NOTE: This essay is formatted so that it can be printed as a booklet for teachers to copy and share with colleagues. (Choose booklet printing so that the order of the pages is correct.)



Math/Science Matters:
Resource Booklets on Research in Math and Science Learning

Booklet 2
Issues of Instructional Technique in Math and Science Learning

# Learning the Habits of Mind that Enable Mathematical and Scientific Behavior

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# Summary Points

**Knowing the thinking skills relevant to math and science is not enough for children to enact the skills. Students must be:**

?sensitive to opportunities to apply the skills.
?able to perform the skills in the real world.
?inclined to apply the skills.

**What habits of mind are important to math and science?**

?openness and appreciation for new ideas.
?skepticism and appreciation for evidence and logic.
?A tendency to consider alternatives.
?creative use of imagination.
?curiosity, integrity, diligence and fairness.

**What do we know about encouraging the growth of these attitudes in students?**

?A culture of good thinking is important..
?Students must learn to recognize opportunities for mathematical and scientific thought.
?Students need to see that such thinking pays off in ways that are relevant to their lives.

**What are the attitudes appropriate to behaving like a scientist or a mathematician? What does research say about teaching such attitudes and dispositions?**

Two high school students, Melissa and Amy, were taught a set of skills for evaluating scientific claims. They both demonstrated the ability to analyze and evaluate conflicting claims on a recent exam. A few weeks later when eating breakfast, Melissa notices the statement on her cereal box, "contains half as much fat as other leading brands." She has noticed this statement before and in fact, it is why she chose the cereal. Until this morning, however, she hadn't recognized it as claim -- one that she can evaluate. She studies the nutritional information on the side of the box and compares it to the other boxes on the table. She finds that her cereal has less fat than some and more than others. She recognizes that she was influenced by the claim on the box, having chosen the first cereal thinking that it had the least fat when her favorite cereal contained less! Melissa reconsiders her decision after having evaluated the evidence for the claim. Amy, however, doesn't use the skills in the months that follow the science lesson except in circumstances where she is directed to, such as on a standardized test.

What is the difference between these two students? Each has demonstrated the ability to use a thinking skill relevant to math and science. Yet Melissa is behaving like a scientist in the course of everyday life. What does this mean? If behaving like a scientist or mathematician is more than knowing a set of thinking skills relevant to science and math, what else is it and what can we do to ensure that students learn it?

Science and math reform documents[1] recognize the important difference between the students in the example. Educational reformers are concerned with the particular attitudes that contribute to a scientific or mathematical stance towards the world. Another essay in this series addressed the importance of teaching the thinking skills relevant to scientific and mathematical thinking. But what about cultivating thinkers who use those skills outside of the classroom? If thinkers are able to successfully evaluate competing claims in a scientific argument and yet do not do so when opportunities arise in their lives, is it really helpful to have the ability?[2]

Concerns such as these have spawned a whole area of inquiry related to the teaching of thinking. Simply put, what are the attitudes or dispositions that promote good scientific and mathematical thinking and how do we encourage them in students? While the thinking skills movement is young, research on thinking dispositions is younger still. While researchers recognize it as an important area of study and there is research in progress, there is still little hard data to cull answers from.

Why then include this question in a booklet on how research informs the teaching of math and science? First, this research raises distinctions which provide educators with a useful tool for considering student thinking and behavior. Second, reform efforts in math and science call for the teaching of habits of mind, including values and attitudes.[3] It is important to consider what we know and don't know about teaching these habits of mind.



**What are thinking dispositions?**

In order to understand the importance of such attitudes more clearly, let's tease apart the example from above to think further about what Melissa did. First, Melissa noticed an opportunity to use a thinking skill pertaining to science. She was *sensitive* to an instance when the thinking skill might be applicable. She noticed a potential "thinkpoint," an instance where applying the skills of good thinking would help her in setting a course of action. Next, she was *inclined* to use the thinking skill in the given situation. She was motivated to apply the skill. She cared about finding out whether the claim was accurate and recognized an opportunity to learn something that might be of value to her in her everyday life. Having gained the information, she can now use it in making decisions pertaining to her breakfast cereal. Of course, she importantly had learned the skills involved in evaluating the claim. So she was *able* to analyze the information. This example illustrates, however, that having the ability is not enough to behave like a scientist or mathematician. One must also be sensitive to opportunities to apply the skill and have the inclination to do so.

Researchers who study thinking dispositions would say that Melissa demonstrated three contributing components that characterize such a disposition: 1) a sensitivity or alertness to occasions to use the behavior; 2) the ability to carry out the behavior; and 3) a felt tendency toward a certain behavior.[4] If any of the components are missing in a given instance, the person probably would not behave as a mathematician or scientist would. It is possible for someone to have the ability and felt tendency but lack the sensitivity towards opportunities to apply them. Or a person might be aware of an opportunity and have the ability, but not the felt tendency to engage in a certain behavior. They may just not care or have the motivation. Likewise, they may be inclined and sense an opportunity but not have the ability to engage in the behavior.

The thinking dispositions research recognizes the need to consider the joint contributions of motivation and cognition to the thinking process.[5] Thinking dispositions can be thought of as "ongoing tendencies that guide intellectual behavior."[6] The need to explore issues of motivation has been recognized broadly by researchers.[7] It is an issue that teachers, frustrated by students who demonstrate high ability and yet underachieve in school, have sought to address for years. The role of cognition and dispositions have been contrasted as the ability or skill to do something versus the attitudes or tendencies to do it.[8] However, the thinking dispositions research suggests that the relationship between attitudes and cognition may be more than separate components contributing to a process. Instead, they may interact -- meaning that attitude helps to determine cognitive engagement and ability, and vice versa. For example, when people feel capable of performing a task, they are more likely to engage in patterns of behavior, such as strategy use, that enable them to perform the task.[9] Also, how people feel about what they are learning may affect their level of cognitive awareness. These examples suggest that while separating issues of cognition and issues of motivation may be clarifying in some instances, there is a great deal to be gained from exploring the role of motivation as it interacts with cognitive processes.



While the example of Melissa and Amy illustrate tendencies that support good scientific thinking, it is also possible to have tendencies that hurt good thinking. For example, one might be inclined to investigate only the most obvious explanation when evaluating scientific evidence and thus might fail to explore alternative explanations. Research suggests that people often fall into such traps. For instance, it is common to explore the arguments in favor of what one wants to do but not those on the "con" side. In a situation where there are two opposing viewpoints, people often fail to consider the case opposite their own.[10]

People also carry around certain misconceptions about thinking. They tend to think that if you can't solve a problem quickly, you probably can't solve it at all -- that good ideas come in the first 5 seconds of thinking.[11] This pushes them towards "premature closure" on problems and the likelihood that some of the most interesting options will be missed.[12] People commonly believe that how well you think is a symptom of how fast one's synapses work and the result of one's genetic inheritance instead of the product of learning, and thus they fail to push themselves in their thinking.[13] It is also common to believe in the existence of a "right" answer if one can only find it and while indeed some problems have right answers, this tends towards little tolerance of ambiguity and a belief that uncertainty is bad. We must help students to recognize and eliminate those tendencies that hurt their thinking and to learn and utilize those tendencies that help.

**What kinds of dispositions are particularly helpful in math and science?**

Professional organizations in science and math have published lists of the types of dispositions that are crucial to expert understanding in each discipline. For instance, The American Association for the Advancement of Science (AAAS)[14] calls for habits of mind that include an openness and appreciation for new ideas complemented by a skepticism and appreciation for evidence, logic, and the consideration of alternatives. Science is presented as a process of extending understanding -- not of discovering unalterable truths. Curiosity, integrity, diligence and fairness are valued. Similarly, the standards set forth by the National Council of Teachers of Mathematics (NCTM)[15] call for habits of mind that help to clarify complex situations -- the development of informed skepticism and sharp insight -- as part of a mathematical perspective on the world. The creative use of imagination balanced with an appreciation for logic is valued in both subjects.

How do these habits of mind fit with lists of dispositions studied by cognitive researchers? As with thinking skills, different researchers compose slightly different lists of dispositions. A survey of these lists shows that they encompass many of the AAAS and NCTM habits of mind and suggest others to consider. For example, the seven dispositions in Table 1. map onto several listed by the AAAS and NCTM.[16] The disposition to be broad and adventurous relates to an openness and appreciation for new ideas as put forth by the AAAS. The dispositions to be intellectually careful and to seek and evaluate



reasons corresponds to a skepticism and appreciation for evidence. The disposition toward sustained intellectual curiosity and the finding and formulating of questions addresses both the NCTM's and AAAS's creative use of imagination and view of science as a process of extending understanding rather than revealing unalterable truths.

Another argument for paying attention to such attitudes is to help students understand and appreciate the particular "games of math and science"[17] Some research suggests that when students do not understand the skills, attitudes, and way that knowledge is generated in a particular discipline, they may feel confused and see the thought processes involved as an incomprehensible "game," and steer clear of the subject.[18]

Science and math are particularly challenging in this respect. For instance, science often attaches more importance to the validity of the process than the actual products of that process and accepted theory is often purposefully discarded as a matter of course.[19] In mathematics, for instance, innumerable supporting examples do not make a proof but one counter example can disprove. So for example, if a statement is made that adding any two single digit numbers results in a single digit number, one can come up with a multitude of cases where this is true. However, all one needs is one example in which it is not true to disprove the statement, such as 9 + 1. Another example is in probability, where the results of preceding trials do not affect the randomness of future trials. Therefore, if a coin is flipped three times and each time it comes up heads, intuitively one might expect that on the fourth flip the chances of tails are

Table 1. Seven Thinking Dispositions

1) The disposition to be broad and adventurous involves open-mindedness, exploring alternative views, and generating multiple options.

2) The disposition toward sustained intellectual curiosity includes the tendency to wonder, probe, find problems, and the ability to formulate questions.

3) The disposition to clarify and seek understanding involves the desire to understand clearly, seeking connections and explanations, alertness to unclarity, and ability to build conceptualizations.

4) The disposition to be planful and strategic includes the drive, ability and alertness to the need to set goals, to make and execute plans, and envision outcomes.

5) The disposition to be intellectually careful presents the urge, ability and sensitivity to the need for precision, organization, and thoroughness.

6) The disposition to seek and evaluate reasons includes the tendency and ability to as well as alertness for the need to question the given, demand justification, weigh and assess reasons.

7) The disposition to be metacognitive includes awareness of and ability to monitor flow of one's thinking.

Tishman, Jay & Perkins (1992)



increased when in fact they are not.

Not understanding the scientific or mathematical thought processes, students may approach these subjects with trepidation. Helping students to understand the "games," to notice opportunities where these "games" are applicable, and to see the value in engaging in them can help students approach math and science with confidence.

**How can positive thinking dispositions be taught?**

Recognizing the importance of such dispositions to scientific and mathematical behavior is an important start. But how does one teach attitudes? How can teachers and parents help youngsters to develop these positive thinking dispositions? Unfortunately, there is little research on interventions specifically designed to help students develop thinking dispositions. However, research in related areas suggests promising approaches.

The research on teaching thinking illustrates the importance of creating a culture of good thinking.[20] A culture of thinking should be effective in helping children learn thinking dispositions. Cultures communicate information about the values of certain practices. A culture that values thinking and its outcomes helps encourage the inclination to use the skills of good scientific and mathematical thinking. Students also need experience finding opportunities to use the thinking skills.

New "infusion" approaches to teaching thinking, such as those discussed in the essay on thinking skills, are often part of a culture of thinking. Infusion helps students learn both generic and context-specific thinking skills by helping students identify "thinkpoints" in the curriculum -- places where using the skills of good thinking will help them deepen their learning. For instance, it might involve evaluating a course of action taken, such as the decision of the South to secede from the North prior to the Civil War or it might trace the causes of a particular event or phenomenon, such as the deforestation of the rainforest.

What is involved in creating a culture of thinking? Researchers have identified six dimensions to a culture of thinking:

> **?** *A language of thinking* refers to specific terms and concepts that provide a means to communicate and encourage high-level thinking.
>
> **?** *A conception of thinking dispositions* refers to ways to think about and encourage sensitivities, abilities, and inclinations for high-level thinking.
>
> **?** *Processes for mental management* refers to ways for students to reflect on and think about managing their own thinking processes.
>
> **?** *A strategic spirit* refers to an attitude that encourages students to build and use thinking strategies.
>
> **?** *Higher-order knowledge* refers to a focus beyond factual information to how knowledge is created, problems are solved, evidence collected and so on.
>
> **?** *Transfer* refers to a concern with connecting knowledge and strategies from one context to others and using them more broadly.



Tishman, Perkins, & Jay, 1995

These dimensions are transmitted and learned by students within the classroom culture through modeling, explanation, interaction, and feedback. In such a culture, students learn when a skill is applicable and experience the rewards of using a skill so that sensitivities and inclinations are part of the learning experience. Teachers can increase student inclination to apply skills by helping youngsters see opportunities where such thinking pays off in their own lives. Choosing examples that are relevant to students, such as evaluating and using consumer information to choose the best bicycle for the best price or inventing a better way to complete their chores, help to make the value apparent. This should encourage students to see the value of their thinking such that they will seek out its value on their own.

A potentially promising area for further research is to see what can be learned from teachers who model passion for their subjects through their teaching. Dispositions can be thought of as passions that mobilize the mind towards good thinking.[21] What do teachers who model passion for their subject communicate to students? We might surmise that students have the opportunity to learn the "attitudes" and "games" of the particular discipline in a context where there is excitement -- or high motivational stakes -- concerning the value of the games. It might also be fruitful to study what happens in apprentice/mentorship relationships such that passions and attitudes are learned by the apprentice. Each discipline has its own particular set of nuances concerning the dispositions listed above so there may be discipline-specific lessons to be learned as well as generalities to be drawn.

The number of questions concerning thinking dispositions outweighs the number of answers and further research in this area is clearly important to developing a scientifically and mathematically sensitive, literate, and inclined society. In the meantime, teachers and parents can begin to draw upon some of the distinctions raised in this research to help them guide today's students in developing positive scientific and mathematical dispositions. There are at least three guiding messages that teachers can bring to their work.

Teachers need to:

? develop student scientific and mathematical sensitivities by helping students notice opportunities to behave as scientists and mathematicians do.

? make sure that students understand and can apply the skills of good thinking.

? develop student inclination to use scientific and mathematical skills by helping students to see



opportunities where such thinking pays off in their lives.

When thinking and behaving like mathematicians and scientists is viewed by students as serving their interests, we've taken a big step toward a mathematically and scientifically literate society.

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For Further Information

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