>understanding of topics in ISTE NETS for students finishing the 12th grade.</p>	<p>the software, save a document you have created, and later return to make further use of your saved document.</p> <ol style="list-style-type: none"> 3. Problem solve at the level of detecting and debugging hardware and software problems that occur in routine use of ICT hardware and software. 4. Convert (represent, model, pose) real world problems from non-ICT disciplines into ICT problems, and then solve these problems. 5. Routinely and comfortably use ICT in the other disciplines you have studied, at a level consistent with and supportive of your cognitive developmental level in these disciplines. 6. Have a conceptual understanding of similarities and differences, and capabilities and limitations, of human mind/brain versus ICT systems. Work comfortably and competently with ICT systems as auxiliary mind/brains.
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Figure 3: ICT cognitive developmental and expertise scale.

Notice the generality of this ICT cognitive developmental scale. It does not speak to specific brands of hardware and software. It does not speak to specific pieces of software. It is inherent to the scale that moving up the scale requires learning to learn ICT and to apply what one has learned. It requires gaining a broad range of skills and increasing confidence in handling the problems that are inherent in using “buggy” ICT hardware and software systems. Here is some additional analysis of the ICT cognitive development and expertise scale.

ICT Sensorimotor and Preoperational

Brain and mind are growing very rapidly during the Sensorimotor and Preoperational stages of the ICT developmental scale. A substantial amount of the learning that occurs is situational and cultural. If one’s home and community environment is bilingual or trilingual, a child becomes bilingual or trilingual. A child learns the culture in an unquestioning manner at a deep, long-lasting level.

Nowadays, the home environment of many children includes computerized toys, computers, cell phones, TV, and electronic games. Research into the effects of growing up in such an environment is rather limited. When I encounter good arguments against early use of computers, I collect them in my Website (OTEC, n.d.)

I like to analyze the situation of a child’s early years in terms of Robert Sternberg’s three-part definition of intelligence. His triarchic model considers creativity, street smarts, and school smarts (Sternberg, 1988). We know that large numbers of students enter kindergarten or the first grade a year or more behind others in terms of their school smarts. Much of this difference can be traced to the socioeconomic and school-oriented home and cultural environment. Students growing up in low socioeconomic environments that place relatively little emphasis on school-oriented activities tend to emphasize use their fluid intelligence and creativity in areas that are classified as street smarts. They are less well prepared for school (on average) than children growing up in higher socioeconomic, school-oriented home environment.

For me, personally, I want my grandchildren to grow up in a home environment that includes computerized toys and music, computers, cell phones, TV, digital still and video cameras, and electronic games. I think that this is an important aspect of preparation for school and their adult lives. And, it contributes to a child moving up the ICT developmental scale.

ICT Concrete Operations

The approximate age range for Concrete Operations is the same as elementary school. The following is quoted from the ISTE National Educational Technology Standards (ISTE, 1998), indicating part of what ISTE feels a student should be able to do by the end of the fifth grade:

4. Use general-purpose productivity tools and peripherals to support personal productivity, remediate skill deficits, and facilitate learning throughout the curriculum.
5. Use technology tools (e.g., multimedia authoring, presentation, Web tools, digital cameras, scanners) for individual and collaborative writing, communication, and publishing activities to create knowledge products for audiences inside and outside the classroom.
6. Use telecommunications efficiently and effectively to access remote information, communicate with others in support of direct and independent learning, and pursue personal interests.

There is considerable emphasis on learning to use a variety of tools. Students tend to be good at learning the concrete operations aspects of a wide variety of computer tools. The tools tend to be concrete in nature. A sequence of mouse clicks and keystrokes produces concrete results that a student's visual and auditory systems can process. There is little need to understand what is going on behind the scenes—a "black box" type of knowledge tends to suffice.

However, this learning situation is made more complex because each tool is designed to help solve problems and accomplish tasks. Many ICT tools are inherently designed for higher-order use. This means that effective teaching of the tools needs to be done in a situated learning environment that has a strong learning toward higher-order cognitive activities. This needs to be done at a time when students are at a Concrete Operations level.

Seymour Papert worked with Piaget for five years and is well known for his work in helping to develop the Logo programming language. Papert has been a long time supporter of the idea that an appropriate learning environment (such as a Logo environment) can hasten a student's movement toward Formal Operations. Many neo-Piagetians support this idea.

Another important aspect of computer use during the Concrete Operations stage is that students can be empowered to address more interesting and challenging problems. Computer graphics, computer animation, and the editing of digital still and video pictures provide a wonderful environment for such activity, as do computer-based music composing and performance systems.

ICT Formal Operations

I believe that many educational leaders understand that lots of elementary school teachers have not achieved Formal Operations over the full range of disciplines they are expected to teach. There tends to be an assumption that Secondary School teachers have reached Formal Operations in the areas they are certified to teach, as they have had to take a significant amount of college work in these disciplines.

Now, consider the situation in which every teacher is expected to routinely incorporate appropriate uses of ICT into their curriculum, instruction, and assessment. (Remember, this is somewhat akin to the expectation that every teacher is expected to contribute to students learning reading, writing, speaking, and listening within each discipline they teach.) Go back to Figure 2 and reread the Formal Operations part of the table. I believe that you will agree that relatively few teachers satisfy this definition of ICT Formal Operations.

This means that our educational system is creating (has created) a situation in which teachers are supposed to be moving their students toward ICT Formal Operations, but the teachers are not at this ICT developmental level. Quite a few teachers face a similar challenge outside of the ICT discipline if they teach a broad range of disciplines (such as elementary teachers do) or teach outside their credentialing areas (as many secondary school teachers do).

This problem does not have a simple solution. However, most teachers have at least one discipline area in which they function at the Formal Operations level. Thus, they know what it means to function at a Formal Operations level. With appropriate thought, most teachers can transfer a number of the key concepts of being at Formal Operations in one discipline they teach, to other disciplines they teach were they are not yet at formal operations.

Final Remarks and Recommendations

The next few decades will bring us continued very rapid progress in ICT hardware and software. They will also bring us continued rapid progress in understanding the human mind and brain. The pace of change in these two disciplines is already a major challenge to teachers, our teacher education system, and to the precollege curriculum. This problem will continue to grow. I recommend four major approaches to this situation:

1. Our educational system at all levels needs to place increased emphasis on problem solving (higher-order cognitive activities) and on students learning to work with ICT in problem solving.
2. Our educational system needs to understand and then act upon the idea of ICT providing us with an auxiliary mind/brain that will be more and more capable as time goes on.
3. Our educational system needs to provide much better opportunities for teachers to learn on the job—often by learning alongside their students. Our teacher education programs need to help preservice teachers learn to learn alongside their students.
4. Our educational system needs to develop an understanding of content knowledge versus maturity, and help students to gain increased discipline-specific and interdisciplinary maturity.
5. Our educational system needs to do better in measuring and then paying attention to each individual students cognitive developmental level in each discipline. Highly Interactive Intelligent Computer-Assisted Learning needs to become available in all disciplines and grade levels.

References

Bloom's Taxonomy (1956.). Major categories in the taxonomy of educational objectives. Accessed 2/27/05: <http://faculty.washington.edu/krumme/guides/bloom.html>.

Bootstrap Institute. Accessed 2/26/05: <http://www.bootstrap.org/>.

Bransford, J.D.; A. L. Brown; & R.R. Cocking: editors (1999). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press. Accessed 2/28/05: <http://books.nap.edu/catalog/6160.html>.

Gardner, Howard (n.d.). Accessed 10/8/04: <http://www.ed.psu.edu/insys/ESD/gardner/menu.html>.

CDMC. Children's Digital Media Center. Accessed 3/5/05: <http://cdmc.georgetown.edu/>

- Goldberg, Elkhonon (2005). *The wisdom paradox: How your mind can grow stronger as your brain grows older*. NY: Gotham Books.
- Healy, A.F., & McNamara, D.S. (1996). Verbal Learning and memory: Does the modal model still work? *Annual Review of Psychology*, 47, 143-172.
- History of I.Q. (n.d.). Accessed 2/28/05: <http://www.testcafe.com/iqtest/history.html>.
- Huitt, W. and Hummel, J. (January 2003). *Cognitive development*. Accessed 6/29/04: <http://chiron.valdosta.edu/whuitt/col/cogsys/piaget.html>.
- ISTE (1998). *National Educational Technology Standards for Students*. Accessed 7/15/04: <http://cnets.iste.org/>.
- McArdle, John et al. (2002). Comparative longitudinal structural analyses of the growth and decline of multiple intellectual abilities over the life span. *Developmental Psychology* Vol. 38, No. 1, 115–142. Accessed 2/27/05: http://66.102.7.104/search?q=cache:0JRtLVQbhvEJ:psychology.ucdavis.edu/labs/ferrer/pubs/dp_2002.pdf+gF+gC+growth&hl=en.
- Moursund, D.G. (2002). Getting to the second order: Moving beyond amplification uses of information and communications technology in education. *Learning and Leading with Technology*. v30 n1. Accessed 7/15/04: http://darkwing.uoregon.edu/~moursund/dave/second_order.htm.
- Moursund, D.G. (2004a). *Brief introduction to roles of computers in problem solving*. Accessed 7/15/04: <http://darkwing.uoregon.edu/%7emoursund/SPSB/>.
- Moursund, D.G. (2004b). Brief Introduction to educational implications of artificial intelligence. Accessed 2/27/05: <http://darkwing.uoregon.edu/~moursund/AIBook/>.
- Moursund, D.G. (2005). *Improving math education in elementary schools: A short book for teachers*. Accessed 2/27/05 <http://darkwing.uoregon.edu/~moursund/Math/ElMath/>.
- Moursund, D.G. (April 2001). Highly interactive computing in teaching and learning. *Learning and Leading with Technology*. Eugene, OR: International Society for Technology in Education. <http://darkwing.uoregon.edu/~moursund/dave/LLT-V28-2000-01.html#Ed%202000-2001%20%23%207>.
- Murray, Bridget (October 2003). *Training young minds not to wander: New research suggests that, beyond genes, experience affects a specific brain network involved in attention*. *APA Online*. Accessed 2/24/05 <http://www.apa.org/monitor/oct03/young.html>.
- NSF News Release (February 11, 2005). *Children, TV, computers and more media: New research shows pluses, Minuses*. Accessed 3/4/05: http://www.nsf.gov/news/news_summ.jsp?cntn_id=102813&org=NSF&from=news.
- OTEC (n.d.). Arguments against using IT in education. Accessed 2/28/05: http://otec.uoregon.edu/arguments_against.htm.
- Sternberg, Robert (1988). *The triarchic mind: A new theory of human intelligence*. NY: Penguin Books. Information about Sternberg and his writings is available at (Accessed 2/28/05): <http://www.psy.pdx.edu/PsiCafe/KeyTheorists/Sternberg.htm>.