## *Several Core Thinking Skills are at the Heart of Learning*



# Thinking Skills for Innovation and Problem-Solving: An Education Perspective

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### Introduction

A purpose of this paper is to encourage a discussion amongst engineers about the importance of thinking skills in elementary and secondary school education. This paper looks briefly at the Ontario Secondary School Technological Design course because of its close association with the goals of an engineering education. Of the nine "Essential Skills" listed by Human Resources and Skills Development Canada[1] (HRSDC), this paper addresses only "Thinking Skills" (but in the general context of learning in any classroom subject). Thinking skills are at the root of learning and should therefore be considered the most important of the nine essential skills (followed closely by Continuous or Lifelong Learning). The major purpose of this paper is to propose a thinking skills framework to enable profound student learning to be well-matched to society's expectations as stated in the Ontario curriculum[2].

"Learning how to learn" should be the driving force in every classroom. Eventually, with very careful progression of learning activities and strategic exercising of high level thinking skills, most students should become capable of designing their own learning activities in support of their own career goals. This should ideally be the ultimate goal of every education system. Student-designed learning activities may be too much to ask of all students, but this strategy could soon be doable for students who have decided to aim for professional engineering. Designing one's own learning activities is good practice for what engineers do a great deal of – design. It would seem reasonable for engineers to develop innovative ways to engage students directly in the design of their own learning.

### Engineering and the Technological Design Course

Technological Design is an important course in the Ontario secondary school curriculum. Technological Design is the union of knowledge, good citizenship, thinking, communication, organization, time management, general employability and other skills across virtually all subject areas. Courses in Technological Design are ideal opportunities to construct well-scoped interdisciplinary views of real-world systems and real-world processes.

To put it another way:

- Technological Design is all about the design process
- Technological Design = Science + Design + Fabrication
- Technological Design is the highest level of problem solving – (Inquiry / Design / Fabricate Models or Prototypes)
- Technological Design is an evolving family of processes and tools
- Technological Design = Engineering (at least as close as you can get)

Engineering education can be viewed as the intersection of general education and education for STSE (science, technology, society and environment) – truly multi-disciplinary.

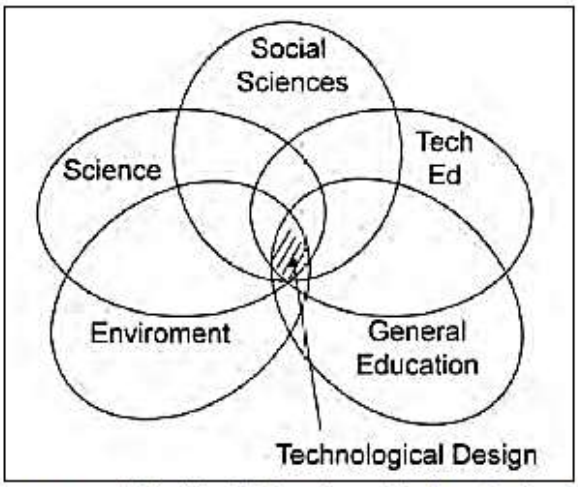


**Figure 1.** A Model of Education – Engineering is at the Heart

**Engineers Design and Solve Problems Largely by Thinking**

What is most critical in secondary school – the "what" to learn or the "how" to learn? – the "product" or the "process"?

To succeed as a designer, one must first learn how to design – grasp relevant concepts, develop good processes, appreciate the value of feedback and incremental improvement. Much more importantly, "design" depends a good deal on creative thinking skills. However, the most creative original idea will not do well in the market if it does not fit a need or meet an opportunity or add value to society. Making sure an idea "fits" depends on careful analysis of the overall system – this is an aspect of critical thinking. Design must be taught by clearly teaching a sound "design process", supplemented by creativity and lateral thinking. So the critical subject matter in school is really the "process".

To succeed in the world of work, one must first learn how to become a good problem-solver. Many students have significant difficulty solving problems in mathematics, often relying on trial-and-error or outright guesswork. So we spend a good deal of time in math class working on solving "word problems" using mathematics. Unfortunately, this often comes down to essentially matching a word problem to one of the most recently taught algorithms.

Successful problem-solving depends at least partly on knowing which "tool" to use in a particular situation, whether in math class, tech class or anywhere else. Knowing that these tools exist, how to use them and "when to use them where" is learning that needs to happen before we can expect to be a good "problem-solver". Our greatest problem-solving tool is the brain – but we spend precious little class time on how to effectively use the brain and its various subordinate tools, thinking skills in particular. Problem solving must be strategically taught by clearly teaching techniques, tools and strategies. So, again, the critical subject matter in school is the "process".

To really succeed in the modern world of work, one must first learn how to become a good thinker. Thinking skills are the single most important of all "Essential Skills". One cannot write effectively without thinking. You absorb very little of value when reading unless you are thinking. Thinking skills are absolutely crucial to becoming a good learner. Thinking is one of the four achievement categories in education in Ontario. (Knowledge / Understanding, Communication and Application are the other three.) Thinking skills are at the very root of successful problem-solving. Yet we spend very little time in school actively and formally learning how to think. We must spend more time in school formally learning how to learn. The critical subject matter is, once again, the "process" of learning.

**What's Critical in Education – Product or Process?**

To summarize the previous section, the process of learning – learning how to learn – is far more important than what many people think of as the "product" of learning or the so-called "content", for example, memorizing definitions or what command to use in a certain software application or the dates of significant events in our political history. "Learning how to learn" should really be the main focus of teaching in elementary and secondary school. This of course suggests that "Lifelong Learning" is second only to Thinking Skills as the most essential of the nine essential skills. The "what" to teach in school is really the "process of learning".

**A Definition, Examples and Applications of "Thinking"**

Human Resources and Skills Development Canada (HRSDC)[3] defines thinking as:

*"Finding and evaluating information to make rational decisions or to organize work."*

And lists the following as typical applications of thinking: identify and resolve problems; make decisions; find information; plan and organize job tasks; use critical thinking; use memory.

The Ontario Curriculum for Technological Education breaks down the "Thinking" achievement category as follows:

1. planning skills (e.g., identifying the problem, selecting strategies and resources, scheduling)
2. processing skills (e.g., analysing and interpreting information, reasoning, generating and evaluating solutions, forming conclusions)
3. critical / creative thinking processes (e.g., problem-solving, design, and decision-making processes)[4]

**Thinking as a Set of Operations in the Brain -- Processing Skills**

Just as we can ultimately teach reading and writing by breaking down ideas into sentences, phrases and words, we can teach thinking by breaking down how we can cognitively handle ideas. The thinking skills model presented below breaks down thinking into seven core processing skills, all of which are operations in the brain and all of which can be practised in class. In this sense, we could perceive Thinking to be just as much a "Learning Skill" (which cannot be marked or graded in Ontario) as it is an Achievement Category (i.e. something that is to be marked or graded). Indeed, the new Ontario policy document "Growing Success: Assessment, Evaluation and Reporting"[5] now lists a new "Learning Skill" – "Self-Regulation". Clearly, self-regulation is quite impossible without serious inward-looking thinking.

To be complete, the learning process must involve a great deal of "quality thinking". After "doing", "seeing" and "hearing", the human mind must do a certain amount of processing in order for a module of learning, knowledge or skill development to be solidified. This is generally called "thinking". Note that reflection "after the fact" is not sufficient in school. While most would classify thinking as a skill, to become a good thinker first requires the learner to develop sound attitudes such as willingness, persistence, flexibility and openness[6].

The general topic of "thinking" seems rather daunting. As with any other seemingly overwhelming problem-solving situation, we can simplify. The following is one simple model of thinking.

*Seven core thinking skills (in order from simplest to most demanding) are: recall, translate, interpret, apply, analyze, synthesize, and evaluate.*

These are seven operations which we can perform in the brain. These cognitive operations are essentially the processing skills listed in the Ontario Curriculum as noted above.

This simple model of thinking skills is based partly on Bloom's Taxonomy[7], a very useful and widely recognized classification of cognitive mastery. Any particular unit of learning should build from simple questioning at the recall of concepts level through to the more challenging system analysis, synthesis of the solution and validation or evaluation of results.

**Creative Thinking and Critical Thinking**

Creative thinking can be used to improve the multifaceted socio-economic-political environment which we all share. Creative thinking is best used in multidisciplinary efforts in very close connection with thorough critical thinking that reaches for a solid understanding of a sustainable social, economic or political system.

Creative thinking is, very generally, a collection of skills, attitudes and concepts centred on the Synthesis form of thinking. Critical thinking is, very generally, a collection of skills, attitudes and concepts centred on the Analysis form of thinking. Skilled analysis, synthesis and evaluation are at the heart of any successful technological design project. "Reverse engineering" a piece of technology, whether simple or complex, is a powerful tool for improving analytical skills. Critical thinking is not just analysis as it involves the thinker having certain well-developed attitudes as well. Critical thinking speaks more to the quality of the thinking that is performed.

**Seven Core Thinking Skills -- A Model of Thinking**

All students should actively practice the following thinking skills where relevant to their application projects. Note that the terms in the right hand column are sample ways to practise that thinking skill.

The higher thinking skills are beginning to develop at the age of 13 or 14. It is important to strategically exercise these skills at this age – or even earlier. It is also important to note that, in using a higher form of thinking, one is also generally using some aspects of each lower form.

| Thinking Skill | Sample Cognitive Activities |
|---|---|
| **Higher Forms of Thinking** | |
| Evaluate | judge against criteria; self-examine |
| Synthesize | output or put together<br>(one aspect of creativity) |
| Analyze | break down or take apart (eg an idea or argument); reverse-engineer; use formal logic<br>(one aspect of critical thinking) |
| Apply | use knowledge of concepts and use skills in a new or different situation |
| **Lower Forms of Thinking** | |
| Interpret | make assumptions; ask questions to obtain clarification; summarize; sort; establish classifications; reveal relationships; combine; make connections with other courses etc. |
| Translate | put into one's own words; decode a sentence; transform from English words into a math equation |
| Recall | remember; pull out of memory |

Here is another view of this simple model of seven core thinking skills that supports the design process, problem-solving and innovation:

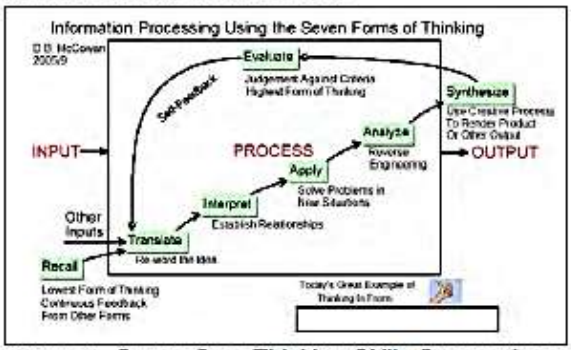


**Figure 2.** Seven Core Thinking Skills Support Innovation

### Grade 9, a Turning Point: The 80/20 Principle and Determining Key Information

Imagine it is September and you are a grade 9 student. You are asked to read a chapter in the textbook – maybe there's a quiz tomorrow. Although you would prefer it, in high school the teacher should not write on the chalkboard the handy 10-point summary of the chapter that you can easily memorize. But now you're in grade nine – finding the key information is now your job. The spoon-feeding is over – you are now an independent learner. To find those 10 key points in the chapter, use the 80/20 principle. This principle basically states that only 20% of the information (e.g. in a chapter of a book) provides 80% of the value. So, how do you know which 20% is most important? Up to say grade 5, the teacher will probably jot these key points on the board – but this must clearly be done with a view to actually teaching the 80/20 principle. But by grade 9, students should be able to determine this key information at least partly on their own. Students can use the following as a very basic guideline when summarizing a chapter or some other collection of information.

**What information here will be useful in some way for the rest of my learning and working life?**

Of course, this is all about the Essential Skill that we call Lifelong Learning or Continuous Learning. Rigorous use of thinking skills profoundly supports Lifelong Learning. This ties directly back to the Overall Expectations in Ontario courses. This connects to the big picture of all learning.

But beware, that key 20% of the information in a chapter that is so valuable may not be spelled out in clear discrete sentences or, better still, in simple easy-to-memorize bullet points. The student may have to manipulate and re-organize and more deeply think about some of the given information to yield the key 20%. More often than not, the value to the student isn't in the given information at all, but rather, in how the student thinks about and analyzes the given information, re-representing it concisely in a more valuable and personal way. This is real learning. Teachers should reduce chalkboard use.

## Concluding Remarks, Summary and Recommendations

Although "Thinking" amounts, mathematically, to 25% of the achievement that is to be measured or "graded" in Ontario schools, we spend very little time explicitly teaching thinking skills in school. Seven core thinking skills, based on Bloom's Taxonomy, should be explicitly and strategically taught and practiced in class such that students can more proactively "self-regulate", a recently identified Learning Skill in Ontario's "Growing Success" document. It is important that students understand, appreciate and think clearly about the importance and significance of the Expectations for each course that they take. Students should spend some time at the beginning, middle and end of a course translating, interpreting and reflecting on the curriculum Expectations. Students should reflect on their achievements relative to those Expectations and, more importantly, "how they got there". Early development of Thinking Skills and Lifelong Learning are crucial for success in the Engineering profession. Lifelong Learning should be the principle goal in secondary school classrooms. The personal career goals of the student, set in the context of the course's fundamental concepts, essential skills and work habits should be a constant factor in the classroom.

Specifically, recommended action is to:

1. Design detailed curriculum for several strategically chosen "flagship" engineering-related projects where rigorous use of thinking skills will guide students through the inquiry / design / build / evaluate process.
2. Identify several school boards and schools which are interested in engaging in a pilot project.
3. Create a fund for the purchase of good hand tools that can be loaned to schools. (A great deal of quality thinking goes into the use of good hand tools when building a prototype of one's own design.)
4. Establish an on-line "Problem-Solving" learning system where engineers can act as mentors
5. Engage in teacher professional development for the purposes of distributing and implementing the above curriculum and in order to ultimately teach students how to design their own career-related learning activities.

Please send comments on this paper and any related ideas to D. Bruce McCowan, P. Eng., bmccowan@netrover.com.

**Keywords**

Thinking Skills, Innovation, Problem-Solving, Analysis, Creative, System, Technological Design, Curriculum, Education

## References

[1] http://www.hrsdc.gc.ca/eng/workplaceskills/essential_skills/what_are_essential_skills.shtml
[2] For example, The Ontario Curriculum, Grades 9 and 10, Technological Education, 2009 and The Ontario Curriculum, Grades 11 and 12, Technological Education, 2009
[3] http://www.hrsdc.gc.ca/eng/workplaceskills/essential_skills/what_are_essential_skills.shtml
[4] The Ontario Curriculum, Grades 11 and 12, Technological Education, 2009, page 26.
[5] Growing Success: Assessment, Evaluation and Reporting in Ontario Schools, Queen's Printer for Ontario, 2010.
[6] R. Case and L. Daniels, Preconceptions of Critical Thinking from a partial draft of Tools for Thought.
[7] Norris M. Sanders, Classroom Questions: What Kinds, Harper and Row, 1966, referring to Benjamin Bloom (ed.) Taxonomy of Educational Objectives: The Classification of Educational Goals, 1956. References to Bloom's Taxonomy abound, for example, http://enpub.fulton.asu.edu/mcneill/blooms.htm#KNOWLEDGE (Ira A. Fulton Schools of Engineering).

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