The Keys to Inquiry

An introductory guide to constructivism and inquiry-based learning in the elementary school classroom

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“We learn best when we learn from our own experiences.”

“Children need to be active learners, seeking answers to questions that they care about.”

“Science should be hands-on and minds-on so that children make sense of what they experience.”

The goal of the Everyday Classroom Tools Project is to provide opportunities for students to learn that inquiry and their own experiences can help them achieve a deeper understanding of their world. It aims to foster a spirit of inquiry in all students. These goals promise to help students grow into life-long learners who are curious and set out to seek and achieve deep understanding of the world that they live in.

This document has two sections. The first is a series of six brief essays to address the kinds of questions teachers often have about inquiry based learning and learning from one's experience. The intent is to place the central concepts of The Everyday Classroom Tools Project in context--to provide a sense of the variety of ways that the concepts have been thought about as well as how they are interpreted in this project. These essays are written for a teacher audience. The second section is a set of big ideas, questions, and attitudes that are central to the project. This section is written with the expectation that teachers will communicate these messages to their students.

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Section I: Inquiry-Learning and Learning from One's Own Experience

Inquiry-Learning

"Inquiry learning" and "learning from one's experience" are at the core of the Everyday Classroom Tools Project. What does this mean, in theory and in practice? While these are terms that are used often in the current science literature, its important to unpack what they mean to consider how they are intended in the Everyday Classroom Tools Project and how this relates to the array of meanings people in the field of science education attach to them.

•Before reading on, take a few minutes to ponder the phrase "inquiry learning." What images does it conjure up?

If you envisioned images of children actively posing questions, seeking answers to questions that they care about, demonstrating a strong interest in outcomes, and discussing their theories and ideas with others, you've shared in a glimpse of what makes educators so excited about the possibilities of inquiry-based learning. At its best, inquiry-based learning makes excellent educational sense.

If on the other hand, you envisioned a chaotic classroom where children were doing things, but weren't clear about what they were doing, or what could be understood from it, or what could really be known from what they found out, you've shared a glimpse of what gives some educators pause about taking the plunge into inquiry-based learning. At its worst, inquiry-based learning can result in miseducation. Either vision is possible. So what can you, as teachers, do to enable the first vision?

Throughout these essays, the issues that teachers need to keep in mind to help children learn well through inquiry and to develop deep understanding are presented. The "Points for Practice" are intended to help you create the first vision and avoid the second.

Knowledge as Constructed

Learning from one's experience and through one's questions is based on a philosophy called "constructivism," put forth by Piaget and others. According to constructivism, we don't just *absorb* understanding, instead we *build it*. Learners need opportunities to figure out for themselves how new learning fits with old so that they can attach it to what they already know, making it part of their existing knowledge structures or "assimilating it." When they figure out that new learning doesn't fit with old learning, they need to restructure their current understandings to fit with the new knowledge or to "accommodate it." These processes, assimilating and accommodating, are part of learners' theory building as they make sense of the world.

What does this mean for the classroom? In part, it means that children cannot just sit like sponges and absorb information. They must *do* something with it. They need to be engaged in activities that help them build understanding. Beyond this, it means that often the child is the best judge of what questions he or she needs to explore to make sense of the information before him or her. For instance, if a class is engaged in an activity on weights and measurement and a child is trying to figure out if you could use pebbles as weights to measure with, introducing a particular standard for measuring weight eclipses that child's opportunity to construct an understanding of whether we need standards of measure and what purpose they serve.

Research shows that unless children actively seek connections in their learning, they are not likely to remember what they've supposedly learned. Not only this, they often cannot apply concepts. The learning is inert or has a ritualized nature. It is also unlikely that children will discover areas of misunderstanding if they don't actively grapple with the ideas. Educational Researcher, David Perkins writes about the problems "fragile knowledge." Fragile knowledge hurts learners and does not empower them to understand or deal with their world.

While most teachers find the central concepts of constructivism appealing, the concepts also tend to raise a lot of questions. The translation from theory to practice contains many possible stumbling blocks. The largest stumbling block has to do with helping students to build understandings that will serve them well in today's world. Constructivism and inquiry-based learning can lead to many dead-ends in that children find out what doesn't work instead of what does; or they find out that they asked the wrong question; or that what they did won't help them to answer the question that they want to answer. These *are* valuable understandings. They help students learn a lot about the process of science and what one must think about when trying to answer certain kinds of questions. However, they don't necessarily help children construct present-day understandings of how the world works.

After all, while individual scientists might spend an entire life time developing an understanding of an isolated phenomenon, we have an accumulated wealth of scientific information that no learner could entirely reconstruct in the course of one lifetime. It has been argued that this is children's rightful inheritance.

The "Discovery-Learning" Movement and "Mediated Constructivism"

Such issues are similar to questions raised in response to the Discovery-Learning movement of the 1960's. Students were encouraged to engage in hands-on tasks to discover science principles. Too often, students didn't have a clue as to what they were doing and why. Activities were hands-on but they weren't necessarily minds-on. Too often, the questions weren't posed by students and they may not have understood why the questions being asked were relevant. Students were learning important messages about discovery and the process of science, but without adequate scaffolding of student understandings, it was difficult to know exactly what science principles students were discovering.

How to strike a balance between children's constructing of understanding and their "rightful inheritance" to an accumulated wealth of scientific understanding presents a puzzle that can be addressed through the work of Russian philosopher and psychologist, Lev Vygotsky. According to Vygotsky, children learn within a "zone of proximal development" which is defined by the difference between the level of understanding that children can achieve on their own and that which they can achieve with adult guidance. The role of the adult is to scaffold children's building of understanding by asking guiding questions and providing opportunities for certain experiences.

From the joint work of Vygotsky and Piaget, arises a concept that can be called *mediated constructivism*. Children construct understanding by learning through their experiences and their own questions but the process is mediated by adults who hold scientific understandings of how the world works. It allows for building understanding as part of a society or community of learners. Children engage in Socratic discussion of ideas, guided by the teacher, to help them build new understandings.

Mediated constructivism involves a thoughtful choreography between student and teacher. The teacher must constantly study the student's evolving understanding, assess what path it is on, and help the child to have and to take advantage of opportunities that enable the child to construct new and more sophisticated understandings. The teacher must guide while taking care not to be directive such that it undermines the child's incentive to explore the question. It doesn't mean that teacher can't arrange certain experiences for children. It does mean that the teacher needs to pay attention to how students are making sense of the experiences and whether the experience helps them to answer a question that they care about.

Pictures of Practice

What might mediated constructivism look like in practice? Here are some snippets from a second grade classroom discussion around a question that arose about where the stars go during the day.

- Teacher: So, let's think about Michael's question, "Where do the stars go during the day?" Michael, what made you think to ask that?
- Michael: Well, you can't see any stars during the day time but then at night lots of them come out.
- Teacher: Okay, so when you look at the sky during the day, you can't see any stars but then you do see them at night. Why might that be so?
- Michael: They go away when the sun comes out and come back at night.
- Teacher: What do some of the rest of you think happens? Let's collect all of our different ideas about what happens.
- Emma: Maybe they're on the "night side" of the sky, so when we spin around we don't see them anymore.

- Teacher: Okay, what do others think?
- Dion: Maybe, they turn off during the day but they're still there.
- Ashley: I think that the clouds and sun and stuff cover them up.
- Teacher: Can you say more about what you mean by "cover them up" Ashley?
- Ashley: ...just make it so you can't see 'em, I don't know.
- Teacher: Perhaps you can think about what makes it so you can't see them.
- Jared: I think that it's not really covering them up but you can't see em because the background isn't dark enough, like when we caught the snowflakes, you wouldn't see it on white paper so we looked at them on black paper.
- Teacher: Okay. ...Seth?
- Seth: I agree with Jared.
- Teacher: What makes you agree with him?
- Seth: Well, it's like camouflage because there's no black to see the stars, they blend in.
- Teacher: Does anyone else agree? And if so, why?
- Donna: It's like you just can't see them. Maybe you need sunglasses. (laughter)
- Annie: But I saw the moon once in the day time and how come it didn't getcamouflaged?
- Teacher: hmm... now that's a puzzle. These are interesting ideas. What could we do to try to figure out which ones help us answer Michael's question?
- Annie: We could look for stars in the day time.
- Jared: We could look at a map of the stars to see if they're only on the night side like Emma said.
- Seth: We could shine a bright light at night to see if it makes the stars go away.

(Laughter follows)

- Tommy: We can't make the stars go away!
- Teacher: Ah, maybe not, but let's talk about Seth's idea. Seth is thinking about possible ways of finding out. He is doing what good scientists do. Is there a way that we could use a bright light to see how it affects our ability to see the stars?

(There is no response and some students shrug their shoulders.)

- Teacher: Okay, well, we'll come back to that question. In the meanwhile, perhaps we could collect some other information. Over the week end, look to see if you can see any stars or the moon in the day time.

The teacher sends home a memo to parents suggesting that next time they with their children near a big city at night or in a football stadium with lights on, or simply in their backyard with a spotbeam on, they see how many stars are visible and then do it again when they are away from bright lights. She also brings in a string of Christmas lights along with a spot light and some black paper so that the class can contrast the visibility of the Christmas lights against the two backgrounds.

Upon Reflection...

Okay, let's revisit pieces of the conversation to look closely at how the teacher is mediating the children's construction of understanding :

- Teacher: So, let's think about Michael's question, "Where do the stars go during the day?" Michael, what made you think to ask that?

[*Here the teacher starts with a child's question. She may have chosen this question to focus on because she saw it as having the potential to help them understand more about what they experience in terms of day and night. It is always difficult to choose which questions to spend limited classroom time on. This question may have been one that a number of children raised or expressed an interest in.*]

- Michael: Well, you can't see any stars during the day time but then at night lots of them come out.
- Teacher: Okay, so when you look at the sky during the day, you can't see any stars but then you do see them at night. Why might that be so?

[*Notice that the teacher asked the child to connect the question back to his experience, to what it was that he observed that made him ask the question in the first place. She then asked him to tell about his own theory of what is happening. Children's implicit theories impact how they construct new theories. She knows that there will need to be new and convincing evidence to help Michael adopt a new stance.*]

- Michael: They go away when the sun comes out and come back at night.
- Teacher: What do some of the rest of you think happens? Let's collect all of our different ideas about what happens.
- Emma: Maybe they're on the "night side" of the sky, so when we spin around we don't see them anymore.
- Teacher: Okay, what do others think?
- Dion: Maybe, they turn off during the day but they're still there.

[*Here the teacher asks for lots of different ideas about what might be happening to open up a realm of possible explanations. She doesn't stop with just a few ideas but continues to encourage children to consider what alternative explanations could be. If a child offered an idea that seemed unlikely or others thought was in some way "silly," she would have reminded them that scientists need to think openly about what they experience.*]

- Ashley: I think that the clouds and sun and stuff cover them up.
- Teacher: Can you say more about what you mean by "cover them up" Ashley?
- Ashley: ...just make it so you can't see 'em, I don't know.
- Teacher: Perhaps you can think about what makes it so you can't see them.

[*Here the teacher asks Ashley to tell more about her idea. Often the children are just figuring out what they think and may not have clear access to their thoughts. The teacher provides an opportunity for this, but doesn't push Ashley for an answer at this point. The teacher leaves Ashley with a follow-up, guiding question to help her in thinking about it further.*]

- Jared: I think that it's not really covering them up but you can't see em because the background isn't dark enough, like when we caught the snowflakes, you wouldn't see it on white paper so we looked at them on black paper.
- Teacher: Okay. ...Seth?
- Seth: I agree with Jared.
- Teacher: What makes you agree with him?
- Seth: Well, it's like camouflage because there's no black to see the stars, they blend in.
- Teacher: Does anyone else agree? And if so, why?
- Donna: It's like you just can't see them. Maybe we need sunglasses.

(laughter)

[*Some of the students are starting to support one idea that they think has potential. The teacher invites discussion of that idea*]

- Annie: But I saw the moon once in the day time and how come it didn't get camouflaged?
- Teacher: hmm... now that's a puzzle. These are interesting ideas. What could we do to try to figure out which ones help us answer Michael's question?

[*Here the teacher direct students to a puzzle that Annie found. She also asks them to think about what experiences or evidence could help them answer the big question. This directs students back to experience, collecting data, and looking for patterns in the real world that address their questions.*]

- Annie: We could look for stars in the day time.
- Jared: We could look at a map of the stars to see if they're only on the night side like Emma said.
- Seth: We could shine a bright light at night to see if it makes the stars go away.

(Laughter follows)

- Tommy: We can't make the stars go away!
- Teacher: Ah, maybe not, but let's talk about Seth's idea. Seth is thinking about possible ways of finding out. He is doing what good scientists do. Is there a way that we could use a bright light to see how it affects our ability to see the stars?

[There is no response and some students shrug their shoulders.]

- Teacher: Okay, well, we'll come back to that question. In the meanwhile, perhaps we could collect some other information. Over the week end, look to see if you can see any stars or the moon in the day time.

[*The teacher encourages the students to look at what they can see, at what their own experience tells them. This validates the importance of their own observations and experiences in finding out the answers to scientific questions.*]

The teacher sends home a memo to parents suggesting that next time they with their children near a big city at night or in a football stadium with lights on, or simply in their backyard with a spotbeam on, they see how many stars are visible and then do it again when they are away from bright lights. She also brings in a string of Christmas lights along with a spot light and some black paper so that the class can contrast the visibility of the Christmas lights against the two backgrounds.

[*The teacher also recognizes that certain kinds of experiments may be beyond the children's ability to generate given their own limited science knowledge and understandings of scientific process. So she creates opportunities for them to gain new experiences relevant to the big question that they are grappling with.*]

Teacher Response

Here are some of the kinds of questions that teachers tend to ask about mediated constructivism.

- **My students are young and have so little experience. How do I help them build understandings when there is so little to help them build it from?**

  While even young children do know quite a lot about the world around them, this is a real challenge and one that teachers of the youngest children face most. In part it means thinking carefully about the kinds of experiences that you in partnership with parents can provide to help children gain and think about particular questions that children are grappling with. In choosing from children's questions to decide which ones to pursue as a class, teachers need to think about the kinds of experiences those questions assume knowledge of, start where the children are, and provide experiences to get them to where they need to be. At different ages, there are questions that teachers will decide not to pursue because it isn't possible to offer the kinds of experiences that will help the students to build a satisfactory understanding

- **How do I keep students on track when they are constructing understandings? They come up with some pretty unorthodox explanations for why things are the way they are.**

  It certainly is true that the path to constructing scientific understandings is a rocky one. As discussed further in later essays, children have certain tendencies that influence the kinds of understandings that they create. For instance, they don't necessarily worry about constructing coherent and consistent explanations for the different instances of the same phenomenon. Through guiding questions and introducing areas of discrepancy, teachers can keep student understandings along a path towards greater explanatory power. Teachers should view their role of helping children evolve better understandings more than one of immediately helping children adopt the scientifically accepted understanding.

Points for Practice

- Try to connect children's questions to what they experienced that made them ask the question.

- Help children to discover what they already know and believe as a starting place to work from in constructing new understanding.

- Help children to see how they can collect evidence from their own experience that helps to inform their questions.

- Use guiding questions to help children develop more sophisticated understandings.

- Use sharing and discussion to help children consider their individual ideas in relation to the ideas of others.

- Create opportunities for children to gain experiences that will help them think more deeply about their ideas.

- Help children identify puzzles that will enable them to push beyond ideas that aren't workable.

The Epistemology of Science

Inquiry-based learning aims to teach much more that science content or science process as we typically think of them. It provides the opportunity for learners to learn how knowledge is created in science, what scientists do to find out and what it means "to know" something in science. This is often referred to as the epistemology of science.

What does it mean to learn the epistemology of science? Instead of learning "facts," students are learning such things as how information is generated, what tools and techniques scientists have at their disposal to help them generate information, what beliefs scientists share about what constitutes knowledge, and what attitudes and habits of mind scientists bring to their work. This is a much more expansive view of what is involved in science learning. The Everyday Classroom Tools Project is about helping children learn how scientists think about and frame investigations by helping the children to rediscover their own curiosity and to cultivate the budding scientists within each of them.

Why is it so important to help children learn the epistemology of science? Research shows that students are sometimes baffled by what they perceive as the "games of science." Scientists engage in certain ways of thinking and generating knowledge, for instance, isolating and controlling variables. These can be puzzling to students who have not had the opportunity to learn how these "games" work and how they are important in the larger context of knowledge generation. Not understanding these "games" often divides those who feel comfortable pursuing math and science and those who don't. Often those who don't feel comfortable with the games are women and minorities. This may contribute to lesser numbers of women and minorities in math and science.

Beyond this, most students carry around certain misconceptions about the nature of disciplinary knowledge. For instance, they often view science as a collection of dusty, old facts--rather than a dynamic, evolving state of how we best understand the world. School practices that don't provide opportunities to learn how scientists come to know and find out can contribute to these misconceptions.

In talking with children about epistemologies, it is often helpful to talk about it in three different ways: as roles; as tools and techniques; and as ways of knowing. The emphasis that the teacher places on each of these depends in part upon how young the learners are and how much "science talk" they have been engaged in. In the early elementary years, one might talk primarily about *roles*, what is it that scientists do and why do they do it? One can also introduce talk about the tools of the discipline. What kinds of *tools and techniques* do scientists use to help them find out? For instance, scientists try to create "fair tests" by attempting to control for extraneous variables. Eventually, teachers with older students should talk with students about the "rules" (and the rationale for them) that scientists employ for knowing and finding out. For instance, science involves the purposeful discarding of theory as discrepant evidence arises and theories with greater explanatory value evolve.

Pictures of Practice

What might such a discussion look like in the classroom? How might teachers of different age groups talk differently about epistemology or processes for finding out and knowing in science? Here are some snippets from classroom discussion at different grade levels:

Kindergarten:

- Jared: My car is the faster one.
- Josh: Can't beat mine!
- Teacher: How can we find out which one is fastest? What would be a fair test?
- Jared: We could have a race.
- Teacher: Should we have both cars start at the same time?
- Josh: yeah, cause otherwise it's not fair.
- Teacher: What about at the same place? What if we started Josh's car up here and Jared's back there?
- Josh: My car would win!
- Jared: But it wouldn't be fair!!
- Teacher: That's right, it would make Jared's look like it took longer to get to the finish cause it has further to go. When a scientist wants to com pare something, like your two cars, he or she tries to make every thing else the same so that the only difference is how fast the cars go.

Second Grade:

- Teacher: Travis wondered if our bean plants really need to have sun to grow cause he found some plants growing under leaves. So let's think about it together. Can you tell about the plants you found, Travis?
- Travis: They were under a pile of old leaves where the sun couldn't get to and when we moved the leaves we found them.
- Teacher: Can you describe them?
- Travis: They were sort of yellow colored and skinny, I think that they were some flowers my mom planted.
- Teacher: What do the rest of you think? Do our bean plants need sun to grow?
- Kate: Everything needs sun or it would be really cold and dark and nothing could grow.
- Timmy: Well, I saw a plant, an Indian Pipe, in the woods once that my dad said didn't need sunlight.
- Teacher: How would a scientist test out whether or not bean plants need light? What would he or she do?
- Chloe: Maybe put one in the dark and see if it grows...
- Teacher: That's a good idea, Chloe. A scientist might try it to test the idea. Let me ask you some questions about that. If we put a seed in the dark and it did grow, what would that tell us?
- Travis: That plants can grow in the dark.
- Scott: Nooo...That doesn't mean that all plants can!
- Travis: Well at least the bean plant could.
- Teacher: What if we put it in the dark and didn't grow? What would that tell us?
- Ariana: ...that it can't grow in the dark?
- Tara: It could have just been a bad seed or maybe we forgot to water it enough.
- Teacher: Okay, how can we solve the problem of maybe getting a bad seed?
- Scott: You could plant a bunch of seeds.
- Teacher: Okay, a scientist would probably test lots of seeds. What about the watering problem?
- Chloe: We should see how much water bean plants need and give them the right ‘amount.
- Teacher: Okay, let me ask another question. Suppose the plant in the dark grew some. Would you know if being in the dark made a difference in how it grew?
- Emma: Not unless you check beans that aren't in the dark.
- Teacher: Okay, so a scientist might compare beans that grew in the dark to beans that grew in the light. The scientist would try to keep everything else the same except the amount of light it had so that he or she would know that the light made a difference. What are some of the kinds of things the scientist would try to keep the same to make it a fair comparison?
- Ariana: how much dirt
- Scott: the kind of dirt, too, I have two, the size of the pot, too.
- Chloe: how much water
- Teacher: Shall we try our experiment?

Fifth Grade:

- Teacher: Okay, so what patterns do we notice in our shadow stick data?
- Eddie: The shadows are getting longer each day.
- Teacher: Ah... Can we make any predictions about what our future data will look like based on the patterns that we see.
- Gina: It will probably just keep getting longer and longer until... I'm not sure what.
- Steven: Well, till the length of the sunlight changes.
- Teacher: Okay, so you're thinking that the length of the shadows has to do with how long the sun is out?Okay so we have a theory about length of time the sun is out making a difference. What kind of evidence would support your theory?
- Steven: If the shadows stopped getting longer when the length of sunlight is lessening.
- Teacher: What kind of evidence would contradict your theory?
- Steven: I guess if the shadows did keep getting longer when the sunlight time was lessening.

A few days later....

- Steven: It's not just the length of time, it's the position of the sun seems to make the shadows longer and shorter at certain times of the day.
- Teacher: What made you want to revise your idea?
- Steven: cause I thought about it and thought well, if the sun was out a really long time, but stayed in one place, like right overhead, it wouldn't make our shadow change size. Then when I looked at where the sun was when we went outside, I saw that the position was different and it reminded me to include position in the theory.
- Teacher: Okay, so we'd like to revise our theory to include information about the position of the sun affecting the length of the shadow. Scientists often make informed guesses based on the patterns that they see but then they make sure to keep their minds open to new information and evidence that might invalidate a theory or make them want to modify it in certain ways.

Each discipline can be viewed as a lens on the world. Certain kinds of questions, tools, and ways of thinking about knowledge are common to each lens.

What are some of the kinds of questions that scientists might explore?

How can I find out about what I can't see, what happened before, what could happen?
How can I find out how it works?
How can I find out what causes what?
How can I prove it?
What evidence can I find for what I think is so?
What patterns can I find? How can I show the patterns I found to others?
How can the tools of math help me to find out?
How can I measure it?
How can I use data to prove it?

What are some of the tools and techniques that scientists use to find out?

experimental method
controlling and isolating variables
observation
collecting data or information
measurement
graphing
mathematical relationships such as means, modes, ranges, etc.

What are some assumptions that scientists make about what knowing looks like?

An objective, "knowable" reality is assumed.
There are regular, orderly phenomenon in our world.
To some extent, we can control situations to know what causes what.
Patterns in the world can be understood and manipulated by quantifying them.
Past information or what happened before can help us predict what will happen next time.
Certain rules enable us to carry out tests that approach objectivity. There is a purposeful attempt to minimize subjectivity.
Abstractions can help us explore the concrete world.
Concrete examples and models can help us understand abstractions better.

Points for Practice

•Talk with children about ways of finding out answers to the questions that they are interested in.

•Help children to see that knowledge changes. As we learn more, we change our ideas about how the world works. Try to share examples of "we used to believe..., but then we learned..., so now we think...."

•Talk explicitly with children about the process of science, about the assumptions that are made and why they are important.

•Many teaching materials implicitly include process experiences and information but never outwardly discuss the processes and the reasons for them with children. Modify existing materials so that there is explicit reflection on the processes for knowing and finding out.

•Seek out materials that help children think about the "whys" behind scientific epistemology, such as books like, How to Think Like a Scientist: Answering Questions by the Scientific Method, by Stephen Kramer.

•Help children realize that science is a way of knowing and understanding the world that is learnable. They can all learn to think like scientists. Some of the tools and techniques they'll be able to understand now, others will make greater sense to them as they continue to study and explore science.

The New Frameworks and Content Standards

Increasingly, the new standards and frameworks set forth by educators, scientists, and policy-makers reflect the need for a greater constructivist approach to teaching science. They recognize the need to emphasize process, and to understand the nature of scientific inquiry.

The new standards call for deep understanding of the ways of scientists--how they come to know and find out, how they think about problems, what they consider to be valid information, and so on. These are the kinds of skills that the Everyday Classroom Tools Project aims to cultivate. The standards also call for helping students learn the habits of mind, the attitudes and dispositions of scientists. By working with scientists in the Everyday Classroom Tools Project, students have an opportunity to come to understand the kinds of attitudes and habits of mind that characterize their work.

What is known about teaching such habits of mind? Researchers David Perkins, Shari Tishman and colleagues stress that helping students develop effective habits of mind entails helping them develop: 1) sensitivity to occasions for certain types of thinking; 2) skills that will enable them to think well; 3) and the inclination to sense opportunities and apply those skills.

How does all this translate into what students need in the science classroom? It suggests that:

1. Students need opportunities to engage in scientific thinking.

A wealth of opportunities creates a rich context for learning. These opportunities should not be "handed" to kids. Rather, students should be encouraged to be sensitive to opportunities for good scientific thinking. They should look for "thinkpoints" or places in the curriculum and in the course of their lives where thinking like a scientist can help them live better, more interesting, more informed, and more thoughtful lives.

2. Students need models of what good scientific thinking looks like and a vocabulary to talk about it.

Good thinking can be harder to learn than other things, because so much of it goes on in people's heads and isn't easily available for examination. Students are helped by teachers who talk their thinking and the rationale for it out loud. "For instance, now I'm going to consider the evidence for this claim. I am going to think about the source of the evidence and whether or not the source is a reliable one. Here are the criteria that I am going to use...."

3. In addition to models of good scientific thinking, students benefit from explicit reflection upon, and self-assessment of, scientific thinking.

A language to talk about scientific thinking and reasoning enables us to unpack what is going on in our minds and share it with others. For instance, a teacher might say, "I'm comparing the two theories in my head to see which better explains what happened but I'm finding it hard to hold all the ideas in my head at once. I think I will download the ideas onto paper so I can think about them without having to remember them all at once." This gives the students a glimpse into what her thinking is like and what she can do to support it.

It is important to be explicit about why certain types of thinking are better than others. Too often, we assume that students notice and understand the rationale for our choices when indeed they may not. If students are to learn good patterns of thinking, we need to help them see what they are, why they work, and instances in which they apply.

4. Students need to be alerted to pitfalls of good thinking and what to do about them.

People often fall into certain pitfalls in reasoning and thinking. Without focused instruction to learn new ways of reasoning, people persist in these patterns. For instance, in science, it is common to confuse correlation and causality. Students will persist in these tendencies unless they have models to help them think about causality and correlation differently.

5. Students need to see the value of the forms of thinking in science to be inclined to use them.

It isn't enough to notice opportunities for good thinking or even to know how to do it. Students also need to see a value in good thinking such that they are inclined to make the extra effort to do it. Therefore, teachers need to make certain that children see the pay-offs of their thinking: increased understanding; solving a puzzle; answering a question, feeling in control of the learning process, and so on.

Some Habits of Mind Called for by the American Association for the Advancement of Science

Integrity	Skepticism
Openness to New Ideas	Fairness
Diligence	Imagination
Curiosity	

(Rutherford, F. J. & Ahlgren, A. (1990). *Science for All Americans.* New York: Oxford University Press.)

Pictures of Practice

What does it look like to teach the skills, attitudes, and inclinations from the standards in the classroom? It is similar to how a teacher talks about epistemology--the way a scientist thinks and finds out. Here are some snippets of conversations you might hear:

- Teacher: If a scientist wanted to answer that question, what might she do?
- Michael: She would test it to get some information.
- Teacher: What kind of information would be good evidence in this case?
- Cindy: Wow, I noticed that this leaf has really different patterns of color than this one even though they come from the same tree.
- Teacher: That is very careful looking, Cindy. What does that make you wonder about?
- Timmy: His shadow seems taller than mine, but we're exactly the same height!
- Teacher: What are some ways that we could find out if his shadow is taller or not? Do we have any tools to help us?
- Sara: I'm not really sure if this experiment answers our question. We're not sure if we measured the shadows right and that could mess up our results.
- Teacher: It is important to think about the quality of the information and to consider whether it tells you what you think it does. Let's think together about what problems if any, your data set might have.
- Chloe: Hey, doesn't it change the temperature of the solution when we put such a big thermometer in it? The thermometer has been

sitting on the cold table, it must be colder than the solution.

- Teacher: Ahh, there's some very careful thinking. What do others think about Chloe's critique of the procedure? Does it impact what we are trying to find out and if so, how?
- Steve: I think it could affect the temperature of the solution. But I don't see how you could ever take anything's temperature without doing that.
- Teacher: It sounds like you're identifying an important puzzle or problem in science. Let's take some time out to think about the nature of the problem in detail and to think broadly about potential solutions.
- Devon: On the way to school, I noticed that there was a lot of muddy water in the river near the new construction site. I never realized how much we needed the concrete walls they're building next to the new mall to keep the river from looking so dirty. It's good that they're making the mall and those big walls.
- Teacher: Let's think together about how the muddy water, construction, and walls are related. In order to figure out what is causing what, we'll need to ask ourselves some questions. For instance, what are some things that contribute to the river getting dirty? Was the river looking dirty before the construction? What are some other questions we might ask?

Points for Practice

•Build upon opportunities that students notice for using scientific thinking. Use these as opportunities to teach the skills of good scientific thinking while teaching content. For instance, when students notice that where they place the seesaw along the supporting beam (fulcrum) matters, use it as an opportunity to get them to make predictions, consider what good evidence for their predictions would look like, design a test of their predictions and so forth, while they are learning about levers.

•Introduce language to talk about scientific thinking. If a good word to explain what you are trying to explain doesn't exist, make one up with your students.

•Explain to students why you reason about certain problems in certain ways. Share contrasting examples to demonstrate what less careful thinking in the particular situation looks like. Be explicit with kids about why certain types of reasoning are better than others.

•Talk your thinking out loud to help students "see" it.

•Be alert to instances of poor thinking or misconceptions about thinking and help students learn how to avoid them.

•Create opportunities for students to work with scientists so that they can learn firsthand how scientists think about particular problems.

Development Interacts with Children's Sense-Making

One of the challenges to inquiry-based learning is knowing how to handle issues of development. Teachers are faced with a number of them. For instance, "We started off on a question that the students were interested in. It sounded simple enough and then all of a sudden, we were into territory that was way over their heads..." Or "The children start coming up with ideas that seem to make a lot of sense, I'm just not sure how to get them to see that scientists think about these things differently." And "I could use a model and a formula to help show the idea, but they don't yet understand the relationship of the model or formula to the real phenomenon or of the formula to the model." These certainly are important concerns and signal areas that need special thought and attention. Let's consider each area in turn.

1. Children's questions sometimes lead to complexity that they're not yet equipped to handle.

"We started off on a question that the students were interested in. It sounded simple enough and then all of a sudden, we were into territory that was way over their heads..."

This is a common concern of teachers who use inquiry-based learning in their classrooms. The students' curiosity about a question leads to complexity that the teacher doesn't quite know how to communicate to young children. Questions that are bound to interest young children, such as "What makes the colors?" "Why do sounds seem louder at night?" "What does it mean to reflect?" can quickly lead to physics concepts that are over their heads. The problem isn't about getting students to understand *some* things about the phenomenon that they are studying--it's about getting them to understand it deeply enough such that they can explain it and can understand the "whys" behind it.

What kinds of solutions have teachers come up with? Here's how some teachers handle the issue:

- "I communicate to kids that there are lots of connections in the world and whenever we study a topic, sooner or later we'll come to a connection that we may not be able to understand yet, but that's okay, we know more than we did before"

- “There are different levels of understanding. Some topics can't be understood at the deepest levels at certain ages. I try to let my students know that they need to come back to topics, you don't just learn them once. You can always come back and explore the topic deeper."

- "I try to scope out the questions that we are going to spend a lot of time with in advance. I look for concepts that will serve as obstacles to understanding at this age. If there are a lot of them, it's not a question that we spend a lot of time on."

2. Children have great ideas, but they're not always very scientific.

"The children start coming up with ideas that seem to make a lot of sense, I'm just not sure how to get them to see that scientists think about these things differently."

Research shows that at a very young age, children theorize about their world and why it is the way it is. They come up with intuitive theories to explain many things. These theories tend to be fairly resistant to change because they make sense to the child, they represent the understandings that children have figured out. Researchers have identified a number of characteristics of these theories. 1) Because they represent the individual child's experience, they can be personal and idiosyncratic. 2) Children don't necessarily hold coherence as a criterion for their theories so the theories may be customized for each event explained. 3) The theories tend to be stable and resistant to change. Children are often quite comfortable with the sense that they have made and have no reason to change a serviceable theory.

This has both a positive and a negative side for inquiry-based learning. It says that children actively seek to make sense of their worlds and that their curiosities help to motivate learning. It also suggests that they have many "figuring out" tools to help them learn. On the other hand, understandings that children evolve do not always represent current day scientific understandings. This presents a challenge for teachers.

Research shows that kids bring a "sense-making mission" to their worlds and that they have many "figuring out" kinds of tools to help them build their theories. Infants as young as six weeks of age demonstrate some understanding of causal contingencies and in the first six months babies show surprise at events in which their causal expectations are violated. Children seek out patterns in the world and attempt to explain those patterns. Children also hold certain perceptual tendencies. These are largely helpful, thought they can support or limit understanding depending upon how they are applied and the phenomenon in question.

Children's Science Learning

1. From an early age, children develop ideas related to how the world works and what different science words mean.
2. These ideas are usually strongly held.
3. These ideas may be significantly different from how scientists view the world.
4. These ideas are sensible and coherent from a child's point of view.
5. Traditional teaching often does little to influence or change these ideas.

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Resource Booklets on Research in Math and Science Learning

At least three broad perceptual tendencies have been discussed in the science learning literature. 1) Children's thinking tends to be based upon what they can observe. They learn most readily from what they can gather through their senses. In many instances, this is a useful tendency. In cases where appearance and reality diverge, it can trip them up. 2) Children consider absolute properties or qualities before those that involve interactions. This often leads straightforwardly to accurate conclusions. However, it can also lead to misunderstandings of complexity. 3) Children tend assume a linear, unidirectional relationship between events and effects that they observe. Again, this often leads to straightforward, accurate answers but in some instances it leads to a misunderstanding of extended and complex effects.

How Can Children Be Taught Scientific Views of the World?

1. Lessons need to start with the ideas that children hold. The current understandings must be revealed.
2. These ideas need to be explored as possible solutions.
3. Children need to be confronted with ideas that are discrepant with their ideas. It is important to provide evidence that is contrary to their expectations on something that they care about.
4. Children need opportunities to compare the differences between the ideas.
5. Children need opportunities to connect the new idea broadly to the world. Otherwisethey may see it as an isolated case.

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We need to help students see when their intuitive theories do not account for scientific phenomenon. They need to see when outcomes are *discrepant* with what their theories would predict. This creates dissonance which invites them to evolve new and more scientifically-accepted theories. They need opportunities to *compare* the differences between the ideas--to see how one has greater explanatory value than the other. Finally, children need to seek connections to *help* them find broad applications for the new theory so they don't view it as an isolated case.

What methods can teachers use to encourage students to reveal and revise current understandings in an inquiry-based approach?

•Interviewing to see how students construe word meanings.
•Interviewing using questions of interpretation that reveal hidden misconceptions and limits of understanding.
•Developing activities that start with a deep question--one that is revealing of current conceptions (Sometimes it is the same activity as the one that creates a discrepancy between an expected outcome and an actual outcome.)
•Asking the question another way.

- Recording kids' talk around a science problem or everyday event.
- Offering students' everyday instances./Asking them what would happen.
- Giving "homework" with everyday instances and see what they reveal to parents and others.

3. The means to an understanding represents developmental hurdles.

"I could use a model and a formula to help show the idea, but they don't yet understand the relationship of the model or formula to the real phenomenon or of the formula to the model."

Sometimes it's not the understanding itself that poses the first developmental challenge. There are some instances where the tools that teachers would use to help students achieve understanding contain developmental hurdles that make them more or less useful at particular ages.

Children's understanding of models represents one such challenge. Around three years of age, children begin to show early understandings that a model is a representation of something else. For instance, research by Judy DeLoache shows that they could use a model room to guide their actions in finding the location of an object in a real room. These early understandings suggest promise that fairly young children can understand some things about models, yet understanding a model as a representation requires an extra leap in that the model is a thing unto itself. Even if the child perceives it as similar to the original room, the child must also reflect upon and realize that it is being used as a representation of the room. According to researcher Usha Goswami, understandings such as this are a form of analogical reasoning in that children need to recognize the relational similarity and reflect upon the similarity in structure. Using a model to show something about a scientific phenomenon involves 1) understanding the model to be a representational object, not the object itself; 2) understanding the process as it applies to the model; 3) considering how relationship between the model and the process is analogous to the phenomenon in question; 4) holding both in one's head at once; 5) mapping the analogous relationships to enable understanding of the phenomenon in question. That's a lot to think about!

Research shows that into middle school and high school, students still tend to view models as physical copies of reality rather than conceptual representations. Students benefit from scaffolding to help them understand models as metaphors, and to map the deep structure of the models, and not to get caught up in superficial features of the model.

Despite the developmental challenges of helping students grasp and use models well, research shows that conceptual models are very important to helping students develop math and science concepts. This is in particular contrast to the focus in many schools on teaching students quantitative explanations or formal laws for understanding science phenomenon.

It is important for teachers to seek a balance between determining that a certain avenue to understanding is over children's heads with offering them early experiences that will lead to developing an understanding of the concept. Teachers can bolster early understandings by coming at them in a number of different ways so that the children are not dependent upon models as a sole means towards understanding. There are numerous activities teachers can introduce which will engage their students and also uncover hidden misconceptions.

Pictures of Practice

Rethinking Why We Wear Coats: How Insulation Works
A Third Grade Science Lesson

The following picture of practice describes a lesson in which students are exploring the purpose of insulation and concepts of heat and temperature. It deals with a common misconception that young students tend to hold that their coats are a source of heat energy.

- Teacher: Today, we're going to work on a special question that has do with coats and how they work. I'm going to ask the question in just a moment, but first I'm going to ask that you don't shout your ideas out loud. That's because I want everybody here to think about their own answer and to get a chance to test it out. We're gonna spend two science periods on this so there'll be lots of time to talk about it later.

  Here's the question: If you wanted an ice cube to last for a long time in our classroom, would you make a thick or a thin coat for it? Just think about it, don't say any ideas out loud. We're each going to design a coat for an ice cube. You can make it thick or thin, and everyone is going to have a coat for their ice cube. First, we'll draw a diagram of what we think the coat should look like, what we need, and why we think it will work. Then we'll make the coats. And in our next class, we'll test them out. Are there questions?
- Dillon: Can we work together?
- Teacher: In this case, I want everyone to think about what their own ideas are, so onceyou have your idea on the paper, if someone else's is similar to yours, you can make the ice cube coat together.
- Stefan: Is it really like a little coat with buttons?
- Teacher: No, it's more like a package. (She shows some examples, a plastic container with styrofoam, a balloon, a plastic envelope)
- Crystal: Can we use whatever we want to make it?
- Teacher: Well, I have lots of different materials here, plastic, balloons, styro foam, etc. But what do you think, should we use any kind of material?
- Crystal: Well, we shouldn't use stuff that's way too big or too hard to get.
- Hanna: If we all use different stuff, how will we know if it was the stuff or how thick the coat was that made it melt faster?

(A discussion ensues about how to make a good comparison. Two volunteers offer to make two coats that are exactly the same except one is thick and the other is thin. The students decide that this will help with a good comparison and that the rest of them can make what they want.)

The students set off to design their coats. Some of them decide that a thick coat will "warm up the ice cube and make it melt faster." Others decide that a thin coat will result in the ice cube melting faster because it is a warm day in June and there will be less around the ice cube.

(At the end of the session, the students come back together to discuss what will happen in the next class. How will they do the test? What will make it fair? It is decided that everyone's ice cube should have the same amount of water and be the same shape.)

In the next session, the class discusses their ideas. Each student shows their container and explains why it will work. There are clear differences of opinion. The teacher stresses that no matter what happens with the ice cube, everyone is helping the class to gather important information they are thinking like scientists.

- Sara: I made mine thick because it is hot in the room and I wanted to keep the warm air away from my ice cube.
- Dillon: Well, I think a thick one will make it melt really fast because it will make it hot.
- Teacher: It's great to see you all thinking carefully about your ideas and reasoning them out. All of us are thinking like scientists and the many different ideas in the class room will help us to learn a lot about how coats work.

The teacher gives everyone their ice cube as quickly as possible, removing it from the cooler with tongs and putting it directly into the children's containers. She explains how she carefully measured the water in each cube. In addition, to putting cubes into the two containers that are identical except for thickness, she puts one cube out on a plate without a coat. Some kids think it is the "luckiest" ice cube and will last the longest, others feel "sorry" for it! The class discusses why it is important to check their ice cubes only at certain intervals, realizing that it would throw off their results to check it every few minutes. While waiting, they brainstorm as many different things that they can think of that would be considered coats.

- Susan: a coat of paint
- Teacher: Ah, how is it like a coat?
- Susan: It covers the wall and keeps it from getting dirty.
- Dillon: A jacket
- Teacher: Okay, tell about a jacket.
- Dillon: It keeps the cold away.

[Notice that the teacher does not correct their use of the terms "cold" and "hot" as entities yet. In some instances, the teacher even uses the exact same words back when quoting a child (i.e. Can you tell me how "it keeps the cold away"?) Their language reflects their mental models and ultimately when they shift to a thermal equilibrium model, she assumes that their language will shift as well or that the shift can be facilitated at that time.]

- Sara: a roof is like a coat
- Teacher: Tell how.
- Sara: It keeps the snow and rain out.
- Stefan: Your skin is a coat.
- Teacher: Ah, what are some things that your skin does?
- Stefan: Well, it keeps germs out of your body for one thing.
- Travis: It also holds your insides in!

Eventually, the whole board is filled with things that are coat-like. The children begin to see that these things keep what's out, out and what's in, in leading to new ideas about what constitutes a coat.

They stop to check their ice cubes. Low and behold, those in thin coats are melting faster! Some of the students are very surprised. And that poor ice cube without a coat, it's melting very fast. The class closes up the coats with the ice cubes inside and continues their discussion.

- Teacher: (She draws a diagram of an ice cube on a plate, an ice cube in a thin coat and an ice cube in a thick coat) What is the air temperature in our room?

After checking:

- Travis: 90 degrees
- Teacher: At least what temperature is your ice cube?
- Class: 32 degrees
- Teacher: Can anyone explain how the things we figured out about other kinds of coats might affect the ice cubes?
- Karem: The thick coat helps to keep the hot out and the cold inside.
- Sara: The ice cube in the thin coat has no protection!

[Notice that the students do not yet have a notion of heat as thermal energy and that they speak of hot and cold as entities. This suggests the importance of helping students see where the concept of a coat as "keeping what's in in and what's out out" breaks down. See more on this below.]

Then they go on to consider other cases. What about the student who put his ice cube in a coat with water around it?

- Anat: The water is warmer than the ice cube so it makes it melt faster.
- Teacher: What happens when you put an ice cube into a warm drink on a summer day?
- Anat: It melts fast!

The discussion continues as they consider the different examples of coats that they have tested. "What about the students who used balloons for coats?" and so on...

Later the class checks their ice cubes again. By now, those wearing thin coats made of balloons are merely balloons filled with water. Those in the thickest coats have barely melted. Many students are still surprised at the differences between the thick and thin coats. Again the teacher stresses how important all of the different information is and that it helps us to find out the way that scientists do. She tells the class that getting the "right" answer is not as important here as thinking like a scientist.

Then the teacher engages them in some connection-making:

- Teacher: If you put your hand in a hot oven, would you want a thick or thin "coat" around it? (She draws the picture of the oven showing how it is at 400 degrees and asks the kids to compare this to their approximate range of their external body temperature on different days.)
- Devon: You'd want a thick one to help keep the coolness of your hand in and the hotter air in the oven out.
- Travis: But it is different with a coat you wear, it makes you get warm.
- Teacher: Let's think about how that happens. Pretend I left my coat outside over night in the winter so it's really cold in the morning. What happens when I put it on?

- Travis: It would feel cold. But after a while, it would warm up.
- Teacher: Where does the warmth come from? Anyone?

(no response)

- Teacher: Okay, what if I put my cold coat on a snowman instead of me, what would happen?
- Dillon: It would stay cold....
- Stacy: not if it was a black coat and was in the sun, then the sun would warm it up.
- Teacher: Okay, but if the sun wasn't out and the coat was white?
- Stacy: It would stay cold.
- Teacher: So why does it "warm up" when it's on me, but not on the snowman?
- Sara: Your body heat!

The discussion goes on to consider body heat and energy.

Realizing that the students need to see that ultimately thermal equilibrium is reached and that insulation cannot permanently keep "what's in in and what's out out" the teacher has the students check their ice cubes throughout the day. Eventually the ones in the thickest coats also melt and the class reconsiders their theory about how coats work.

- Dillon: Well coats can't really keep what's in, in and what's out out, after a while the warmth gets in.
- Sara: It's like the coat slows it down but it still happens.
- Teacher: What still happens?
- Sara: The ice cube melts. The outside and inside get to be the same temperature.
- Travis: The hot takes over the cold.

[Notice that some of the students think of hot and cold as entities and other students are beginning to speak in terms of reaching thermal equilibrium. The class will revisit concepts of thermal energy throughout the year and it won't be until the students have learned about the nature of energy and the particulate nature of matter that they will come to a yet deeper understanding of what insulation does. With older students, a natural extension would be to talk about heat transfer processes: convection, conduction, and radiation, and how the ice cube is impacted by each in each case, no coat, thin coat, and thick coat.]

In the next few days, the teacher gives the students as individuals another opportunity to think about the question. She has them design a better ice cream cone, one that will insulate well between the temperature differential between the hand and the ice cream. The reason for doing so is that she knows that some children may have changed their ideas based upon the ice cube experience and some children may see it as one isolated instance.

Note: This example borrows from concepts in a curriculum unit developed by ESS on heat and temperature. The particular modifications and examples given draw from the work of Tina Grotzer and students in the Burlington Public Schools, Burlington, MA.

Points for Practice

•Questions that interest young children will sometimes lead them into phenomenon they can't understand deeply. Encourage them to see that they will continue to revisit questions throughout their lives.

•Try to focus the most time and attention on questions that students can grasp with a fair amount of depth.

•Communicate to children that there are connections between questions.

•Create opportunities for students to explore the efficacy of their theories in different instances.

•Attend to group and individual understandings.

•Sometimes it takes careful planning in order to gain the most information about each. Group responses influence individual responses.

•Provide multiple opportunities to rework and rethink concepts.

•Students may not realize that they already have experiences that connect to the new question in some way. Help them to see the connections.

• Some children are more reticent than others at letting you know what they're thinking. Try to get at what is really in their minds.

•Give children the opportunity to reveal and discuss their personal theories.

•Watch out for sophisticated language that can conceal children's real understandings.

•Seek a balance between determining that a certain avenue to understanding is over children's heads with offering them early experiences that will lead to understanding of the concept.

•Bolster early understandings by coming at them in a number of different ways so that the children are not dependent upon means that are developmentally challenging as their sole avenue towards understanding.

•Be alert to instances when potential misunderstandings may be generated due to children's perceptual tendencies.

Engendering Lifelong Learners

Taken together, constructivism, inquiry-based learning, and learning the epistemologies of the sciences can lead to an entirely different attitude towards learning. No longer is science a subject that is tucked away between 1:00 and 2:00 from Monday through Friday. Instead, science is a way of living your life, a way of seeking understanding, a lens that we use to know and find out.

When learning is connected to children's questions, as in the Everyday Classroom Tools Project, it sends a clear message about who the learning is for. Children come to expect that the result of their inquiry should be increased understanding of the thing they were puzzling over and at least as often as not, a new set of questions to try to answer.

By building upon children's tendency to wonder, we help them to develop a tendency to seek out puzzles and to investigate. According to teacher and writer, Hilary Hopkins, who interviewed many different scientists, what stood out for as distinctive about their childhoods was a burning desire to know "Why?" Nourishing this desire in all children will help to encourage lifelong learners who approach their lives with the eye and heart of a scientist even if they spend their days in some other profession!

Pictures of Practice

What does it sound like to communicate messages about lifelong learning to students? Here are some examples:

- Teacher: I've always wondered about what it would be like to visit Antarctica. Last night, I watched a program on it and now I have some new questions. I'd like to learn how penguins are able to stay under the water for as long as they do.

- Student: But we already learned about volcanoes in second grade!

- Teacher: One of the wonderful things about learning is that the more you know, the more there is to know. Last year, you learned some things about what a volcano is and how it erupts. This year, we'll learn some things about where there tend to be active volcanoes and how this connects to the rocky plates on the earth. You'll have fun discovering the relationships.

- Student: What are you going to do for the vacation, Mr. Thompson?

- Teacher: Well, I've always wanted to learn about the patterns on those old cemetery stones in Concord. I'm thinking that I'll go and read them and see what different kinds I can find and if there are any books to help me understand them.

Points for Practice

•Encourage students to investigate their personal "why" questions.

•Help your students to see that they will revisit similar questions again and again in their lives, evolving increasingly sophisticated explanations.

•Encourage students to see that you as an adult continue to ask questions and to learn new things.

•Encourage students to see that their parents/caregivers continue to ask questions and to learn new things. Encourage them to dialogue with their parents about what their parents wonder about.

The Keys to Inquiry

Section II: Big Messages to Communicate Around Learning from Experience

What are the big messages that you intend to communicate to your students?

Inquiry involves risk-taking, observation is an important means for learning, keeping records helps in exploring and sharing patterns, interpreting patterns involves seeking evidence while looking out for discrepancies, inquiry through our experience is part of a history of sense-making, and our questions evolve to become more expert over time.

Inquiry Involves Risk-Taking

Asking questions involves taking risks. How can you communicate this big message to your students and help them take risks in their learning? What does this mean in a concrete sense? There are at least three areas where teachers can help students learn to feel comfortable taking risks in their thinking: 1) The environment must support risk-taking in learning; 2) The curriculum needs to allow for some uncertainty and ambiguity about exactly what children will learn; and 3) Students need opportunities to learn forms of thinking that embody risk-taking and openness.

1. The environment needs to support risk-taking in learning.

Contrast the following two classroom scenarios. Which one encourages students to engage in more risk-taking? What is happening in one classroom as opposed to the other and why does it encourage students to take a risk?

> **In Mrs. B's room**, the students are working to find the answer to a science mystery from a book on science riddlers. It's a who-dunit sort of mystery and students are to read the information carefully to piece together what happened. Sean heads up to Mrs. B's desk. "I think I know what could have happened. It looks like the prints are headed into the swamp and that the strange animal is a swamp dweller. But it could be that the animal has feet that are really different from ours so it was actually coming out of the swamp." Mrs. B responds, "No, that's not it. You need to go back and reread what it says more carefully." She sends him back to his seat and then looks to the class, "Class, in finding the answer it's important to think about what really could happen, not to come up with far-fetched ideas that proba-

bly didn't happen." About ten minutes later, she canvasses the class, "Who has figured out the answer?" One team enthusiastically waves their hands in the air. She calls on them and they give an answer. "That's it, you've got it. Would you explain how you got it to the rest of the class?" says Mrs. B.

In Mrs. C's room, the students are working to find the answer to a problem that they've found in their classroom. Just about every day around the same time, a spot of sunlight appears on the floor of the classroom. The students wonder where the light is coming from. They're investigating possible sources for the light. The students offer possible explanations for the patch of light. "I think someone could be shining a flashlight into our room," says Mike. "Maybe the decorations on our windows make it so the light comes in at that spot" offers Sara. Mrs. C. says, "Let's write these ideas on the board to help us remember all of them" as she begins a list. "Maybe somebody in our room is doing it and they're trying to trick us, " says Tommy. The class begins to laugh. "How could they trick us without our knowing about it? laughs Paul. Mrs. C reminds the class that when brainstorming, it's important to explore lots of different possibilities and that even ideas that sound impossible to us may not be or may lead us to new ideas about what happened. She lists the idea on the board. After the class has a long list, Mrs. C. asks how they could narrow it down. Amy says, "Well, we know it only happens when the sun is out, so that makes some explanations more likely than others. "It sounds like we should think more about when it happens and exactly what happens," says Mrs. C.

Inquiry-based learning requires an environment that supports risk-taking.

This means that:

- question-asking is invited.
- "mistakes" are valued for the learning they provide and as natural parts of the inquiry process.
- open-ended questions are asked and appreciated.
- there's more than one possible answer.
- theorizing and considering evidence is considered more important than a "right answer."
- sometimes questions are asked and not answered.
- all ideas are okay to share.
- ideas are discussed for their explanatory potential, ability to solve the problem, and the thinking that they inspire as opposed to being called "good" or "bad," "right" or "wrong."

Teacher Response

Teachers in the Everyday Classroom Tools Project were asked what kinds of things they could do to create an environment that is conducive to inquiry. Here is some of what they had to say:

"ask open-ended questions."
"set up situations where children are asked to observe and predict."
"take a "how could we find out" approach to kids' questions."
"use the outside environment as a starting point for questions and observations."
"model "what if?" situations.
"encourage sharing ideas (all welcome)"
"validate and respect student responses (for instance, list them on a chart)"
"be non-judgmental"
"welcome questioning"
"model inquiry (as a teacher)"
"ask, don't tell"
"create a 'holding environment.'"
"make time to explore and observe."
"create a positive atmosphere with encouraging words and actions."

It is also important to help your students understand the rationale behind the things that you and they do to support risk-taking in learning and thinking. In the context of classroom discussion, make a point of explaining that we respect many different ideas to encourage everyone to get involved, to think through problems, and to separate critiquing from generating concepts. Understanding that certain types of environments inspire good open-minded thinking in science will help them to go off to seek out and/or recreate such environments when they are adults.

2. The curriculum needs to allow for some uncertainty and ambiguity about exactly what children will learn.

One of the puzzles for teachers around inquiry-based learning is that they worry about what content children will learn. The learner-directed nature of inquiry-based learning means that teachers can't dictate learning outcomes as much as they may have with more traditional curriculum. This bit of uncertainty raises concerns for some educators and parents.

What should teachers do? Well, first of all, it's important to realize that there are lots of ways to come at teaching the same set of underlying science concepts. Of the many questions that children ask, there will be a whole set of them related to evaporation and condensation, for example, or to weight and density, for another example. By deciding which questions to pursue with greater depth, teachers do have the ability to choreograph learning to a certain extent.

It's also important to realize that there's a trade-off in part because students are learning so much more than content. They are learning how science is conducted.

This provides them with tools that will serve them throughout their lives even when the content knowledge that they have learned has become outdated.

At its best, inquiry-based learning starts with children's questions and their prior knowledge and experience. A wealth of learning research underscores the importance of starting with what children already know in helping them build new understandings. Sometimes this means that teachers find themselves faced with more basic questions than the curriculum objectives they hoped to achieve. So, should teachers address these more basic questions or those called for by the curriculum? The choice here is very clear based upon what we know from research on learning. Without understanding the more basic questions, children can't develop an understanding of the more complex ones. This does not mean reducing question to neat little chunks. It means grappling simpler question before more complex ones.

In order to learn to understand concepts deeply, students must have a conceptual framework to fit the information to. Learning can be thought of as constructing increasingly complex networks of connections and understandings. If we teach concepts and facts that are isolated from students other knowledge, they will have little basis for understanding it and remembering it.

It's not only important to start from what kids say they know, it's important to probe those understandings and make sure that kids really do understand what they think they do.

3. Students need opportunities to learn forms of thinking that embody risk-taking and openness.

There are different modes of thinking and these modes map onto to different problem types to help us think well in a variety of situations. Researchers David Perkins and Shari Tishman refer to seven different thinking dispositions and the sensitivities, skills, and inclinations that are associated with each. At least two of these relate to the open-ended forms of thinking: 1) The disposition to be broad and adventurous and 2) the disposition towards wondering and problem-finding.

A description of each form of thinking is provided below. Each form of thinking has a set of key moves defined by Perkins, Tishman, and colleagues. Additionally, a set of prototypical questions can be associated with each key move. The key moves and questions are given for each disposition.

A. ***The disposition to be broad and adventurous refers to the tendency to be open-minded, to generate multiple options, to explore alternative views, to have an alertness to narrow thinking.*** Its purpose is "to push beyond the obvious and reach towards a richer conception of a topic or a broader set of options or ideas" according to Tishman and colleagues.

Key moves:

This means helping students to ....

- ...push beyond the obvious and seek unusual ideas.
  - How else can we think about this?
  - Is there anything else we can do?
  - What wacky and unusual ideas can you come up with?
- ...see other points of view. How would ________ think about this?
  - What if you were on the other team, what would you think?
  - If you were looking at it from where a bird is what might it look like?
- ...look for opposites, things that are contrary.
  - What is the exact opposite of the way we are thinking about it?
  - What if we thought about it in an opposite way?
- ...challenge assumptions. Is there anything that we are taking for granted?
  - Are we sure that we have to do it this way?
  - What if we tried to get the kite to come to us instead of us trying to get the kite?
  - Are we creating any "rules" that aren't really rules?
- ...explore new territory, go beyond the boundaries.
  - What if we change the way that we think about the problem?
  - Are we using the most open-ended wording of the question?
  - What are some other ways to think about this that we haven't tried yet?

B. ***The disposition toward wondering, problem-finding, and investigating:*** The tendency to wonder, probe, find problems, a zest for inquiry, an alertness to anomalies and puzzles, the ability to formulate questions and investigate carefully. Its purpose is "to find and define puzzles, mysteries and uncertainties; to stimulate inquiry" according to Tishman and colleagues.

In addition to helping students use these forms of thinking in their school science, encourage them to use these forms of thinking on their own in their every day lives. It's important for them to see how thinking in the ways outlined above leads to noticing something of interest or brings them to a deeper understanding. Linking the form of thinking to an improved outcome increases the chances that students will engage in the thinking on their own.

Key moves:

This means helping students to...

- ...to be curious! ...to wonder about things! What do you wonder about this?
  Are there some things that you want to know about it?
  What questions do you have about it?
- ...to find problems, questions, and puzzles. Is there anything that seems odd to you?
  Is there anything that you want to fix?
  Why do you think the writer, artist, etc. did that?
  What would you change if you could?
  How would you make it better? ...different?
- ...seek out what's hidden or missing. Do you notice anything that seems to be missing?
  What would you add if you could add something? (Why do you think it's not there?)
- ...to play with what if? questions.
  What if _______________? (...there were no gravity? ...there were no rules? ...dinosaurs never existed? ...we didn't have any numbers? ...it didn't get dark at night?)

 "Key Moves" developed by Shari Tishman in conjunction with The Patterns of Thinking Project. The project was supported by the MacArthur Foundation through a grant to the Co-Principal Investigators, David Perkins and Shari Tishman. "Sample Questions" developed by Tina Grotzer.

Observation is an Important Means for Learning

What does it mean to really *look*? Is there a difference between looking and *seeing*?

These are good questions to ask your students. Their responses can help introduce explicit discussion on the how we observe the world around us and how sometimes we don't.

Often when you ask students these questions, they respond with statements like:

> "Well, you can look at something and not really see it."
> "Seeing can mean that you actually study it and think about what is there."
> "Sometimes you can look at something and even if you try, you just can't see what is there, like when a caterpillar is camouflaged."
> "When you really look at something, you notice details that you otherwise wouldn't see."

In order to help students think about what it means to look and what it means to really see, ask them to try to visualize the following in their minds and see how they do:

1) What does the face of a penny look like? Try to visualize all of the details.
2) Does the clock in your kitchen at home have anything to mark off the minutes between the numbers? If so, what is it (dots, lines, etc.)? Does it have second hand? If so, what color is it?
3) What brand of tires is on your bike?
4) What color is the front of your school? If the school is brick, what is the pattern like?
5) How are the knobs laid out on the front of your TV set?

Students often find these questions hard to answer, even thought they seem fairly straight forward. Why is this the case?

Much of our cognition is pattern-driven. This has both benefits and drawbacks. We need to be somewhat selective about what we pay attention to or our world would be overwhelming to us. Beyond this, attending to certain kinds of patterns is more efficient than others. For instance, noticing the relationship of the hands on the clock to each other is probably much more helpful to us than noticing the color or form of the markers between the numbers. At the same time, our tendency towards efficiency can also keep us from noticing certain patterns in our world. It can keep us from noticing and thinking about everyday patterns that are all around us.

1. We can learn a lot by noticing what goes on around us.

The difference between looking and seeing in the exercise above really comes down to "active processing." When we actively process information around us by perceiving it and reflecting upon it, we are much more likely to notice patterns, to make connections to other things that we know, and to develop an appreciation for what we are looking at. Stopping to reflect can lead to noticing puzzles and deepened understanding. It's important to help students understand the importance of noticing patterns and to experience the rewards of doing so.

2. Noticing patterns is a first step in asking why certain patterns exist and why there are certain puzzles or oddities in patterns.

As we start to notice patterns, we also begin to notice puzzles to be explored in the patterns. These puzzles can lead to a deeper understanding of our world. For instance, in the Everyday Classroom Tools Project, students are encouraged to begin to notice different patterns that are related to the seasons. As they start to notice these patterns, they uncover puzzles that reveal areas that need investigation in order for the students to understand them.

3. We need to try to think openly about what we experience, remaining alert to tendencies or "lenses" that may be limiting.

We need to try to keep our thinking as flexible as possible and not get stuck in one way of seeing something. This is discussed further below under the idea, Interpreting Patterns Involves Seeking Evidence while Looking for Discrepancies.

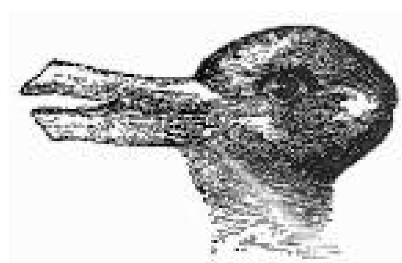
Even when we are trying to remain open in how we observe, there are certain obstacles that can get in our way. For instance, what do you see in the two drawings below?

If you see an old lady,
can you also see a young lady?

If you see a young lady,
can you also see an old lady?

If you see a rabbit,
can you also see a duck?

If you see a duck,
can you also see a rabbit?



Keeping Records Helps in Exploring and Sharing Patterns

Keeping records of our observations can help us to explore and understand patterns as well as share and discuss them with others. Drawing upon tools can extend our ability to detect and share patterns. Each point is explored in turn.

1. Keeping records can help us to explore patterns.

Keeping records of experiences can help in detecting patterns. Not all patterns in the world occur close enough in time that we can detect them just by looking. In addition, micropatterns and macropatterns can sometimes tell a very different story. Keeping records of events can help us to notice patterns over time and in broad and small scale. For instance, if we were to observe the weather in a given area for a week in the summer, it is possible that we would decide that a given area has very dry and hot weather. If we expand our looking by keeping records over the course of a year, we may see that at certain times the weather is very wet while at other times, it tends to be drier. If we extend our looking by keeping records (or looking at kept records) over the course of a number of years, then we might see quite different patterns.

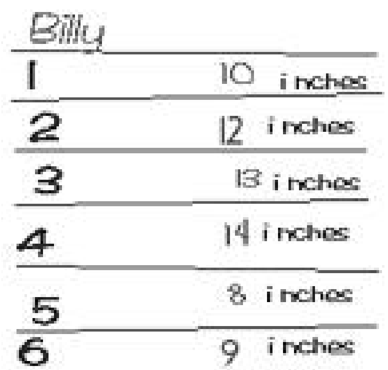
One of the reasons why it is so important to help children keep records to explore patterns is because their sense of time is different from adults. Our understanding of our experiences is relative to our other experiences. You might recall that as a child, summer vacation seemed to last forever whereas now it just flies by. Relative to how long you had lived as a child, summer vacation WAS a long time. So what seems like a long time for a pattern for children is quite different from an adult perspective.

Time helps to create context. We sometimes take the context of our experiences for granted until some child asks a question which reveals that we hold a different context than he or she does. Questions like, "Were there refrigerators when you were a kid?" or "What was the cold war?" remind us that we interpret our experience through the context of earlier experiences. The blizzard of '78 is ancient history to kids, but part of our recent memory. Long-term knowledge of weather patterns accumulates to provide a rich context in which to interpret information that we receive from the environment. We've experienced a different set of extremes and have a greater sense of norms.

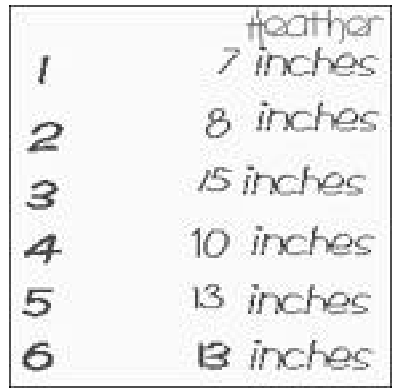
Teachers who focus on inquiry-based learning need to keep these differences in mind. In so doing, teachers can help children use tools to facilitate pattern-finding in their experiences (charts, graphs, journal entries, etc.) Teachers can also help children learn to look at records of patterns charted by others. This invites students to benefit from the experiences of others--to learn from a rich history of accumulated knowledge of patterns. The sharing of patterns, both those students find and those that others have found, is where we turn next.

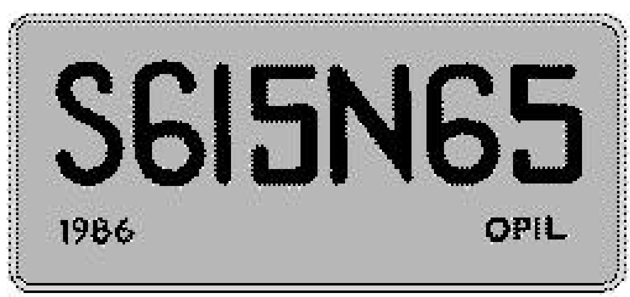
2. Recording patterns makes it easier to share and discuss them with others.

We may sense that a certain pattern of events is occurring or has occurred. By recording our observations, we amass evidence that helps us to detect the pattern and to share the pattern with others. This is particularly important in classrooms using mediated constructivism as a means to advance knowledge. The collecting of evidence allows individual learners to detect patterns and to construct understanding of them, and it provides a means to share them with others such that the community of learners benefits from the collective experience of those in the group.



Sharing recorded patterns with others also invites consideration of discrepancies in the patterns that individuals find. Scientists record and share their data with others. This invites discussion, opportunities to notice discrepancies between data sets, and to seek and evaluate reasons which help to explain the discrepancies. Often this process points out differences in how data was collected and highlights variables that need to be taken into account. For instance, one student may have collected the shadow data in Figure 1 while another student collected the data in Figure 2. A priori, the students may not have had a clue that they needed to also attend to what time in the day they collected their shadow lengths. However, by looking at the discrepancies between the data they collected, they can construct an understanding of the importance of the variable, "time of day."

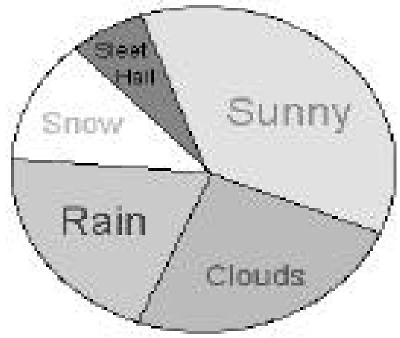




Sharing recorded patterns with others invites consideration of the best mechanisms by which to communicate specific patterns. Different types of graphs emphasize different aspects of patterns and thus the choice of graph is a decision about how to communicate one's experience to someone else. For instance, the two graphs below emphasize different

aspects of the same form of data--information about rainfall. One graph is intended to emphasize the types of weather relative to other types (the pie graph) whereas the other (bar graph) stresses the seasonal variation in rainfall. Deciding how to present patterns to others involves students in thinking about what it is that they wish to communicate about the pattern.

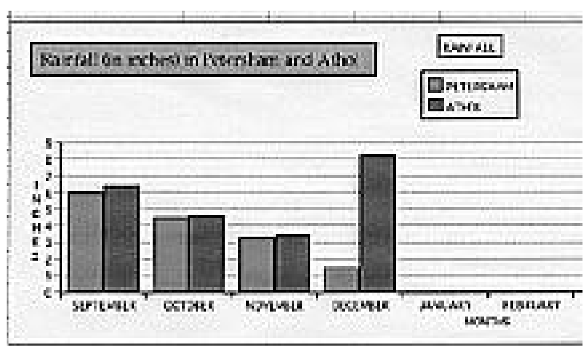
Invite your students to share their data visually and verbally. Provide a safe and supportive "scientific community" where discrepancies in data sets are viewed as scientific questions to be investigated, not errors--but steps on a path of closer approximations to scientific "truth."



3. Tools can help in finding out about patterns.

Not all patterns reveal themselves to us through our direct observation. Tools can help us to see patterns that we otherwise would not see and to learn about the patterns that we do detect in ways that we otherwise wouldn't. Classrooms need to help students view tools as perception-extending devices.

Tools come in many forms. There are actual mechanical tools that serve as aids to perception. For instance, the telescope is a tool for extending vision. The magnifying glass or microscope extends vision in another way.



The internet can be viewed as a special kind of tool of this type. It belongs in a class of tools that extends our ability to experience and share our experiences more broadly. Through the internet, we can extend our sense to know that it is night in Japan when it is daylight in Ohio or that it is winter in Australia when it is summer in New England.

Beyond these actual mechanical tools, are tools that transform patterns in a more abstract sense. For instance, statistical transformations can be viewed as tools that allow us to see patterns in transformed data that were not so accessible to us in the raw data set. Our number system can be viewed as an ingeniously designed tool. For students, these types of tools are probably best understood in the "tool sense" by drawing analogies to concrete tools students are probably more familiar with.

Interpreting Patterns Involves Seeking Evidence While Looking Out for Discrepancies

One of the primary goals of the Everyday Classroom Tools Project is to get students to notice patterns in their experience and then ask "why?" The goal is to encourage them to go beyond describing and seek to explain. At this point, they move from pattern noticing to hypothesis building. In some sense the distinction is a false one because many scientists hold an a priori notion of what might happen in their heads and seek patterns that confirm or disconfirm it. In any case, the pattern noticing doesn't stop because even after scientists notice a pattern and formulate a hypothesis about it, they continue to seek patterns in a confirmatory or disconfirmatory mode.

Formulating a hypothesis is when you consider what you think might be happening and seek reasons for why you think it might be happening. It is an attempt at interpretation or explanation.

One of the potential pitfalls of formulating a hypothesis is closing off one's mind to alternative explanations. It is important to gather evidence in support of a hypothesis while keeping an eye out for disconfirming evidence, puzzles that can't quite be explained by the present interpretation. Keeping an eye out for potential "cracks" will help your students to evolve the best explanations and to understand that science involves the purposeful discard of theory as better theories come along.

Interpretation involves reasoning about and evaluating evidence. Research shows that students don't necessarily evaluate evidence well on their own. There are certain types of problems that they run into. For instance, it is not uncommon to only consider evidence on one side of a case, to make unwarranted claims, or to not notice when claims are unwarranted. Therefore, it's important to help students learn to think well about evaluating evidence and to help them learn to do so.

At the end of the Keys of Inquiry is the Evidence Evaluation Poster which you may consider photocopying to poster size.

Inquiry Through Our Experience is Part of a History of Sense-Making

Often when teachers begin inquiry-based learning with their students, they help their students to
discover the importance of on-going inquiry in a broader sense. They invite their students into the company of scientists and sense-makers throughout history who have sought to understand the world that we live in. There are a number of important lessons that students learn.

1. We are still finding out how the world works. We don't know all the answers.

When science class only consists of facts and figures that we know to be "true," it communicates to students that we know all the answers, instead of letting them know that our ignorance far outweighs our knowledge. It keeps them from finding out that there are lots of mysteries that we can't begin to answer. Letting students in on the mysteries of the world ignites their curiosity and opens the door to a lifetime of finding out. In the late 1980s into the 1990s, NASA conducted the Space

Seeds Program in which they invited school children across the nation to participate in a grand science experiment in which students compared seeds that had been in space to seeds that served as a control group here on Earth. One of the many wonderful things about this project was that it communicated to children that there are questions we don't know the answers to and that they can participate in finding out.

2. For centuries, people have tried to understand the world and make sense of it based upon what they could perceive.

Often the theories that students evolve as they first grapple with explaining different phenomenon are not unlike those that ancient (and not-so-ancient!) people created to explain similar phenomenon. This is a common enough occurrence that it is referred to as "recapitulation" or "ontogeny (individual growth) recapitulates phylogeny" (our collective growth). Often the basis for the similarities has to do with certain ways of seeing and measuring information. Certain perceptual information seems to lead to certain conclusions. For instance, it does appear that the moon follows you when you walk. Thus young children think the moon is following them, and are basing their knowledge on what they see just as people did centuries ago. With a balance of constructivism and scaffolding we can help students see the common sense of their intuitive theories while we help them to reach towards more current day scientific notions based on our collective knowledge and the tools and techniques we have available to us today.

Today, we continue to create theories about the world and try to make sense of what we observe. It is important to continue to visit and revise those theories as we learn to ask increasingly sophisticated questions.

Our Questions Evolve to Become More Expert Over Time

Research shows that experts and beginners tend to notice different kinds of patterns when they consider scientific phenomenon. Experts structure their understanding and construe meaning from information differently than beginners. Experts tend to notice patterns related to deep structure while novices tend to notice more superficial features or may get drawn to those features that most attract their attention whether or not these are the patterns that are most relevant. Experts tend to consider the bigger picture and to notice larger, systemic patterns. Experts also tend to monitor their activity in a self-regulatory way.

A novice looking at weather patterns might consider the localized effects of warm and cold fronts and the weather implications of the fronts meeting, while an expert might look beyond the immediate patterns to consider how they are linked in a complex causal relationship with weather patterns such as El Ninio or with the patterns of flow in the Gulf Stream. Experts are also more likely to contrast their explanation of what is happening with commonly accepted theories to see if it complements or contradicts those theories and whether they have considered the right set of variables to know.

This finding is certainly not surprising considering that experts have contextualized knowledge, background information that helps them decide how to attach importance to particular findings. Indeed as someone becomes expert in a given domain, their manner of attaching importance to patterns undergoes a shift. This is referred to as the "novice-expert shift."

What does the "novice-expert shift" imply for inquiry-based science? Students need opportunities to revisit questions and concepts as they spiral towards increasing expertise. Students' early questions will be those of a novice and only as students seek answers to their questions and gain in expertise will their questions become increasingly sophisticated and focused on the deep structure of the knowledge in the domain that they are studying. This doesn't mean that teachers can't scaffold students' question-asking to some extent. However, teachers should not scaffold students beyond the level at which the questions make sense to the student and generate from what the student believes is sensible to ask.

This argues for giving students plenty of time to delve into topics deeply. If students are not given sufficient time to delve into a topic, they will merely inquire at the surface of the topic and never reach the more meaningful patterns and understandings to be constructed at deeper levels.

Communicate the process of increasing expertise with students by letting them know that:

- Once you've learned certain things, your questions change.
- One question may take you part of the way towards understanding, then you often need to ask a new question.
- Deeper questions often come from earlier questions.
- Atsomepoint,thingsconnecttootherthingsthatweknow.Trytofindconnections to help you better understand both what you are learning and what you already know.
- Identifying relevant questions is a process. It is fruitful to pursue asking a next and more sophisticated question.

Evidence Evaluation Point!

Consider the evidence carefully
by asking yourself some questions:

1. Where does the information come from?

- What observations can *you* make?
  (directly from looking at the evidence or from seeing something happen)

- Think about possible sources of bias or error.

- What information comes from *other sources*?
  (from other people by what they say or have written)

- Think about possible sources of bias or error.

- Think about how credible the source is.

2. What patterns can you see in the evidence?

- Think about whether you are making any assumptions.

- What do you know for sure?

- What do you think might be true?

- Think about whether there are any missing links in your logical argument for what you know is true and what you think must be true.

- What information do you need to fill the missing link?

3. What is the most <u>plausible</u> explanation based on the *current* evidence?

- Consider what you know for sure.

- Consider what information you still need.

- Ask yourself: Does the situation require being certain beyond the shadow of a doubt? Or is a good theory acceptable?

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