SCIENTIFIC ARGUMENT

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TEACHING HOW SCIENCE REALLY WORKS BY CARL BEREITER AND M ARLENE SCARDAM ALIA

Two approaches, which convey different ideas about the nature of science, are:
1) *Science as argumentation.* This is an expansion of traditional work on hypothesis testing. Students investigate rival hypotheses and then engage in evidence-based argument about competing factual claims. Sometimes the argument takes the form of a debate.
2) *Science as explanation.* The focus here is on developing theories that explain puzzling facts and working to achieve better theories.
Science involves both of these so both have a legitimate place in science education, but the science-as-argumentation view is the more widely accepted among educators. This may be because it is closer to the familiar 'scientific method' and because it is concrete, dealing with observables such as the lengths of pendulums and the exposure of plants to light. However, it has serious limitations. It deals with the testing of scientific ideas, but it has little more to offer than the traditional 'scientific method' about how new scientific ideas originate and develop. Thus it omits the creative core of science. Furthermore, the success of science-as-argumentation depends on making a clear distinction between hypothesis and evidence. This has been found to be inordinately difficult for school students – and no wonder. Science educators themselves have trouble agreeing on whether to classify particular statements as hypotheses or evidence.2

Why the neglect of science-as-explanation? The dread word 'abstractness' probably has much to do with it. Can young students really be expected to produce explanatory theories? The answer is decisively yes. Even in Grade 1, children have no trouble understanding that the job of a theory is to explain. Give them any problem of explanation they can understand, and a Grade 1 class will produce a flood of 'theories'. There is even evidence that infants behave in a theory-generating manner.3
Can students actually build coherent, factually grounded theories? While that is not so easy, most children have a good intuitive model already available to build on: the model of a well-formed story. Underlying the mathematical models mature scientists build are 'qualitative' theories, which are essentially 'how it works' narratives. The questions one may ask of qualitative theories are essentially the same as those one may ask of a story plot: Does it make sense? Does it hang together? Are there any holes in it?
With enough teaching and learning on stories, young students learn not only how to ask these critical questions but also how to repair a story that fails on these counts. Once they discover they can do the same with scientific theories, they are on the road to doing real knowledge creation in science. And they love it. Who wouldn't?
Unfortunately, science-as-argumentation plays into the hand of those whose approach to knowledge is more ideological than scientific. As reported in the *New York Times*, a new strategy being adopted by anti-evolutionists in the U.S. is to no longer press for the teaching of 'creation science' or 'intelligent design', but to require the schools to teach the 'strengths and weaknesses' of evolution. To many people this is an unassailable position and opposing it is anti-scientific. As one writer to the *Times* declared, "Any scientist who is afraid of an honest, open discussion and exploration of the weaknesses and strengths on any scientific theory is not a good scientist and should be barred from academic research."

The whole 'strengths and weaknesses' gambit rests on the belief that the business of science is testing truth claims, and this is what 'scientific method' instruction and science-as-argumentation teach. In fact, the business of science is producing better theories. Seldom is a theory abandoned except when there is a better theory to take its place. The story of evolutionary biology in the century and a half following publication of *The Origin of the Species* is only in small part a story of testing and confirming or rejecting Darwin's hypotheses. It is mainly the story of improving on the original theory, incorporating new knowledge of genetics and new findings from many different fields of biology. This is an exciting story. Exposing students to it could make good educational experience in science, and it is decidedly not a story of biologists closing ranks against criticisms and alternative theories. It is a story of progress on a large scale in making sense of the world, progress to which many researchers have made contributions, large and small.

The real job of science is to produce better explanations – and no matter how they are formulated, explanations are structures of ideas. Everything else is secondary. Myth, common sense, and imagination also produce explanations.

What sets science apart is the sustained effort to improve on the available explanations; in short, science is theory-building. Careful observation, methodical testing, marshalling of evidence – these are all important parts of scientific practice, but theories are the goal and the guides. They are what make patient observing and testing worthwhile and personally rewarding. Can young students grasp this? Yes, but this is not the place to marshal evidence for it. Instead, we end with the words of a Grade 5 girl who we think has as good a sense of what science is about as many a philosopher: *"...I think that I can tell if I've learned something when I'm able to form substantial theories that seem to fit in with the information that I've already got; so it's not necessarily that I have everything, that I have all the information, but that I'm able to piece things in that make sense and then to form theories on the questions that would all fit together..."*

Bereiter, C., & Scardamalia, M. (2008). Teaching how science really works. *Education Canada*, *1*, 14-17.

Scientific argument

If teachers pursue scientific argument in a more in depth way, encouraging students to identify fact, opinions, evidence and assumptions maybe some of the issues identified by Bereiter and Scardamalia (2008) can be overcome.

Through encouraging students to look at their arguments using the questions suggested by the authors could enable students not just to develop scientific arguments, but also to write scientific explanations where they draw on a range of ideas that they have accumulated from observations, methodical testing, and evidence to produce their own interpretation or theory.

Does it make sense?
Does it hang together?
Are there any holes in it?

How can we support this process for students?

One way is using the Fact/Opinion thinking through engaging students in assessing statements made from observations as in the set on "Gulls" in the following table. Requiring students to decide on the evidence or assumptions they have made in making the statement leads to deeper thinking about the basis of the observations.

Statement	Fact	Opinion	Assumption	Evidence
Gulls have webbed feet				
Gulls are graceful in flight				
Gulls build untidy nests of sticks and twigs				
The cries of gulls are eerie or frightening				
There are several species of gulls				
Some gulls have both red eyes and red legs and feet				

Sample responses could be :

Statement	Fact	Opinion	Assumption	Evidence
Gulls have webbed feet	Yes			You can see their feet
Gulls are graceful in flight		Yes	Everyone may not think their flight is grateful	Gulls fly
Gulls build untidy nests of sticks and twigs	Yes	Yes	Some people may describe their nests untidy, others may see a pattern to the arrangement of the twigs	The appearance of their nests may provide protection
The cries of gulls are eerie or frightening	Yes	Yes	Some people may not find the cry eerie or frightening	Gulls do make a cry rather than a song
There are several species of gulls	Yes			Common types are red billed, black billed, black backed gulls
Some gulls have both red beaks and red legs and feet	Yes			Red billed gulls have both red beaks and legs

DEVELOPING REASONING ABILITY

Matthews, M. R. (1994). *Science teaching: The role of history and philosphy of science*. New York: Routledge.(pp. 99, 104)

Another important process to develop with students is the reasoning ability that is required in arguments. Often students will employ an invalid form of argument:

T implies	O	A theory T implies an observation O
	O	The observation O is made
Therefore	=T	Therefore T the theory is true

(Matthews, 1994, p. 88)

This is invalid because there could be several other theories that imply this observation, even though some of the theories may be unknown, thus this conclusion is invalid.

For example – the road is wet (O) so the hypothesis can be that it rained last night (T) – but equally well it could be wet from a broken water main or from a road cleaner having washed the road, as both could give the same result.

Students need to be made aware of the five common types of faulty reasoning:

- Assuming that events which follow others are caused by them
- Drawing conclusions based on insufficient number of incidents
- Drawing conclusions based on non-representative instances
- Assuming that something that is true in specific circumstances is true in general
- Imputing causal significance to correlations
- (tautological reasoning)

Example 1
Communists believe in evolution
Fred believes in evolution
Therefore Fred is a communist

What is wrong with this reasoning?

Example 2
If farmers are cunning and deceitful they can increase the milk produced by adding water to milk.
Farmer Fred increases milk production from his farm.
Therefore Farmer Fred is cunning and deceitful.

What is wrong with this reasoning?

Use your understanding of reasoning in science to answer the following questions

Task 1
If chloride ions are added to a silver solution then a white precipitate is produced.
Addition of chloride ions to solution K produced a white precipitate.
Therefore......

Task 2
If an element has a low electronegativity then it is a metal.
Element sodium is a metal.
Therefore ....