

## The Elementary Science Classroom is the Place for Teaching Thinking

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A comparison of the Virginia Standards of Learning documents across the third and fifth grade curriculum reveals a significant focus on higher-order cognitive skills in elementary science classrooms. Science teachers need to be aware of this and address the teaching of skillful thinking so that it can be transferred to other disciplines and serve as a foundation for later learning. Researchers review recent research on brain function and discuss how this research can help the teaching of cognitive and metacognitive skills.

### Introduction

Mathematician György Polya opens his book on problem solving, *How to Solve It* (Polya, 1945), with the admonition:

“One of the most important tasks of the teacher is to help his [or her] students. This task is not quite easy; it demands time, practice, devotion and sound principles.”

Polya, an excellent teacher himself, clearly recognized that teachers must possess, in addition to mastery of their subject, an awareness of their students’ needs and the means to satisfy those needs. In short, “how you teach” is as important as “what you teach.”

In this paper we will discuss the Virginia Standards of Learning and associated documents that serve as the source of curricular content for Virginia’s teachers. This is the “what you teach.” We will also discuss recent research on the brain and how it functions, emphasizing ways this recent research can promote student learning. This is the “how you teach.”

The importance of excellence in science teaching is clear. Science has played a central role in the development of human culture and, through education in the sciences, it plays a vital part in the propagation of that culture. The United States is facing a changing world with globalization and evolving telecommunications technology providing more and more competition for our industry (Friedman, 2005). To maintain our position among nations we must continue to be the technological innovators we were in the last century. To do this we must have a steady supply of talented young people interested in science and engineering.

In our review of the Virginia Standards of Learning documents we have uncovered another reason to stress excellence in science teaching. As we hope to illustrate in a sequel article, an examination of the standards for English, Mathematics, Science and History/Social Studies shows that each of these disciplines sets the acquisition of higher-order cognitive skills as an objective. However, examining the tasks suggested by the standards documents to achieve these objectives we find it is the tasks in science that involve the preponderance of complex thinking (see appendix for details). Students learn many of their thinking skills in science. Science teachers need to be aware of the responsibility that accompanies this fact so that they can address the teaching of

skillful thinking in a manner that allows these skills to be transported to other disciplines. The teaching of skillful thinking in the early elementary years provides an essential foundation for successful learning in later years.

### **Research on How People Learn**

Recent research from widely divergent fields has led to a new view of the brain and how it functions. This has implications for how we can help our students learn. Research comes from three main areas:

1) The 1990's – the Decade of the Brain – generated more understanding about how the human brain operates than was acquired in the entire previous history of neuroscience. We are now close to being able to answer the fundamental question of how the mind emerges from the brain; that is, to determine the biological basis of the conscious mind. This approach to learning from the biosciences is from the “top down” (Damasio, 2001).

2) Cognitive and developmental psychologists have approached learning from the “bottom up.” An understanding has emerged that learning requires an individual's introspection into how he or she learns – a metacognition. This process is complex because the mind is observable only to its owner. As teachers leading students in the development of their own minds we need to be aware of relevant pedagogical developments and we need to make our students aware of them (Bransford, 2000).

3) A body of “discipline-based educational research” is emerging in several fields (Hestenes, 1985). This is the study of learning in a discipline carried out by members of that discipline. From this research have come teaching and learning techniques adapted to that specific discipline (Crouch, 2001).

We first review the three pedagogical findings appearing in the National Academy of Science report “How People Learn” (Bransford, 2000). These provide a basis for the ‘sound principles’ Polya mentions in the quotation opening this paper.

#### **Finding 1**

Students come to the classroom with preconceptions about how the world works.

If their initial understanding is not engaged they may fail to grasp the new concepts and information that are taught, or they may learn them for the purpose of a test but revert to their preconceptions outside the classroom.

Student preconceptions result from their initial effort to figure out how the world works. These preconceptions (sometimes misconceptions) can be deep seated and difficult to change and often they seem able to “explain” the world at least partially.

Consequently, they may interfere with learning (Smith, 1993). If they are not addressed by the teacher and the student, essential learning may be thwarted.

A concept closely related to preconception is a student's prior knowledge. Marzano recognizes this in his elaboration of the strategy of "Cues, Questions & Advance Organizers" (Marzano, 2001), writing:

"Educational researchers have shown that the activation of prior knowledge is critical to learning of all types. Indeed, our background knowledge can even influence what we perceive."

### **Finding 2**

To develop competence in an area of inquiry, students must:

- (a) have a deep foundation of factual knowledge,
- (b) understand facts and ideas in a context of a conceptual framework, and
- (c) organize knowledge in ways that facilitate retrieval and application.

Experts acquire new information and organize it differently from novices. Experts may transfer (teach) information but not their organization of that information. The organization must take place in the student's own mind and that means that students should think about how they learn and how they organize information they are presented. The process of "study" is largely about organizing information so that it can be accessed and used efficiently.

### **Finding 3**

A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

By "metacognition" we mean more than just "thinking about thinking." As the word is used by cognitive scientists and educators, metacognition refers to the conscious application of an individual's thinking to their own thought processes with the specific intention of understanding, monitoring, evaluating and regulating those processes. Young children, even preschoolers, have demonstrated the ability to perform simple metacognitive tasks (Flavel, 1970, Butterfield, 1987). Furthermore, as they grow, children's knowledge base increases and so does their ability to monitor that knowledge (Schneider, 1985). There is growing evidence that young children can learn metacognition and that this ability facilitates subsequent learning (Bransford, 2000).

It is important to remember that the ability to think skillfully and to reflect on our thinking is not an innate human characteristic. These skills need to be explicitly taught to students. Research has shown that around 30% of the adult population does not engage in metacognition (Chiabetta, 1976, Whimby, 1980).

Effective learning will only take place when all three of these principles are an integral part of the curriculum. Teaching the ‘stuff of science’ may contribute to the development of a significant knowledge base, but without a conceptual framework to support it, it remains inert knowledge and students are unable to transfer what they have learned into novel or unfamiliar contexts. The ability to make these transfers is at the heart of innovation. David Perkins stated these ideas concisely (Perkins, 1992): “Learning is a consequence of thinking.”

### **Examination of Virginia’s Learning Standards**

Many elementary teachers are required to teach across all four tested academic areas. In schools where there is a level of departmentalization teachers may teach grouped subjects – for example social studies and science, or science and mathematics. It would be an unusual circumstance for a generalist teacher in the elementary school never to be required to teach science.

Educators have long pointed to the importance of recognizing students’ individual learning differences and needs. An effective teacher observes the students and adapts teaching techniques to cater to these differences. Good teachers also need to be aware of the discipline-based pedagogical research and the differences imposed by the forms of assessment that students are mandated to complete. The strategies utilized by competent teachers of science in Virginia will differ in many respects from the strategies required for teaching reading or history if the mandates of the Virginia Standards of Learning and the associated assessments are to be met.

It is worth comparing the requirements of science teaching in Virginia with the requirements for another fundamental curriculum area – history. By comparing both the curriculum content and the assessment requirements of these two disciplines it becomes clear that the science curriculum as it stands now is a fertile field for the development of skilled, flexible, innovative thinkers and requires teaching strategies that incorporate the development of flexible, adaptive thinking.

### The Language of Instruction and Assessment in Virginia Studies

There are some fundamental differences in the language used in the grade 5 science and Virginia Studies curriculum frameworks. The introduction to the Virginia Studies Curriculum Framework lists the skills students should develop. Among others it specifies in VS 1 that students should be able to “*interpret,*” “*evaluate,*” “*analyze,*” “*draw conclusions and generalize.*” These skills are cited in the “*Essential Skills*” column of the document alongside each of the standards (VASoL History4). But an examination of the “*Essential Knowledge, Questions and Understandings*” in VS 2, for example, shows little or no opportunity for students to actually exercise these cited higher-order skills since they revolve, almost entirely, around locating and identifying geographical features. Using Bloom’s taxonomy of cognitive tasks to analyze these criteria the focus is clearly at the “*knowledge*” level although there is an attempt to make it appear as if these are higher order “*analysis*” tasks.

In the Enhanced Scope and Sequence content for VS 2, the word “*know*” is used 14 times, “*locate*” three times, “*identify*” six times, “*recognize*” once, and “*describe*” is used twice (VASoL, Virginia Studies).

The summary of VS standards 2, 3, 4 and 5 shows a similar bias towards factual knowledge.

VS 2 has five standards, four of which require the student to be able to “locate” and one to “describe.”

VS 3 has seven standards, six of which require the student to be able to “identify” or “describe” and only one requires an explanation.”

VS 4 has four standards, two of which require “explanations” and two require the student to be able to “describe.”

VS 5 has three standards and they all require identification.

In summary, out of these 21 standards only three require the student to carry out a cognitive task of a higher order than the knowledge level.

The examples given of strategies to teach children cause-and-effect do not actually require analytic thought so much as the ability to connect recalled facts in the correct order. For example, consider the following cause-and-effect table from the VS Enhanced Scope and Sequence document:

Table 1

Cause	Effect
The Virginia Company of London stockholders wanted to establish a colony in America	The colonists chose Jamestown as their settlement site
Jamestown had water deep enough to dock ships and was a good site to defend the settlement from the Spanish	The stockholders asked the king’s permission
The Virginia Company of London stockholders asked the king of England for permission to settle a colony in America	The king granted the Virginia Company of London a charter to establish a colony in America

A thoughtful analysis of this table would allow for various links to be made if the exercise were primarily requiring the student to consider and analyze possible cause-and-effect connections. In fact, the “correct” links are largely dependent on the student recalling factual links that have been previously taught. In other words, it is an exercise primarily in recall rather than seeking causal links.

The 20 test items for VS given in Attachment F in the Enhanced Scope and Sequence document of Virginia Studies are all knowledge-based, and none requires any analysis, interpretation, evaluation or the need to generalize (VASoL, Virginia Studies). The same is true of the 2003 Virginia Studies Released Test Items where nine out of ten items are based on recall (VASoL, History Assessment).

Passing tests like these does not require flexible, lasting learning. Consider the following passage from Lewis Carroll's "Jabberwocky":

Twas brillig, and the slithy toves  
Did gyre and gimble in the wabe;  
All mimsy were the borogoves,  
And the mome raths outgrabe.

A knowledge-based multiple-choice test on this piece of poetry might include questions such as these:

The weather in the poem was:

- a) Cloudy
- b) Brillig
- c) Mome
- d) Slithy

Where did the toves gyre?

- a) In the borogoves
- b) Behind the raths
- c) In the wabe
- d) Beside all the mimsy

It is clear that students can answer these kinds of questions even though they have no significant understanding of the content. Their knowledge is inert, not transferable and probably forgotten as soon as the test is over. The ability to answer these questions does draw on a deeper level conceptual structure – the implicit understanding of English grammar – but it does not demonstrate any conceptual understanding of the subject.

### The Language of Instruction and Assessment in Science

By contrast, the science curriculum consistently requires higher-order thinking skills. The essential skills are not separated out as they are in Virginia Studies (VASoL, Science 5). Instead the *Overview* provides the content and the *Essential Knowledge, Skills, and Processes* provide guidance for the teacher in developing specific curriculum and learning activities. The richness and fascination of science lends itself to inquiry learning where students are actively constructing their own understandings. To attempt to teach it as a set of facts to be remembered is to diminish its ability to develop students as skillful thinkers.

Science students are expected to be active discoverers of knowledge. Consider the following lesson suggestions from the grade 5 Science Enhanced Scope and Sequence document (VASol, Science 5).

*5.4 Design an investigation to determine how heat affects the states of matter (e.g., water). Include in the design ways information will be recorded, what measures will be made, what instruments will be used, and ways the data will be graphed.*

The student is expected to design an investigation and uncover that “As its temperature increases, many kinds of matter change from a solid to a liquid to a gas. As its temperature decreases, that matter changes from a gas to a liquid to a solid” through inquiry and active investigation.

In another lesson investigating the structure and states of matter students are required to determine whether air takes up space. They then form a hypothesis and design an experiment to prove their hypothesis, concluding that all matter takes up space regardless of its state.

In this lesson the teacher begins with a whole-class discussion by asking students whether they believe air takes up space. The preconceptions and prior knowledge of students are revealed and engaged—satisfying Finding One of “How People Learn,” above. This inquiry-based lesson provides a learning environment in which students are building for themselves a conceptual framework within which to place their new knowledge – attending to Finding Two of “How People Learn.”

An examination of the verbs used in the grade 5 Science Curriculum Framework shows a bias towards the knowledge and comprehension levels of Bloom’s taxonomy but also a significant emphasis on the higher-order cognitive skills of synthesis and evaluation that is reflected in the suggested lesson plans in the Enhanced Scope and Sequence document. The distribution of these verbs over Bloom’s taxonomy of the cognitive domain is shown in Table 2 and their percentage is reported in Figure 1.

Table 2

<b>Grade 5 Science verbs</b>	
<b>Bloom</b>	<b>CF Skill</b>
Knowledge	22
Comprehension	23
Application	5
Analysis	13
Synthesis	13 (create, design, compose)
Evaluation	10 (measure, explain, compare)

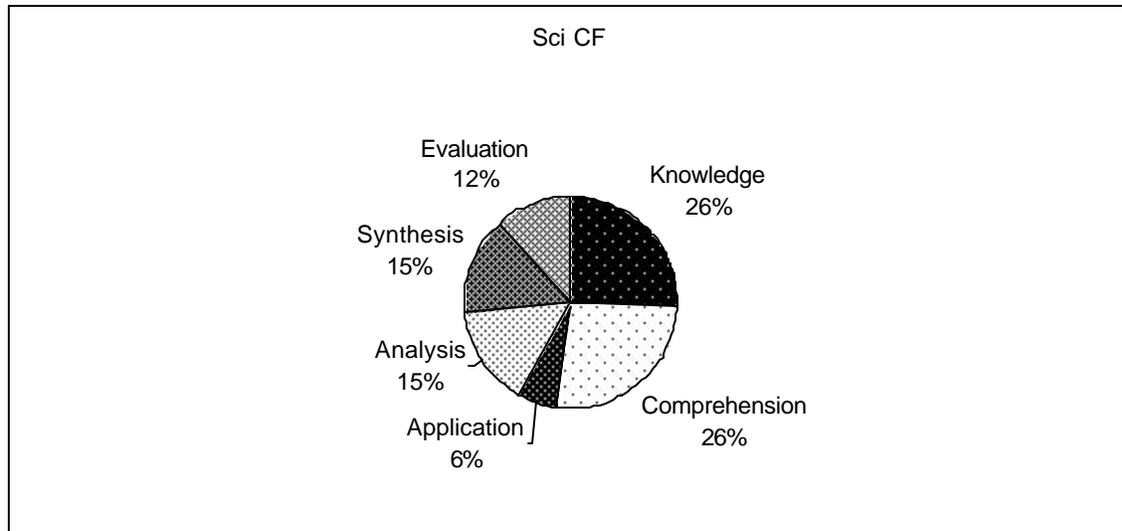


Figure 1. Distribution of cognitive skills (according to Bloom's taxonomy) implicit in the verbs used in the Grade 5 Science Curriculum Framework in Virginia's Standards of Learning.

This comparison between the History and Science educational objectives leads us to conclude that it is important to look closely at the actual learning tasks required of the students in order to discover the required level of thinking. Simply saying that any given curriculum develops higher-order thinking skills doesn't make it so.

Skilled science teachers design lessons that actively involve students in discovery. The lesson samples provided in the Enhanced Scope and Sequence document for grade 5 science incorporate genuine inquiry learning, based on knowledge and comprehension, but incorporating the higher-order cognitive levels of analysis, synthesis and evaluation.

### Metacognition

What is missing in these suggested lessons, however, is any structured attention to Finding Three in "How People Learn"—students must learn how to self monitor their learning through metacognition. For effective, lasting learning to take place students must also understand the levels of metacognitive thought. These levels were first developed by David Perkins and Robert Swartz (Swartz, 2001). These require that metacognitive thinkers:

- 1) be aware of the kinds of thinking they are doing,
- 2) know the strategies they are using to do the thinking,
- 3) reflectively evaluate the effectiveness of their thinking and
- 4) plan how they would do some similar kind thinking in the future

Opportunities for metacognition need to be interwoven into every lesson. An effective technique for this is Think-Aloud Problem Solving (TAPS). Science lessons like the one described provide fertile ground for TAPS where students are invited to:

- describe their plans and strategies for solving the problem,
- share their thinking as they are implementing their plan,
- reflect on/evaluate the effectiveness of their strategy,
- plan the best strategy for the next similar thinking task

These strategies can be incorporated in existing strategies for increasing student's conceptual understanding such as Peer Instruction.

Metacognition is engaged and sustained in science teaching when the teacher (Costa, 2001):

- encourages students to **check for accuracy** by asking students questions such as -  
“How do you know you are right?”  
“What other ways can you prove that you are correct?”
- creates opportunities for students to **clarify** –  
“Explain what you mean when you said ‘I just figured it out.’”  
“When you said you started at the beginning, how did you know where to begin?”
- provides data, not answers, when students are on the wrong track or confused –  
“I think you heard it wrong; let me repeat the question.”  
“You need to check your observations or data.”
- resists making judgments –  
“So, your hypothesis is .....?”  
“Who has a different thought?”
- makes sure students stay focused on thinking –  
“Tell us what strategies you used to solve that problem.”
- encourages persistence –  
“I know you can do this. Let's try another approach.”

### **The Next Step**

When it is well taught, science is exciting for all students. In Virginia we have a science curriculum that provides ample opportunities for classroom teachers to address the first two key findings of “How People Learn.” The next step is to find ways to infuse the third finding, the need to develop metacognitive skills in our students. When we do that, the science classroom will become a rich environment in which we teach the foundational thinking skills and dispositions that support all learning in all disciplines. We will also create life-long, creative and innovative thinkers who will lead our success in the global community.

## Appendix

We have examined the distribution of cognitive skills across the elementary school curriculum for grades three and five using Bloom’s taxonomy as a basis for assessing the level of cognition.

To examine the tasks associated with the Standards of Learning, we used the bullet points under the Essential Knowledge, Skills, and Processes from the Curriculum Framework documents for the third and fifth grades in the subject areas English (Reading and Writing), Mathematics and Science. In History/Social Studies we have used the Essential Questions because, in our opinion, the Essential Skills do not always reflect the tasks tracked in the Essential Understanding, Questions and Knowledge document. The results of this study are shown in the table below. Since we are interested in comparing the occurrence of higher-level skills we have combined the results for the first three items in Bloom’s taxonomy (knowledge, comprehension and application) in one category and the second three (analysis, synthesis and evaluation) in another category.

**Table A - 1**  
**Distribution of Cognitive Skills in Tasks Required of 3<sup>rd</sup> and 5<sup>th</sup>**  
**Grade Students in Virginia (in percentage per subject)**

<b>Bloom Categories</b>	<b>Knowledge Comprehension Application</b>	<b>Analysis Synthesis Evaluation</b>
<b>Subject</b>		
	<b>Grade 5</b>	
<b>English</b>	<b>44</b>	<b>56</b>
<b>Mathematics</b>	<b>68</b>	<b>32</b>
<b>Science</b>	<b>12</b>	<b>88</b>
<b>History</b>	<b>64</b>	<b>36</b>
	<b>Grade 3</b>	
<b>English</b>	<b>56</b>	<b>44</b>
<b>Mathematics</b>	<b>64</b>	<b>36</b>
<b>Science</b>	<b>27</b>	<b>73</b>
<b>History</b>	<b>67</b>	<b>33</b>

Results for both grades show the preponderance of higher order thinking skills in science.

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