Promoting critical thinking in science

1. What is critical thinking?

Critical thinking occurs when students attempt to make reasoned judgments based on relevant criteria. Questions and tasks that require critical thinking invite students to carefully consider and deliberate about the content of the curriculum, the quality of their thinking and the world around them. Critical thinking is a methodology that helps students develop a deep understanding of the concepts and competencies required to succeed in science. Students are thinking critically in science when they:

- make reasoned judgments about what to do (decisions) and what to think (conclusions) in relation to scientific concepts and contexts
- consistently consider the criteria or grounds for a thoughtful decision or conclusion and not simply guess, mechanically follow a procedure or routinely apply a formula
- use relevant intellectual tools to deepen their thinking in increasingly self-regulated ways

What does critical thinking look like in the classroom?

A middle school teacher wanted her students to think critically as they created inquiry questions to frame their own experimental investigations. She recognized that framing a good question for critical inquiry is not simply a mechanical task. She wanted students to think critically about the quality of their questions and therefore they would need some criteria.

She asked students to identify the differences in various examples of testable and non-testable questions. With their teacher, students decided that testable questions for their scientific experiments had to meet four criteria. Testable questions:

- investigate features that change (variables)
- focus on how one variable might have an effect on another
- allow for results that could be observed
- be feasible (students could manage and measure the variables)
The teacher posted the criteria in a prominent place and the class turned their attention to a topic they were studying. Together they identified the general components of the topic and how they could “vary” each component to create variables. The teacher modelled the process of choosing two variables and combining them in a question for investigation. Using the criteria, students discussed whether the question was testable, and then set about creating and judging their own questions.

For example, when studying the concept of dissolving, students identified four general components: solvent, solute, stirring and room conditions. They varied the components to create variables such as ‘temperature of solvent’ and ‘particle size of solute’ and used them to create their testable questions. “Does the particle size affect the rate of dissolving?” met the criteria, whereas, “Does hot gasoline dissolve anything?” did not.

2. Why promote critical thinking in science?
Time invested in developing critical thinking pays off when students “learn to think and think to learn.” Students who are critically thoughtful throughout their learning in science develop:

- **deeper engagement and understanding.** Research and common sense tell us that, no matter how hard we try, we cannot think or understand for our students. We can, however, create conditions that encourage students to actively engage in learning science through critical inquiry. Critically thoughtful engagement results in deeper learning of science concepts and processes.

- **greater independence and self-regulation.** By helping students develop a repertoire of thinking tools that they learn to use independently, we can support their growing confidence in thinking for themselves and monitoring their own learning.

- **stronger competence with scientific inquiry skills.** Current standards in science education call for a focus on learning to undertake scientific inquiry, including initiating and planning, performing and recording, analyzing and interpreting, and communicating. Each of these competencies is strengthened when students are supported in thinking critically in every aspect of their science program.

3. When should we invite critical thinking?
Since a critically thoughtful approach helps students better understand what they are learning, it makes sense to invite students to make reasoned judgments about virtually every aspect of science, including:

- learning science concepts
- choosing the most appropriate way to represent a scientific concept or situation
- assessing the plausibility of scientific theories
- deciding how to approach a problem or scientific situation for which they have no ready-made solution or procedure
- identifying reliable sources of information to support their investigations
- selecting from a body of evidence
- analyzing their own responses and asking, “Does this make sense?”
- communicating their scientific conjectures, reasoning and conclusions effectively
- making meaningful connections between scientific concepts, their own lives and the wider world
4. How can I support critical thinking in science?
Science teachers can promote a thinking classroom by working on the four interrelated facets illustrated in the following diagram.

Shape the climate to support thinking
- Deliberately nurture a classroom culture in which discussion about questions the students have about the scientific and technological phenomena found in the world around them is part of the daily routine.
- Encourage students to offer sound reasons or explain their thinking.
- Turn student questions back to them (“What do you think? How could we find out?)
- Draw the class together after a problem solving session to share, discuss and analyze the various approaches they used.
- Together develop guidelines for working collaboratively in active, hands-on and scientifically meaningful investigations.

Create opportunities for thinking
- Use different types of questions to frame engaging and thought-provoking science tasks.
- Present problem solving opportunities for which students have no predetermined solutions and for which there are more than one reasonable solution.
- Challenge students to look for opportunities to use science and technology in real world situations.
- Encourage iterative thinking where students revisit initial ideas and share their evolving thinking through conversations, class discussions and written reflections.
- Sustain inquiry through use of learning provocations.
- Orient learning around a rich over-arching inquiry and an over-arching challenge that frames key curricular outcomes.
**Strategies for framing questions that invite critical thinking**

How might we tweak common activities so that they invite more critical thinking? Here are six practical ways to frame tasks so students are prompted to use criteria to explore science content more deeply.

<table>
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<tr>
<th>Prompts</th>
<th>Examples</th>
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<tr>
<td><strong>Critique the piece</strong></td>
<td>• Are our conclusions reasonable, based on the tests we did?</td>
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<td><em>Assess the merits or shortcomings of a teacher-provided or student-generated product or performance.</em></td>
<td>• Is my drawing an effective representation of this concept?</td>
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<td><strong>Judge better or best</strong></td>
<td>• Which of three graphs most effectively displays the data from the experiment?</td>
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<td><em>Judge from among two or more options which better or best meets the identified criteria.</em></td>
<td>• What are the five most important things to know about mechanical advantage?</td>
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<td><strong>Rework the piece</strong></td>
<td>• Change the use of variables to make this experiment fair.</td>
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<td><em>Rework a product given a new audience, perspective or piece of information.</em></td>
<td>• Modify the diagram of the cell to accurately reflect the phenomenon of cell division.</td>
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<td></td>
<td>• Modify the design of this experiment to make it effective in cold temperatures.</td>
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<td><strong>Decode the puzzle</strong></td>
<td>• Provide a reasonable explanation for the observed changes.</td>
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<td><em>Given a set of informative clues, solve a puzzle or mystery and justify your solution.</em></td>
<td>• Make an informed guess as to the purpose and function of the nucleus.</td>
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<td><strong>Design to specs</strong></td>
<td>• Create a cartoon that explains in a humorous and effective way the importance of controlling variables in an experiment.</td>
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<td><em>Develop a product that meets given criteria.</em></td>
<td>• Design an effective plan for an insect habitat.</td>
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<td>• Design an experiment collaboratively to test the principles of magnetic force.</td>
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<td><strong>Perform to specs</strong></td>
<td>• Deliver an effective demonstration of using a microscope.</td>
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<td><em>Undertake a course of action that meets given criteria.</em></td>
<td>• Given certain materials, build an effective device to filter water.</td>
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<td>• Mount an effective campaign to protect a particular ecosystem.</td>
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**Build capacity to think**

- Co-construct criteria with students.
- Teach thinking strategies such as how to evaluate data or how to represent cause and effect relationships.
- Foster helpful habits of mind such as being attentive to detail during hands-on experiments.
- Develop background knowledge through critical inquiry.
- Teach key vocabulary related to thinking to help students recognize important distinctions and offer more precise observations and conclusions.
A classroom example of teaching thinking tools

An elementary school teacher noticed that his students were confusing observations and inferences. He decided to spend a lesson explicitly teaching the difference. He asked his students to examine images and statements about animals that he projected on the whiteboard. They used hand signals to indicate which statements were observations and which were inferences. The teacher asked several students to explain their choices. One girl commented, “If I could see that an animal has a hooked beak, that would be an observation. But if I guessed it could eat meat because of the shape of its beak, that’s an inference.”

By the end of the lesson the teacher was confident that the class understood the difference between the two terms. However, he noticed that although students now understood what an inference was, they were not always making plausible inferences. He recognized they would need some criteria to make decisions about the plausibility of inferences. During the next lesson, they agreed that a highly plausible inference must be consistent with all the observations and offer a more believable explanation than other options. He asked his students to sort another set of inferences as highly plausible, possible and unlikely, considering the facts available to them. During the discussion that followed, students became animated and engaged as they explained and supported their ratings.

Provide guidance to inform thinking

- Use co-constructed criteria to support self-assessment and peer feedback.
- Offer various ways for students to provide evidence of their thinking (e.g., use written reflections in a ‘Thoughtbook’ to capture and develop ideas or refine their theories and hypotheses).
- Ensure that your assessment reinforces the value of explaining one’s thinking and supporting one’s conclusions with evidence.

5. Where can I learn more?

If you would like additional materials to help you embed critical thinking in your science class, you may wish to check out the following resources:

Tip sheets
Tweaking questions and tasks to deepen critical thinking in science [http://tc2.ca/uploads/PDFs/TipsForTeachers/Tips4Teachers-TweakScience.pdf]
Ten tweaks for your questions [http://tc2.ca/uploads/PDFs/TipsForTeachers/ten_tweaks_for_questions.pdf]

Article

Videos
Understanding critical thinking [http://tc2.ca/cd.php]
Embedded skill development [http://tc2.ca/cd.php]

Books
Creating Thinking Classrooms [http://tc2.ca/en/professional-learning/professional-resource-library/professional-books/ctc.php]
The Competency Toolkit (Available November 15 through www.tc2.ca)