CHAPTER 14

TEACHING CRITICAL INQUIRY IN SCIENCE: THE ROLE OF DIALECTICAL CONTEXT IN SCIENTIFIC REASONING

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1. INTRODUCTION

This paper examines the role of the dialectical context in scientific reasoning. In our textbook, *Reason in the Balance: An Inquiry Approach to Critical Thinking* (Bailin and Battersby 2016), we have introduced a dialectical approach to fostering critical inquiry, centered on a comparative evaluation of reasons and arguments. This type of evaluation requires knowledge of the dialectical context surrounding an issue. We argue here for the salient role of this dialectical aspect in scientific reasoning and its central importance in science education.

2. INQUIRY AS DIALECTICAL

We have argued elsewhere (Bailin and Battersby 2009, 2016) for the centrality of critical inquiry for learning reasoning in a variety of areas. By critical inquiry we mean the enterprise of coming to a reasoned judgment on an issue or question. Coming to a reasoned judgment is at the heart of the kind of reasoning which takes place in a variety of contexts, disciplinary as well as everyday. In our book we demonstrate how the process of critical inquiry is manifested in such diverse areas as the social sciences, philosophy, and the arts, and, of course, in science.

An important aspect of critical inquiry is that it is essentially a dialectical enterprise (Bailin and Battersby 2009, 2010). This means that it takes place in the context of some debate or disagreement and that there is a diversity of views on the issue in question. It also means that there is an interaction between arguers and between arguments involving criticisms, objections, responses, and frequently revisions to initial positions. An implication of this view is that it is seldom the case that reasons and arguments can be evaluated individually, other than in a preliminary, *prima facie* manner (Bailin and Battersby 2016). Rather, they must be evaluated in the context of this dialectic. In order to reach a reasoned judgment, arguments need to be evaluated comparatively, in light of alternatives and competing arguments and views (Bailin and Battersby 2009, 2016).

3. DIALECTICAL CONTEXT

This type of evaluation of arguments and views in light of alternative arguments and competing views requires knowledge of the dialectical context. Dialectical context is a term which refers to the various aspects of the debate surrounding an issue. The primary of these is constituted by the details of the current debate, which Johnson refers to as the dialectical environment (Johnson 2007). The dialectical environment, which he defines as "the dialectical material that congregates around an *issue*," is composed of the various arguments, objections and criticisms, responses to the objections, counterarguments and alternative arguments and positions which have been put forward regarding the issue. In order to reach a reasoned judgment, simply identifying reasons and arguments in support of one's judgment is generally insufficient. In addition, it is necessary to respond to criticisms and objections to one's position and to comparatively evaluate its strengths (and weaknesses) in light of the available alternatives.

Included also in the dialectical context is the history of the debate. Knowledge of the history of the argumentation which has led to the current debate is important for evaluating the various positions which are currently contesting for acceptance. This includes knowing which arguments have been rejected and why, and why current views are accepted. This aspect of dialectical context will reveal the nature and strength of the arguments that contending views are up against. Also, importantly, it will play a role in determining where the burden of proof lies.

In addition to this dialectical context, there are several additional aspects of contexts which are relevant to reaching a reasoned judgment by playing a role in the determination of both the significance and the weight of reasons. These include the intellectual, social, political, and historical contexts. The combination of social and political forces at work at a particular time may affect debates by bringing certain issues to salience and by exerting pressure in support of or in opposition to certain positions.

4. ARGUMENT TO THE BEST EXPLANATION

This dialectical aspect is particularly evident in the form of argument which is predominant in science – argument to the best explanation. Scientific reasoning goes beyond the presentation of the evidence and arguments which support a theory. It includes, as well, and importantly, an attempt to show that the proffered theory offers a better explanation for the phenomenon under investigation than competing or alternative theories. We use the term "argument to the best explanation" rather than "inference to the best explanation" in order to underscore this dialectical dimension. Inference implies a direct move from reasons (or premises) to conclusion, whereas it is our view that this type of scientific reasoning involves the making of arguments which must be evaluated in a context and in comparison with alternatives.

Given the comparative dimension of this type of reasoning, it is clear that the history and the state of the controversy in which a scientific theory is put forward play a crucial role in the evaluation of the theory. It is, for example, only possible to understand the ascendancy of a current scientific theory by knowing what other theories they defeated and why. Only in this way is it possible to understand why the dominant theory is seen as the best explanation and what issues still remain contested. In addition, the current standing of a theory or claim determines the initial burden of proof of a new or counter claim. Without knowing the history of a scientific inquiry, one cannot make a reasonable assessment of the new claim.

Other types of contexts, including the intellectual, social, and political contexts, also often assert an influence on the evaluation of scientific theories, as is evident in several of the examples below.

5. EXAMPLES FROM THE HISTORY OF SCIENCE[1]

The importance of dialectical context is evident when we examine examples of scientific reasoning. We can see how scientists not only offer the observations and evidence in support of their theory, but also how they address objections and counter-arguments, both existing and possible, and attempt to demonstrate in what ways their theory provides a better explanation of the phenomenon they are investigating than existing or competitor theories. We can also see how the state of the controversy, the history of the debate, and other contextual factors play a role in the evaluation of the theories in question. We present here several examples from the history of science which demonstrate the dialectical aspect of scien-

1. These examples are taken from Bailin and Battersby 2016.

tific inquiry and could be used with students to illustrate the role of dialectical context in scientific reasoning.

5.1. Galileo's *Dialogue Concerning the Two Chief World Systems*

The first is an example from Galileo's *Dialogue Concerning the Two Chief World Systems.* In this excerpt, Salviati (representing Galileo's position) argues that the existence of sun spots constitutes evidence that heavenly bodies can change, while Simplicius calls on the authority of Aristotelian teaching that the heavens are unchanging.

> **Simplicius:** To tell the truth, I have not made such long and careful observations [of sun spots] that I can qualify as an authority on the facts of this matter; but certainly I wish to do so, and then to see whether I can once more succeed in reconciling what experience presents to us with what Aristotle teaches. For obviously two truths cannot contradict one another.
>
> **Salviati:** Whenever you wish to reconcile what your senses show you with the soundest teachings of Aristotle, you will have no trouble at all. Does not Aristotle say that because of the great distance, celestial matters cannot be treated very definitely?
>
> **Simplicius:** He does say so, quite clearly.
>
> **Salviati:** Does he not also declare that what sensible experience shows ought to be preferred over any argument, even one that seems to be extremely well founded? And does he not say this positively and without a bit of hesitation?
>
> **Simplicius:** He does.
>
> **Salviati:** Then of the two propositions, both of them Aristotelian doctrines, the second — which says it is necessary to prefer the senses over arguments — is a more solid and definite doctrine than the other, which holds the heavens to be inalterable. Therefore it is better Aristotelian philosophy to say "Heaven is alterable because

> my senses tell me so," than to say, "Heaven is inalterable because Aristotle was so persuaded by reasoning". Add to this that we possess a better basis for reasoning about celestial things than Aristotle did. He admitted such perceptions to be very difficult for him by reason of the distance from his senses, and conceded that one whose senses could better represent them would be able to philosophize about them with more certainty. Now we, thanks to the telescope, have brought the heavens thirty or forty times closer to us than they were to Aristotle, so that we can discern many things in them that he could not see; among other things these sunspots, which were absolutely invisible to him. Therefore we can treat of the heavens and the sun more confidently than Aristotle could.

It is of note that Galileo (a.k.a. Salviati) does not simply cite observations of the existence of sun spots and argue that these constitute evidence that heavenly bodies can change. He also argues against the Aristotelian doctrine that the heavens are not alterable. He does this, first, by using another of Aristotle's doctrines – that what sensible experience shows ought to be preferred over any argument. He further argues that contemporaries could have more confidence in their judgments about the heavens than could Aristotle because of the telescope, supporting this confidence with another of Aristotle's pronouncements – that those whose senses could better represent the heavens would be able to philosophize about them with more certainty. For these reasons, Galileo/Salviati argues that the alterable heavens view is a better explanation for the existence of sun spots than the unalterable heavens view.

This dialogue forms part of Galileo's case for the Copernican view that the earth and other planets revolve around the sun. In order to make this argument, he had to defend the Copernican view against the Aristotelian picture of the universe which was prevalent at the time. Such was the hold of the Aristotelian geocentric cosmology that Galileo, in making a case contradicting this view, had to discharge a strong burden of proof. The burden of proof was particularly strong given the predominant role of abstract argument in theorizing about the natural world. Thus Galileo also had to make the case for the crucial role of sensory evidence, a case which we see him making in the excerpt. In addition, strong influences from the religious context affected the debate. Because of the religious implications attached to the geocentric view, championing the heliocentric view was seen as heretical (as is well known, Galileo was, in fact, convicted of heresy by the Inquisition).

5.2. The History of Geology

5.2.1. Hutton

The next series of examples come from the history of geology. Hutton's work in the late 18th century will provide a starting point. At the time Hutton began his research, biblical scholarship had determined that the earth was a mere 6000 years old. Hutton developed a very different view based on observation rather than biblical scholarship. Observing that there were two different kinds of rocks on his two farms, he hypothesized that there must be a place where these two kinds met. He did, in fact, find horizontal layers of gray shale piled on top of vertical layers of red sandstone. In addition, he noted that there were fingers of granite running into the sandstone. From these and other observations he concluded the following:

1. The lower, upturned sandstone layers must have been deposited a long time ago, tilted and then eroded down.
2. These sandstone layers must then have been covered with

new layers of sedimentation that had also eroded and created the upper layers.
3. The fingers of granite meant that the granite must have been molten at some time and therefore there must be great heat in the earth where this process could occur.

In addition, from observation of the current, almost undetectable rate of erosion and depositing of sand in the oceans, he reasoned that all these processes would involve enormous amounts of time.

In terms of dialectical context, Hutton's insights about the evolution of the earth's crust and therefore revision of the view of the age of the earth had to go up against the acceptance of the Genesis view of the earth's creation which claimed a much shorter time frame. Hutton's theory offered an explanation for the observed phenomena which the biblical-based account was unable to explain. Nonetheless, Hutton's breakthrough required a significant revision of the current understanding of the world. The ease with which such a revision is accepted depends to some extent on the degree to which the view conflicts with well-established views.

5.2.2. Wegener

In 1912, Wegener proposed a theory of *continental drift* to account for the apparent fact that the continents such as Africa and South America appear to fit together. Some earlier geologists had speculated that the continents had at one time fit together, but what Wegener added to earlier theories was the observation, supported by considerable evidence, that the rock formations and fossilized plants and animals showed appropriate similarities at matching continental margins. His theory was, however, greeted with considerable hostility, as the following comment by Dr. Rollin T. Chamberlin of the University of Chicago indicates:

> Wegener's hypothesis in general is of the footloose type, in that it takes considerable liberty with our globe, and is less bound by restrictions or tied down by awkward, ugly facts than most of its rival theories (cited in UCMP).

A major issue was that Wegener was unable to offer a convincing mechanism for such continental movement. Because he was unable to give an account or *model* of how continents could "drift" around the world, his theory was largely rejected. His theory explained some observations, but was not credited because it could not be made coherent with what was then believed about the physical structure of the oceans and continents. Since these existing beliefs were well established, Wegener's theory bore the burden of proof. It was unable to discharge this burden because it could not offer a plausible alternative account of how the continents could move.

5.2.3. Hess

The theory of continental drift was revived in the 1960s, led by an American geologist, Harry Hess, who offered the theory of plate tectonics to explain the phenomenon. The theory was that the recently discovered mid oceanic ridges were spreading and that the continents were sitting on plates which were propelled by the slowly moving "currents" of the underlying mantel.

Hess addressed likely objections to his theory by acknowledging that it was initially speculative. In addition, it was lacking in confirming data, and it ran contrary to current theories. He argued for its superiority to existing theories by demonstrating that it did have the virtue of being the most reasonable inference from existing knowledge, providing a way to account for Wegener's observations and an increasing collection of anomalies regarding sedimentation, the fossil record, and the magnetic orientation of rocks. (There was magnetic data accumulating that showed that rock near the equator had formed at locations much nearer the poles than their current locations.) Since continental movement had been rejected, there was no adequate explanation for these observations. Hess explicitly argues for his theory as providing a plausible explanation for these unexplained phenomena:

> …mantle convection is considered a radical hypothesis not widely accepted by geologists and geophysicists. If it were accepted, a rather reasonable story could be constructed to describe the evolution of ocean basins and the waters within them. Whole realms of previously unrelated facts fall into a regular pattern, which suggests that close approach to satisfactory theory is being attained (Hess 1962).

Hess's theory of sea floor spreading was quickly confirmed by the discovery of additional data that was supportive of his theory. New measurements of ocean floor changes in magnetism showed that indeed the ocean floor was moving away from the oceanic ridges. A U.S. Geological Services article about Hess's discovery summarizes thus:

> In 1962, Hess was well aware that solid evidence was still lacking to test his hypothesis and to convince a more receptive but still sceptical scientific community. But the Vine-Matthews explanation of magnetic striping of the seafloor a year later and additional oceanic exploration during subsequent years ultimately provided the arguments to confirm Hess' model of seafloor spreading. The theory was strengthened further when dating studies showed that the seafloor becomes older with distance away from the ridge crests. Finally, improved seismic data confirmed that oceanic crust was indeed sinking into the trenches, fully proving Hess' hypothesis, which was based largely on intuitive geologic reasoning (U.S. Geological Services).

6. DIALECTICAL CONTEXT IN SCIENCE EDUCATION

The history of science is replete with examples such as these that could be used to illustrate the dialectical nature of scientific reasoning. In our book, *Reason in the Balance* (Bailin and Battersby 2016), we have students inquire into historical cases such as these. This involves laying out the reasons and arguments offered on various sides of the issue, as well as criticisms, objections, and responses; investigating the history of the debate; and inquiring into other relevant aspects of context. Finally, they look at how the reasons and arguments were comparatively evaluated and the conclusion reached. The same structure can be used for evaluating scientific claims in contemporary debates, for example the safety of vaccination or the relationship between fat consumption and heart attacks.

This process gives students a sense of the dynamic and evolving nature of scientific inquiry. Emphasizing that science is a dialectical enterprise that involves argument within an ongoing context of debate is a welcome corrective to the widely held misconceptions among students (and the general public) about the nature of science as involving a collections of facts which have been proven to be true by studies and experiments. Such a misconception leaves them vulnerable to taking as "proven fact" the results of every new study reported in the media. Correlatively, the discovery that there are conflicting positions with respect to a claim or theory may result in relativism or even scepticism about the possibility of scientific knowledge. Learning that scientific inquiry takes place through a process of argument to the best explanation involves an understanding that having competing theories is the norm, but that there are better justified and less well justified views and that it is possible to comparatively evaluate claims and arguments. It also highlights the importance of seeking alternative views when evaluating claims and theories, in science and in other areas of inquiry.

REFERENCES

Bailin, S. and M. Battersby. 2009. "Inquiry: A Dialectical Approach to Teaching Critical Thinking." In *Argument cultures: Proceedings of OSSA 8* CD-ROM, edited by J. Ritola. Windsor, ON: OSSA.

______. 2016. *Reason in the Balance: An Inquiry Approach to Critical Thinking,* 2nd Edition. Cambridge, Mass: Hackett; 2010. 1st Edition, McGraw-Hill Ryerson.

Battersby, M. and S. Bailin. 2011. "Critical Inquiry: Considering the Context." *Argumentation* 25, 2: 243-253.

Hess, H. 1962. "History of Ocean Basins." In *Petrologic Studies: A Volume in Honor of A.F. Buddington,* edited by A.E.J. Engel, H.L. James, and B.F. Leonard, 599-820. New York: Geological Society of America. Retrieved from http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1283&context=sio/lib.

Johnson, R.H. 2007. "Anticipating Objections as a Way of Coping with Dissensus." In *Dissensus and the Search for Common Ground,* CD-ROM, edited by H.V. Hansen, et al., 1-16. Windsor, ON: OSSA.

Mathez, E.A., ed. 2000. *Earth: Inside and Out.* New Press. American Museum of Natural History. Retrieved from http://www.amnh.org/education/resources/rfl/web/essaybooks/, accessed Apr. 16, 2011.

U.S. Geological Services, "Harry Hammond Hess." [This Dynamic Earth, USGS]. Retrieved from http://pubs.usgs.gov/gip/dynamic/HHH.html, accessed Apr. 16, 2011.

University of California Museum of Paleontology. Retrieved from http://www.ucmp.berkeley.edu/history/wegener.html, accessed Apr. 16, 2011.