Dimensions of Inquiry

By Arthur H. Camins
Elementary Mathematics and Science Coordinator
Hudson Public Schools, Hudson, Massachusetts

Over the last two years I have been deeply embroiled in a struggle over the content of the Massachusetts Mathematics and Science and Technology/Engineering Curriculum Frameworks. Much of the debate has centered on the role of inquiry in mathematics and science instruction.

Two things have become clear to me. First, although many people are using the term inquiry, we don't all mean the same thing. Second, people bring different values about the goals of education to the discussion. Clarifying what we mean by inquiry and its role in what we value about learning is essential if we are to shed any light on what should be happening in classrooms.

Although much of the recent discussions about improving mathematics and science education has revolved around the term "inquiry," there is still a great deal of confusion about what it means. A point of agreement is that all inquiry involves asking questions and framing explanations. Over the years, I have witnessed more than a few discussions that evaluated science curriculum and instruction based on the degree to which they were perceived as being inquiry-based. These discussions turned on the extent to which questions and investigative methods were generated by students or teachers.

This is not a trivial question, but it glosses over a number of prior questions which, if explored thoughtfully, could provide useful direction to teachers. A good place to start, I think, is to ask the following questions.

What do we know about the process by which people learn? How do scientists and mathematicians go about asking and answering questions or solving problems? What are the skills that people need to engage in scientific inquiry and mathematical reasoning? What habits of mind support these modes of thinking? What pedagogical strategies support these notions of learning and thinking?

However, before we can sort out these dimensions of inquiry, we need to set aside two ideas that tend to confuse the discussion. The first such notion is that there can be "pure inquiry." In designing instructional experiences, we need to make decisions about the relative degrees of students' self-direction and teacher direction in relation to nature of the particular subject matter, levels of student cognitive development, and available time and resources.

Second, we need to be clear that although the urge to inquire is a fundamental human trait, we are always inquiring about something. We want students to learn how to inquire, so that they develop more nuanced understandings about the world that are grounded in reason and evidence.

Teacher professional development should help bring some clarity to these questions in order to guide what happens in classrooms. Unless teachers develop some passion for why inquiry is important, not much will change. Teachers need to engage in inquiry themselves and then reflect on the question of inquiry and how to implement the practice in their classrooms.

There are a number of implicit values that are the foundation upon which to build our work. I place a high value on scientific thinking and mathematical reasoning as a way to make sense of both the physical and social realms. This is related to the notion that reason and logic, systematic testing and altering of explanations in the light of evidence, and openness to peer critique are superior to simple intuition or prejudice as a way of knowing.

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As educators we are faced with the challenge of preparing students to live in a world that we cannot yet imagine. This implies that learning how to learn and how to make sense of and interpret information in the natural and social spheres is our most important challenge. Since knowledge and understanding inform the questions we are able to ask, we also want children to gain as much conceptual knowledge as is reasonable and age appropriate. I also believe that the only chance we have of addressing issues of inequality, poverty, prejudice, and environmental degradation is for students to internalize the habits of mind and skills associated with inquiry. They need to learn how to utilize them to make sense of and interpret information and to make decisions. If, as educators, we can do this in a context that places value on respect and dignity for all people, we will have done our jobs.

What Are the Characteristics of Inquiry?

I propose that we need to think of inquiry as having five distinct, yet interdependent, dimensions.

- As a description of the cognitive processes by which people make sense of patterns and relationships in the natural and social world. This is a biologically-determined, but socially-mediated process. That is, it is based on how the brain works and how people interact with one another in the social world.
- As the processes of investigation, problem solving, and verification that are the essential core of mathematics and science.
- As a set of skills or abilities that we want students to develop in order to be effective thinkers and problem solvers.
- As a description of the "habits of mind," attitudes, and behaviors related to learning and knowledge that we value. Many of these are part of the ways of thinking and problem solving that are part of the enterprises of natural science, mathematics, and social science.
- As a description of the instructional practices that build upon the four categories above.

The significance of these distinctions can be clarified by a simple example. Measurement is an essential aspect of mathematics and science. We can teach students how to use a graduated cylinder to measure volume in a step-by-step fashion. However, unless our teaching is informed by an understanding of how children develop images of three-dimensional space and notions of standard unit or how they come to understand measurement as an iterative process, they will soon forget the skill. Unless students understand the process of inquiry they cannot make judgment about when it is appropriate to measure or how to use measurement as part of a logical explanation. Finally, unless they develop not only the skills to measure with precision and accuracy, but value it as well, our teaching will ultimately prove useless. Teachers will need to develop different strategies to address skills, processes, and habits of mind.

What do we know about how people learn?

Inquiry Builds Upon Innate Cognitive Processes

Learning is an active process in which people identify new patterns and relationships in the natural and social worlds. The ability to decipher patterns grows out of innate human cognitive capacities, and it develops in a fairly predictable order. These biologically-based capacities need nurturing and a rich experiential base in order to develop full expression in thought and behavior. Effective teaching for particular educational goals makes full use of and exercises these cognitive capacities through planned, developmental, structured instructional experiences. It builds upon children's questions and natural curiosity, as well as seizes upon teachable moments and opportunities for independent learning. These cognitive capacities are the substructure upon which all thinking, attitudes, and behavior are constructed. For the purposes of understanding, organizing, and responding to teaching and learning experiences, the following fundamental cognitive processes can be considered.

- Observing
  Children observe the world through their senses, including looking, touching, tasting, smelling, and listening.
- Communicating
  Humans are by nature social animals with the unique ability to communicate through invented language and symbols. The development of knowledge, skills, and understanding is, therefore, inextricably linked to social interaction and communication.
- Comparing
  This process builds upon observations and deals with similarities and differences in both qualities and quantities and between the known and the unknown. Frequently comparing objects leads to finer observation.
- Organizing
  Human brains have the capacity to bring order to observations and comparisons by "putting objects or phenomenon together on the basis of a logical rationale," including seriating, sequencing, grouping, and classifying.
- Relating
  Seeing relationships involves under-standing interactions, dependencies, and cause-and-effect.
- Inferring
  This process involves our ability to draw logical conclusions from events, phenomenon, or ideas that may be remote in time and place based on orderly reasoning from evidence or premises.
- Applying
  This is the process by which humans bring all other processes together to tie knowledge, relationships, and inferences together into a comprehensive framework or theory or to apply these in a

new or novel situation.

An awareness of these cognitive capacities and their developmental trajectory should guide instructional design and questioning strategies.

Inquiry Builds Upon Prior Knowledge

Current research indicates that children arrive in school with fairly well-developed mental schema, ideas, and values about how the natural and social world works. Conceptions are formed through the construction of complex webs of interconnections among neurons in the brain. These ideas or conceptions serve as filters, constraints, and springboards for all school-based learning. Research has demonstrated how resilient and powerful these conceptions can be. Learners will often hold onto preconceptions or intuitive ideas even in the light of new evidence or teaching.

There are two implications for acquiring new knowledge. First, we know that new information is interpreted through existing mental schema. Second, we know that contradictory or discrepant information only alters existing schema when those contradictions are realized and resolved on a conscious level (reflection). People often hold simultaneous but contradictory conceptions; however, the ideas with the more "hard-wired" interconnections are most often used to interpret new information. Third, although knowledge consists of constructions in an individual brain, the process by which information is processed is socially mediated. Therefore the social context for learning exerts powerful influence on what is learned and how learning takes place.

How do scientists and mathematicians go about asking and answering questions or solving problems?

Inquiry Models the Processes Used by Scientists and Mathematicians

Over the course of conscious human existence we have generated an enormous body of knowledge that has sought to bring some order to the natural world. Essentially, this order-seeking is a uniquely human endeavor in which we look for patterns to make sense of the world around us. The formal enterprises of mathematics and science have developed systems of reasoning and logic, rules of evidence, and means of verification and revision. Our educational goal is for students to learn, practice, and adopt these modes of investigation in their everyday existence.

- Questions and Conjectures
  Scientists and mathematicians ask questions and make conjectures that are answerable based on evidence. (This is distinct from questions that can only be answered based on personal feelings or faith.)
- Observation and Tools
  Scientists and mathematicians use technology to extend their senses, manipulate data, and to improve the accuracy of observations.
- Evidence and Explanation
  Scientists and mathematicians develop explanations using observations (evidence) and what they already know about the world.
- Reasoning and Proof
  Scientists and mathematicians offer explanations and proofs that are based on reasoning that is logically consistent.
- Communication and Critique
  Scientists and mathematicians make their explanations public so that investigations are subject to replication and verification.
- Revision and Change
  Scientists and mathematicians consider alternate explanations and revise their explanations in the light of new evidence.

Inquiry is Enriched by Rich Conceptual Knowledge
In discussions about learning, inquiry is often discussed as a separate entity from content knowledge. However, research that compares how novices and experts in particular disciplines approach solving problems has highlighted the importance of conceptual understanding in framing how individuals make observations and incorporate those observations into new understandings. Experts notice more features and nuances of a phenomenon or situation than novices do. Their conceptual under-standings make it possible for them to make connections among what may seem like disparate phenomenon to novices.

In addition, experts monitor their own learning (meta cognition) so that they can check for what they may not know or what requires additional information. Being an expert is not innate. Novices can learn to be experts. Being an expert in one field does not imply expertise in another. An expert in microbiology may behave as a novice in another area of inquiry such as astrophysics or piano playing. However, experts' habit of first seeking to develop an understanding of a problem and search for patterns tends to differentiate them from novices whose knowledge tends not to be organized around big ideas. Inquiry, therefore, is contextualized within specific areas of knowledge.

What are the skills that people need to engage in scientific inquiry and mathematical reasoning?

Scientific Inquiry Skills

Our natural abilities are quite distinct from the extent to which we exercise them. Being physically able to throw a baseball is rather different from throwing a strike, much less throwing strikes consistently. Being able to observe and see patterns does not mean that we have the repertoire of experience and practice to do so with care, refinement, or routine. There are, therefore, skills that must be practiced in order to become an effective learner. From an instructional point of view, it is not only critical to be aware of the cognitive process available to children, but also to organize engaging experiences for students to practice these skills in a variety of meaningful and engaging contexts. Below is a non-exhaustive list of some of these processes drawn from science education, but which have application to other subject areas.

- Identifying questions that can be answered through scientific investigations;
- Systematic, careful, or refined observing;
- Sorting on the basis of single or multiple properties;
- Communicating through written expression (pictures, words, sentences, paragraphs, reports, etc.);
- Graphing (concrete, pictographs, histograms, bar, pie, Cartesian, etc.);
- Constructing and using data tables and charts;
- Measuring with a variety of tools and units;
- Using various types of scales (temperature, hardness, etc.);
- Identifying variables;
- Predicting;
- Using the tools of scientific investigation to gather data and extend the senses;
- Interpreting and organizing data;
- Designing and conducting scientific investigations;
- Making predictions on the basis of evidence;
- Constructing logical arguments on the basis of evidence;
- Locating information from a variety of sources;
- Working effectively as a team member; and
- Following directions.

What habits of mind support scientific and mathematical modes of thinking?

Habits of Mind
Research indicates that direct teaching of science process skills or mathematical procedures without conceptual under-standing does not result in effective learning. However, even if children are taught to apply the methodologies of scientific and mathematical inquiry in a school context, they may not ultimately assimilate these ways of thinking, problem solving, or verifying into more generalized thinking and attitudinal patterns. Neither our biologically determined capacities nor the socially mediated skills needed to exercise them necessarily mean that students will, in fact, think or behave, for example, as a scientist or mathematician. For students to be effective problem solvers or critical thinkers they need to adopt and assimilate the values, attitudes, and ways of thinking associated with the scientific inquiry and mathematical investigation. This requires instructional direction and focus. Most importantly, it means that students need regular opportunities to apply these skills and process in personally meaningful contexts. Listed below are some of these "habits of mind."

- Curiosity: A willingness to ask questions about the natural or social world; wonder;
- Open-mindedness: A willingness to change ideas in the face of new contradictory evidence; valuing both skepticism and theory; valuing and practicing collaboration with others in the process of experimentation and the creation of knowledge;
- Respect for Evidence: A desire for accuracy and precision in observation and measurement; valuing and practicing the use of data, evidence, and reason in the construction of explanations; valuing and practicing accuracy and precision in explanation;
- Persistence: A willingness to persist and take risks to find answers and ask new questions in the face of ambiguity, challenge, and contradictory evidence; and
- A sense of stewardship and care: A sense of responsibility for the well-being of others and the environment.

What pedagogical strategies support these notions of learning and thinking?

Effective teaching based on inquiry in all the facets discussed above is not simple or easy. It requires deep conceptual knowledge on the part of teachers who have access to high quality curriculum materials that are thoughtfully developed across at least a K–12 continuum. It requires subject specific knowledge about how particular conceptions typically develop, as well as what confusions may arise. It requires a great deal of continual planning and constant assessment and reframing of instruction. It requires a supportive social context for students and teachers. It requires ongoing, honest collaboration among teachers, administrators, and parents. It requires time!
We can note some general features of inquiry-based teaching.

Inquiry-Based Teaching

- Focuses on learning with understanding.
- Is rooted in students' knowledge.
- Is guided by student curiosity and questions.
- Engages students in active learning.
- Identifies, builds upon, and, when necessary, consciously challenges students' existing ideas and preconceptions.
- Provides opportunities for learning that build upon students' interests, questions, curiosity, and existing knowledge.
- Engages students in self-conscious sense making, self-assessment, and reflection.
- Engages students in applying knowledge, skills, and understanding.
- Engages students in learning activities that require collaboration in order to reach and verify conclusions.
- Engages students in critical questioning.
- Engages students in using evidence to reach and verify conclusions.
- Engages students in communicating tentative thinking, as well as ideas about which they are more confident.
- Self-consciously establishes goals in the areas of significant content knowledge, skills of inquiry, and modes of thinking and behaving consistent with inquiry.
- Creates a positive social context that supports inquiry.
- Uses ongoing assessment to improve instruction and meet the diverse needs of children.

Why should we care about inquiry?

Finally, inquiry-based teaching is rooted in a belief that inquiry matters in children's lives and in our own. One of my most vivid enduring memories as a child recalls a bus ride home subsequent to the arrest of Adolph Eichmann for his role in the extermination of Jews in Nazi concentration camps. Although I was only about 7 or 8 years old, I was keenly aware of the events as well as my minority status in my community. I don't quite remember the context that prompted the conversation, but I heard one of my classmates, sitting behind me on the bus say, "He should have killed six million more." Two things stand out for me in this memory. The first, is that I did not yet have the courage to speak up. I regret this even to this day. Second, is the deeply troubling recurrence of unexamined prejudices. For me, inquiry is about helping to build a community of inquirers in which speaking up is not only safe, but encouraged and where attitudes, values, and beliefs are able to be challenged in the light of evidence. Each of us will have to find our own set of motivations, but I believe that our efforts need to be driven by a passion for personal and social values.

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