

Chapter 3

Understanding Objectivity in Research Reported in the Journal *Science & Education* (Springer)

3.1 Method

The journal *Science & Education* (Springer, <http://www.springer.com/11191>) started publishing in 1992 with Michael R. Matthews (University of New South Wales, Australia) as its Editor. This journal specifically deals with the contributions of history, philosophy, and sociology of science to science education, and is indexed in the Social Sciences Citation Index (Thomson-Reuter). Consequently, it seems that an evaluation of literature published in this journal related to objectivity can help science educators to better understand the evolving nature of objectivity in the history of science. It is interesting to note that Daston and Galison (1992) first presented their ideas with respect to the historical evolution of objectivity (same year that *Science & Education* started publishing), which were later elaborated in Daston and Galison (2007).

In November 2014, I made an online literature search on the website of *Science & Education*, with the keyword “objectivity” (<http://www.springer.com/11191>). This gave a total of 180 articles published between 1992 and November 2014. All articles were downloaded and a preliminary examination showed that 45 articles could not be included in the study due to the following reasons: (a) Book reviews in which the reviewer refers to the subject of objectivity and not the original author; (b) Book notes, for the same reason as for book reviews; (c) Golden oldies, which included articles by famous historians/philosophers of science written much earlier than 1992; and (d) In some articles the authors provided a reference and the word “objectivity” appeared in the title of that reference.

3.1.1 Grounded Theory

Grounded theory (Glaser & Strauss, 1967) provides a set of guidelines that helps to focus on data collection procedures, based on successive levels of data analysis and conceptual understanding. In the present study, I first classified the selected

articles from *Science & Education* in different levels (details are presented below), which were later assigned a category, and finally in Chap. 7, categories from different studies (Chaps. 3–6) are compared to facilitate conceptual understanding. This procedure can be summarized in the following steps: (a) Comparison of data sources (articles) to assign a level (I–V); (b) comparison of these levels (presented later) which facilitated their classification in categories; and (c) comparison of categories from different studies to facilitate understanding and draw conclusions. Following guidelines were used while developing the different steps of the procedure (based in part on Charmaz, 2005, p. 528):

1. Familiarity with the setting and topic of study in each of the selected articles.
2. Evaluate classification of the selected articles to see if they are based on appropriate evidence.
3. Systematic comparisons between the classifications and the categories.
4. The need for the categories to represent a wide range of experiences represented in the classifications.
5. Establish a logical and conceptual link between the classifications, categories, and arguments for the analyses.

Although the guidelines presented above were of considerable help in different stages of data analysis, a word of caution is necessary: "... grounded theory does not refer to some special order of theorizing per se. Rather, it seeks to capture some general principles of analysis, describing *heuristic strategies* that apply to any social inquiry independent of the particular kinds of data: indeed it applies to the exploratory analysis of quantitative data as much as it does to qualitative inquiry" (Atkinson & Delamont, 2005, p. 833, italics added). The emphasis on heuristic strategies is particularly important in the present study, as they facilitated conceptual understanding.

3.1.2 *Classification of Articles*

Finally, a total of 131 articles were evaluated and classified in the following levels (criteria for evaluation are based primarily on Daston & Galison, 2007):

Level I Traditional understanding of objectivity as presented in science textbooks and some positivist philosophers of science. It is based on an ideal of objectivity as an important human value and part of the scientific outlook.

Level II A simple mention of objectivity as an academic/literary objective. It recognizes that although science is not value free, but still this does not affect the objective status of science.

Level III The problematic nature of objectivity is recognized. However, no mention is made of the changing/evolving nature of objectivity.

Level IV An approximation to the evolving/changing nature of objectivity, based on the social and cultural aspects of objectivity.

Level V A detailed historical reconstruction of the evolving nature of objectivity in the history of science that recognizes the role of the scientific community and its implications for science education.

Following the guidelines presented above (cf. Charmaz, 2005), and in order to facilitate credibility, transferability, dependability, and confirmability of the results I adopted the following procedure: (a) All the 131 articles from *Science & Education* were evaluated and classified in one of the five levels; (b) After a period of approximately three months all the articles were evaluated again and there was an agreement of 90% between the first and the second evaluation; and (c) After another period of three months all the articles were evaluated again, and there was an agreement of 92% between the second and the third evaluation. This procedure was particularly helpful in understanding the underlying issues as according to Denzin and Lincoln (2005): “Terms such as *credibility*, *transferability*, *dependability*, and *confirmability* replace the usual positivist criteria of internal and external validity, reliability, and objectivity” (p. 24, original italics).

A complete list of all the 131 articles from *Science & Education* that were evaluated is presented in Appendix 1. In the section on Results and Discussion, 71 examples of the different levels are provided, with the following distribution: Level I = 2, Level II = 15, Level III = 42, Level IV = 10, and Level V = 2. These examples provide an understanding of how the subject of objectivity has been discussed by authors in this journal. It is important to note that all the articles evaluated in this study referred to objectivity in some context, which may not have been the primary or major subject dealt with by the authors. Detailed examples of all five levels are presented in the next section. Distribution of all the articles according to author’s area of research, context of the study, and level (classification) is presented in Appendix 2.

3.2 Results and Discussion

Each of the 131 articles from *Science & Education* was evaluated (Levels I–V) with respect to the context in which they referred to objectivity. Based on the treatment of the subject by the authors following 37 categories (sections) were developed to report and discuss the results (cf. guidelines presented above from Charmaz, 2005). These categories along with the examples are presented in alphabetical order. It is important to note that some of the articles could easily be placed in more than one category. The idea behind the creation of 35 categories (sections) is to facilitate the reader to find the subject of her/his interest. It is important to note that *Science & Education* has a readership and contributors that include science educators, historians, philosophers of science and sociologists that cover many areas of the science curriculum. Given the wide range of subjects discussed by the authors over a period of more than 20 years, it is difficult to create the semblance of a continuous storyline (as suggested by one of the reviewers).

For example, in the 1990s constructivism was a subject of considerable importance, and in recent years the research community seems to have lost interest in it. Similarly, due to limitations of space it is not possible to present a detailed critical analysis of every article. Complete information about each article and the author is provided in the appendices (1 and 2) which can be consulted by the interested readers. Next, examples from the 35 categories are presented.

3.2.1 *Argumentation and Objectivity*

The role of argumentation in the classroom has been the subject of considerable research in the science education literature. Drawing on the work of Longino (1990, 2002), Jiménez-Aleixandre (2012) has explored the relationship between objectivity in science and explanatory plurality:

Longino (1990) undertook an analysis of scientific knowledge with the goal of reconciling the objectivity of science with its social and cultural construction. Recently she has explored the epistemological consequences of the recognition of the social character of scientific inquiry in connection to pluralism, or the acknowledgement of *explanatory plurality* (Longino, 2002). For Longino (2008) knowledge itself is social, because what matters is what the scientific community comes to agree or disagree on Viewing scientific knowledge as socially constructed has influenced both the design of science classrooms as communities of learners, and the ways of studying classroom interactions, in particular the discursive ones, as argumentation (p. 469, italics added). Classified as Level IV.

With this background the author has followed argumentation in genetics classrooms requiring models to build explanations, which leads to the framing of genetics issues in their social context. Campbell (1988a) a methodologist had referred to “explanatory plurality” as plausible rival hypotheses, quite similar to Longino. The presentation of Jiménez-Aleixandre (2014) comes quite close to what Daston and Galison (2007) have referred to as trained judgment.

3.2.2 *Classification of Species and Objectivity*

According to Takacs and Ruse (2013), classification presents a number of interesting issues in the philosophy of biology:

Everybody recognizes that there is a certain degree of subjectivity involved in classification, so much so that there is sometimes debate about whether classification is a science or an art. However, it is generally agreed that at the lowest level, the level of species, there is significantly more reality or objectivity. No one, for instance, thinks that it is a matter of choice about whether Michael Ruse or Peter Takacs should be included in the group *Homo sapiens*, and that Toto the dog and Secretariat the horse should be excluded. The question now becomes that of wherein lies the objectivity or reality of species, as opposed say to genera (p. 23). Classified as Level IV.

Authors also go beyond by pointing out the subjectivity involved in for example in the inclusion of *Homo sapiens* along with *Homo erectus* and *Homo habilis*

in the genus *Homo*. Again they raise the issue of whether there would be consensus in including the *Australopithecus afarensis* (to which the famous fossil Lucy belongs) in the genus *Homo*. This clearly shows how different interpretations lead to controversies that produce tension in our understanding of the objectivity–subjectivity duality.

3.2.3 *Commodification of Science and Objectivity*

Commodification and commercialization of science has been the subject of recent research in science education (see the special issue edited by G. Irzik, 2013). This research shows that scientific knowledge becomes more and more like a commodity as part of the market economy in which the influence of money and corporate research become dominant. In some cases universities and research institutions become increasingly organized like a private company.

In this context, according to Vermeir (2013):

These *basic characteristics and norms of science* may be lost with increasing commodification. Current science policy sees some of the positive and constitutive properties of science as obstacles, because they hinder the commodification and market adaptation of science. Legislation and policy try to remedy these perceived “obstacles” by social engineering: the nonexcludability, positive externalities and cumulativity of scientific knowledge are reduced by intellectual property regimes, for instance; the importance of trust and values are replaced by standardization; expert judgment and peer-to-peer self-regulation are replaced by techniques of mechanical objectivity (pp. 2506–2507, italics added, footnote states: “For mechanical objectivity and expert judgment as different regimes of objectivity, see Daston & Galison, 2007”). Classified as Level IV.

The *basic characteristics and norms of science* refer to the Mertonian norms that include: sharing and openness in scientific practice, truthfulness, objectivity, trust, accuracy, and respect for expertise (Merton, 1979). The transition from trained judgment to mechanical objectivity in the context of commercialization of science is a cause of concern for Vermeir and perhaps also for many science educators. However, according to Daston and Galison, the transition from one extreme (mechanical objectivity) to another (trained judgment) can go back and forth.

3.2.4 *Consciousness and Objectivity*

According to Marroum (2004):

What complicates the objectivity of any educational study is that unlike scientific research, which deals with sensible data, educational research must also deal with the data of consciousness (of both students and teachers). Teachers’ perceptions and beliefs about learning significantly affect how they approach the material and what they teach. The same can be said of students, and their perceptions affect how they learn. Teachers who follow the inquiry approach to teaching, for example, have varying conceptions of what

inquiry means. Thus, a theory adopted by different teachers can lead to contrary results. This might provide a clue as to why some research shows that teaching standard textbook physics does not produce significant changes in the conceptual understanding of the material, while others show the contrary (pp. 538–539). Classified as Level II.

Marroum's work is based on the cognitional theory of Bernard Lonergan, who does not provide ready-made answers to readers. His approach requires teachers to first self-appropriate what they are teaching to the students. It facilitates the integration of the history of science into the curriculum. He suggests that when students discover what they have in common with Archimedes, Aristotle, Galileo, Newton, Maxwell, and other scientists, they will develop confidence in their ability to learn (It is not clear if Marroum follows this historical approach. For further details on Lonergan's theory, see Roscoe, 2004). Furthermore, in order for learning to be meaningful, the student must move beyond subjective knowledge to objective knowledge.

3.2.5 *Constructivism and Objectivity*

Given the considerable amount of controversy in the science education literature with respect to radical and social constructivism, this section has the following four presentations: Suchting (1992), Slezak (1994), and Garrison (1997, 2000). However, in recent years interest in constructivism has declined.

In the context of his criticism of the subjective realism espoused by radical constructivism (Ernst von Glasersfeld), Suchting (1992) clarifies that contrary to popular belief, immutability and certainty have nothing essential to do with our understanding of objectivity (p. 226). For example, the Galilean transformation equations of classical kinematics proved not to be immutable, as they are replaced in special relativity by different and more general equations. Similarly, the approximations in Galilean equations are not less objective than the previously non-approximate ones. The other characteristic that sometimes is invoked to understand objectivity is certainty. For example, the statement that "Isaac Newton was born on 4 January 1643" is considered to be certain and an instance of objective knowledge. However, even such statements are problematic as the information included may be erroneous or false. In this context, for Suchting (1992), understanding of immutability and certainty show the problematic nature of objectivity. Classified as Level III.

According to Slezak (1994):

Besides the facts and theories conveyed in a science education are certain values and norms of conduct. Some of these are more specifically pertinent to the practice of science, while others are general moral precepts of the community at large. Besides the academic conventions concerning citations, acknowledgments and other scholarly practices are the noble ideals of objectivity and truth which have been seen as among the important human values embodied in the scientific outlook. The inculcation of these broader values has been widely taken to be among the important functions of a science education, but the doctrines of social constructivism may be seen as posing a fundamental challenge to this ethical dimension of science education as well (p. 269). Classified as Level I.

In order to facilitate the ethical dimensions of science (which may be weakened by social constructivism) the author endorses Merton's "ethos of science" (p. 270). Furthermore, the traditional conventions regarding scientific publications have been the subject of considerable controversy in the history and philosophy of science literature (e.g., Medawar, Holton, Polanyi), as they depart from how science is actually done, namely "science in the making" (cf. Niaz, 2012).

Garrison (1997) critiques Von Glasersfeld's radical constructivism as subjectivist and instead recommends Deweyan social constructivism based on experimentalism as an alternative:

The difference between subjectivist constructivism and social constructivism comes down to the difference between practical overt operations of inquiry (for example, experimental science), and the occult internal operations of "mind" characterized by von Glasersfeld's "mental operations" at the level of "*reflective abstraction*." For the pragmatist a clean shave with Ockham's razor whisks away von Glasersfeld's needless subjectivism and mentalistic abstractions, thereby clearing the face of reasonable science education for genuine experimentalist and objective social constructivism (p. 553, original italics). Classified as Level II.

Garrison (2000) also refers to Ernst von Glasersfeld's constructivism as subjectivist: "It is a peculiarly subjectivist form of constructivism that should not be attractive to science and mathematics education concerned with retaining some sort of realism that leaves room for objectivity" (p. 615). Garrison ignores the historical context in which objectivity is always achieved in degrees, namely the recognition that it is a process. It is plausible to suggest that Garrison's position approximates to an academic form of objectivity that is Level II. In the framework of Daston and Galison (2007), both presentations by Garrison (1997, 2000) represent mechanical objectivity.

3.2.6 *Controversy and Objectivity*

According to Hildebrand, Bilica, and Capps (2008), controversies in science education are more intractable than those in science as they involve a wider range of considerations, such as epistemic, social, ethical, political, and religious. Authors then consider the controversy between Intelligent Design Creationism (IDC) and evolution and present the following possible strategies generally used in the biology classroom: (a) Teach the controversy—this strategy assumes that students should be allowed to make up their own minds on controversial issues; (b) Avoidance—in this case teachers may choose to omit controversial topics; and (c) Dogmatism—this alternative would dismiss the controversy altogether. In contrast, these authors suggest a proactive, philosophically pragmatic approach based on the work of John Dewey (1925/1983), according to which knowledge is achieved primarily through a process of inquiry that is characterized by its social, experimental, and fallible nature. Furthermore, inquiry begins for most people not with abstract puzzles but with concrete problematic situations. This approach

neither avoids nor ignores controversy and thus goes beyond the *narrow epistemological solutions* generally presented in school science:

In consequence, this means that narrow epistemological solutions will often be insufficient to resolve controversies in science education: it cannot be enough to prove a particular theory is “true” or “verified.” Consider an example that illustrates this: the proponents of IDC advocate for a “teach the controversy” approach to teaching evolution. This pedagogical approach, proponents argue, is necessary because of the scientific community’s commitment to “objectivity” and “fairness.” To exclude some views would amount to the unfair marginalization of an unpopular view (Hildebrand et al., 2008, p. 1036). Classified as Level III.

The problematic nature of objectivity in this presentation is quite peculiar. Proponents of IDC support a commitment to objectivity as this would allow them to include their ideas with respect to evolution. This clearly shows how biology teachers may have to be more thoughtful while introducing objectivity in the classroom.

Following a historical reconstruction of the topic of chemical equilibrium in the chemistry curriculum, Quílez (2009) has suggested that the inclusion of such details can motivate students to study chemistry and even perhaps understand the underlying controversial ideas. According to the author: “Objectivity, certainty and infallibility as universal values of science may be challenged studying the controversial scientific ideas in their original context of inquiry ...” (p. 1204). Classified as Level III. This seems to be sound advice for making the science curriculum more relevant for the students.

3.2.7 *Discovery and Objectivity*

According to Kipnis (2007), learning about discovery helps students to understand how scientists work. This led him to conclude that discovery is objective in the sense that having been created it exists forever and cannot be undone: “As to the discovery, if it is done, it is done; it acquires a certain objectivity which no subsequent labeling can remove” (p. 907). This presentation ignores the social context in which scientific discoveries are evaluated, critiqued, accepted, reinterpreted, and eventually even changed by the scientific community. Classified as Level II.

3.2.8 *Disinterestedness and Objectivity*

Kolstø (2008) has argued that the post-academic science differs from academic science in the past, and the inclusion of history of science in the curriculum can facilitate democratic participation and the disinterested pursuit of objective truth. Finally, the author concluded: “Furthermore, in the post-academic mode of research, the scientists’ autonomy is reduced. Although the researchers might have

autonomy on the more detailed level, the problem area to be studied is typically defined by the funding agency. Thus, the typical post-academic scientist has become a contractor and has to make dispositions that might give him research contracts. Such research funding relationships makes it hard to claim full objectivity and disinterestedness” (p. 980). Classified as Level II. Achieving “full objectivity” is a complex *process* and needs to go beyond being disinterested.

3.2.9 *Diversity/Plurality in Science and Objectivity*

Allchin (2004) has explored the history of craniology and phrenology to show that these were considered to be scientific endeavors, based on huge amounts of data, considered as a “Baconian orgy of quantification” in the nineteenth century. For several decades anthropologists, such as Paul Broca, tried to use skull measurements to prove sexual and racial differences in intelligence. At the time, however, craniology seemed like a straightforward application of the principle of structure and function, namely if mental functions take place in the brain, then the brain’s size should reflect mental capacity. Similarly, phrenology, the study of cranial shapes and proportions seemed very plausible:

Moreover, craniology was quantitative, following one oft-cited hallmark of science. Craniologists used over 600 instruments and 5,000 measurements ... Of course, the prospects of craniology and phrenology went unfulfilled. When women eventually entered the field, they challenged claims earlier deemed acceptable by men. Standards of evidence rose. The whole field soon dissolved. In retrospect one can see that the community of (white) European male researchers was culturally biased (not that any practitioner recognized his own bias). Now the episode is a persuasive example of *how diversity in a scientific discipline can contribute to its objectivity* Craniology is wrong, not misguided. History thus offers complementary lessons in science and pseudoscience. It helps reveal vividly how science works and why, sometimes, it errs (Allchin, 2004, pp. 190–191, italics added). Classified as Level III.

The reference to “Baconian orgy of quantification,” instruments and measurements in the nineteenth century approximates to Daston and Galison’s (2007) mechanical objectivity. However, Allchin’s perspective does not foresee the transition from mechanical objectivity to trained judgment, but rather emphasizes that *diversity in a scientific discipline can contribute to its objectivity*. In a sense this approximates to the interpretation of science as social knowledge as suggested by Longino (1990).

Carrier (2013) has outlined the role played by values, value-ladenness, and pluralism in understanding objectivity in scientific development based on the following facets of history of science: (a) The traditional notion of objectivity was strongly shaped by Francis Bacon (p. 2549). Bacon’s notion of objectivity required the scientist to be neutral and detached from the research project; (b) Contrary to Bacon’s rules, history of science shows that values play an important role in the development of science as facts/data in and by themselves do not determine how they are to be interpreted; (c) Values tend to be contentious and thus can be

regarded as a threat to scientific objectivity; (d) As Baconian objectivity is hard to follow, pluralism based on value-judgments is a virtue rather than a liability; (e) The social notion of objectivity was introduced by Popper (1962) and Lakatos (1970) and focuses on conflicting approaches adopted by scientists; (f) Longino (1990) has recommended science as social knowledge as the pluralist approach to objectivity helps to correct flaws and thus enhance the reliability of scientific results. Longino is widely considered to have undermined or dissolved the distinction between the epistemic and the social; (g) Pluralism remains as a step in the development of science and eventually gives way to consensus. This is supported by Kuhn's normal science and also based on the work of Kitcher (1993), Laudan (1984) and Collins and Evans (2002). Finally, Carrier (2013) concluded that pluralism does not detract from scientific objectivity but is a means to achieving objectivity: "Scientific consensus formation is possible because, regardless of divergent epistemic inclinations and predilections, scientists have a fundamental commitment in common, the commitment, namely, to give heed to certain rules in debating knowledge claims. Adopting such rules serves to curb subjective preferences for the sake of producing knowledge that enjoys intersubjective assent" (p. 2565). Classified as Level V. An important aspect of this presentation is the emphasis on a pluralistic value-laden nature of scientific judgments, within a historical context that facilitates an intersubjective consensus in the scientific community.

3.2.10 Enrollment Practice and Objectivity

In the 1960s the Swedish government became concerned of the declining number of students who chose to study science as a career. Based on this in the 1970s and 1980s, initiatives were taken to make science more attractive and a fun subject to students, referred to as the TEK-NA projektet (1975). This campaign to foster interest in science led to a conflict as some sectors of the society perceived it as a threat to an individual's right to a free choice. Lövheim (2014) depicts the dilemma in the following terms:

The TEK-NA project also targeted student counselors in their strategy to achieve a change of attitudes. This confirmed the belief in career guidance as a way of creating positive propaganda; the Swedish government had stressed the need for such a development during the 1970s Consequently student counselors were involved as a direct channel to pupils approaches to science. As a technology of government they were part of every-day school life without interfering with direct class room practice The text also contained sections with advices on how to guide pupils—especially girls—into identities as engineers or scientists ... the project lead to protests from student counselors who claimed they were forced to persuade pupils into the high school Science program and that the material lacked a sense of objectivity ... (pp. 1776–1777). Classified as Level II.

This is an interesting example of how some reform efforts (more experiments and less abstract textbooks) can be construed to be less rigorous than the traditional science curriculum and thus lack objectivity. Similar relationship between traditional science and objectivity can also be found in other countries.

3.2.11 *Evolution, Creationism and Objectivity*

Difficulties involved with these complex and controversial subjects is referred to by Smith, Siegel, and McInerney (1995) in the following terms: “It is important to note, however, that good science seeks to be as objective and impartial as possible. The expert scientist not only recognizes that his work may be influenced by personal biases but also overtly seeks to identify and eliminate improper influences” (p. 29). Classified as Level III.

With respect to teaching creationism in public schools, Pennock (2002) stated:

The charge that such a policy violates academic freedom is not so easily dismissed. One might reasonably dispute about whether academic freedom applies in the public elementary and secondary schools in the same way that it does in higher education, but prima facie there seems to be no good reason to think that this important protection should be afforded to university professors and not to others of the teaching profession who serve in other educational settings. However, academic freedom is not a license to teach whatever one wants. Along with that professional freedom comes special professional responsibilities, especially of objectivity and intellectual honesty. Neither “creation-science” nor “intelligent-design” (nor any of the latest euphemisms) is an actual or viable competitor in the scientific field, and it would be irresponsible and intellectually dishonest to teach them as though they were (Pennock, 2002, p. 121). Classified as Level II.

Finally Pennock concluded that neither “creation-science” nor “intelligent-design” is an actual or viable competitor in the scientific field, and based on objectivity it would be irresponsible and intellectually dishonest to teach them as though they were. Although this may seem to be sound advice, at least some science educators may not agree with it.

Homchick (2010) has studied the controversy between the evolutionists and the creationists in the context of the American Museum of Natural History’s Hall of the Age of Man during the early 1900s. Henry Fairfield Osborn, president of the museum based his curatorial work on the purported use of objectivity as a means to communicate the validity of the evolutionary theory. However, this was criticized by the Baptist pastor John Roach Straton by establishing a different type of objectivity based on pluralistic approaches to theories of origin that included both evolutionary theory and creationist account. Consequently, established as a common value, objectivity ceased to discriminate between scientists and non-scientists. Next, Homchick considers that both Daston and Galison (1992) and Gergen (1994) provide useful lenses to look at the Osborn-Straton debate. With respect to the historical origin of objectivity, Homchick (2010, p. 486) noted:

Objectivity, often connected with the rise of Baconian science, came to be associated with a particular matrix of values in the nineteenth century. Lorraine Daston and Peter Galison in their article, “The Image of Objectivity,” discuss the use of objectivity during and after the nineteenth century (Daston & Galison, 1992). They identify atlases as bearers of the concept of objectivity specifically because of the association between the visual and the factual embedded in this type of artifact. Additionally, the authors establish how objectivity is not only powerful through the visual content, but that the use of this concept actually represented an apparent superiority of judgment through a “self-denying moralism.” (Daston & Galison, 1992, p. 99)

Similarly, according to Homchick, Gergen (1994) considers objectivity not to be a static characteristic of texts and objects and differentiates objectivity through two general categories that of process and product. Thus, it seems that Osborn relied primarily on the objectivity of the product, namely the artifacts displayed in the museum exhibit. In contrast, Straton used the objectivity of process to criticize Osborn for not including the creationist account. Finally, Homchick (2010) concluded:

Here Osborn appears to embody Daston and Galison's identification of objectivity as allowing "nature to speak for itself" (Daston & Galison, 1992, p. 81) and Gergen's identification of objectivity as surfacing through the "true" character of the natural world. In this formulation, objectivity emerges through the product—the artifact of nature (p. 491). Classified as Level V.

Daston and Galison (2007) refer to this form of objectivity as "truth-to-nature." The Osborn-Straton controversy also shows how the pluralistic approach to science (Giere, 2006a, b) can also be used not only for promoting the scientific endeavor but also the creationist account. Such controversies can provide teachers an opportunity to include topics in the classroom that can lead to lively discussions.

3.2.12 *Expert Knowledge and Objectivity*

Lindahl (2010) has investigated students' reasoning about conflicting values concerning the human–animal relationship exemplified by the use of genetically modified pigs as organ donors for xenotransplantation:

The students' use of scientific knowledge (expert knowledge) as well as personal or everyday knowledge (embedded in local practice) in arguments was used to deepen the analysis of the students' understanding and to discern their appreciation of expert knowledge and disembedded practices. The use of scientific knowledge for their argumentation was regarded as an appreciation of expert knowledge, and their support for biotechnology relating to the discussed example was interpreted as their appreciation of disembedded practices. Typically, the use of expert knowledge was seen as a way to create objectivity and distance to the dilemma When a student contradicted his/her contextualized argument with expert knowledge, it was seen as an attempt to objectify (p. 885). Classified as Level II

Following is an example of an episode in which expert knowledge was manipulated by a government for its own political agenda. According to Legates et al. (2015):

A better approach to determining an appropriate methodology to identify and quantify a consensus can be found in the work of Lefsrud and Meyer (2012). They argue that building a consensus "fundamentally depends upon expertise, ensconced in professional opinion" (p. 1478). Even here, a Classical purist might legitimately argue that appealing to the authority of experts, however well qualified, is the Aristotelian logical fallacy later labeled by the medieval schoolmen as the *argumentum ad verecundiam*—the argument from reputation. Experts can be unanimously wrong, as the case of the 100 German

authors who opposed Einstein's theory of relativity in the years leading to World War II. They were wrong because the regime demanded them to make scientific objectivity subservient to the racial politics of the regime (p. 12). Classified as Level III.

This episode provides an interesting and thought-provoking backdrop to Daston and Galison's (2007) regime of trained judgment as an alternative to mechanical objectivity based on expert knowledge. In other words the opinion of the experts can be politically motivated and hence the difficulties involved in accepting trained judgment as an alternative to mechanical objectivity.

Allagaier (2010) has explored the role of scientific experts in the creation/evolution controversy as presented in the UK press:

Following traditional accounts of expertise, a scientific expert is a formally trained specialist in a scientific discipline The scientific community developed through professionalisation and formal training and established a professional ideology ... in which they portray themselves as value-free, neutral and objective experts However, from a sociological point of view, scientists cannot operate outside society; they are as much members of the public as anyone else. The notion that a scientific expert can be entirely neutral, value-free and objective cannot be sustained from a sociological perspective (e.g., Restivo, 1994). (p. 800). Classified as Level III.

The presentations by Allagaier (2010) and Legates et al. (2015) provide interesting examples with respect to the role played by experts and expert knowledge in modern society. As part of society experts also have difficulty in being entirely objective and value-free. Perhaps similar constraints can also be observed in the peer-review process used by most scientific journals.

3.2.13 Feminist Epistemology and Objectivity

Based on a critical appraisal of feminist epistemology (Harding, Keller, & Pinnick), Ginev (2008) has advocated a theory of gender plurality that leads to a conception of dynamic objectivity. Harding (1987) considers that using women's lives as grounds to criticize the dominant forms of scientific knowledge can decrease the partialities in the picture of the world presented by the natural sciences. Keller (1985) has suggested a multi-gendered scientific research that leads to the idea of dynamic objectivity. Pinnick (2005) is, however, more critical by asserting that there are no data that would test the validity of the hypothesis that there is a causal relationship between women's lives and science's cognitive ends.

Finally, Ginev (2008) concluded: "In a hierarchically organized society, objectivity cannot be defined as requiring value-neutrality: The politically engaged standpoint of feminism is less partial and distorted than the standpoint of conventional scientific inquiry. By implication, the former should lead to pictures of nature and social relations that are 'more objective' than those obtained by means of the existing natural and social sciences" (p. 1142). Classified as Level III. This shows that we need to explore the degree to which a field of inquiry has achieved objectivity.

3.2.14 *Genetics, Ethics and Objectivity*

Blake (1994) has analyzed three pioneer programs (at three universities in USA) that attempt to integrate genetics and ethics in the classroom. A major critique of the study is the lack of continuity between the pedagogical goals and the theoretical framework of these programs. The programs adhered to an underlying framework based on “tacit assumptions” (Keller, 1992, p. 27) that undercut the veracity of ethics, and emphasized reason, empirical evidence, and objectivity. Finally, Blake (1994) concluded:

The curricular possibilities of the “new genetics” for the science classroom—gel electrophoresis of DNA fragments, recombination of DNA into bacterial plasmids—have a similar intoxicating effect which distracts the science educator from the task of critical reflection on the “tacit assumptions” of their programs. This is not merely a priority of science over ethics in the science classroom but a much more fundamental disparity. This modern view of science and consequent epistemological privilege have been critically examined by philosophers, sociologists and historians of this century (cf. Feyerabend, 1975; Keller, 1992; Kuhn, 1962; Lakatos, 1970; Midgley, 1985) The ideals of objectivity, rationality and empirical privilege have been seriously and soundly challenged Science has an historical and social context; science is contingent and subjective (p. 387). Classified as Level III.

This presentation was classified as Level III as it clearly shows the problematic nature of objectivity. Furthermore, Blake (1994) refers to two major issues that are of considerable importance to science education. First, she refers to the problem of two cultures, introduced by C.P. Snow (1963), namely a gulf of mutual incomprehension between the literary intellectuals and the scientists. Second, based on Keller (1992) she asserts that scientists are probably less reflective of “tacit assumptions” that guide their reasoning than any other intellectual of the modern age. Indeed, this is all the more ironic as Polanyi’s (1966) *tacit dimension* was published almost half a century ago. Polanyi (1964, 1966) differentiated between two kinds of knowledge: (a) explicit, articulated, and formal knowledge; and (b) tacit, unarticulated, and non-formalized knowledge. He argued that the first cannot be achieved without the second. These considerations led Polanyi to question the false ideal of “objectivity” in post-Enlightenment scientific thinking.

3.2.15 *Historical Contingency and Objectivity*

The contingent nature of science has been recognized by physicist-philosopher James Cushing (1989). According to Cushing (1995), David Bohm’s (1952) work can be seen as an exercise in logic, thus providing evidence that the Copenhagen interpretation of quantum mechanics was not the only logical possibility compatible with the facts:

Given the presumed objectivity and impartiality of the scientific enterprise, one might expect that such an interpretation [Bohm’s] would have been accorded serious consideration by the community of theoretical physicists. However, it was basically ignored, rather

than either studied or rebutted. Just as external factors had played a key role in establishing the Copenhagen hegemony, so they once again contributed to keeping this competitor from the field. That a generation of physicists had been educated in the Copenhagen dogma made it all the more difficult for Bohm's theory (Cushing, 1995, pp. 139–140). Classified as Level III.

According to the contingency thesis, the same experimental observations can be explained by rival theories (in this case the Copenhagen and Bohm's interpretation of quantum mechanics). In other words the order in which events take place is an important factor in determining which of two observationally equivalent theories is accepted by the scientific community. With respect to the presumed objectivity of the scientific enterprise, it is interesting to note that Bell (1987) a leading scholar on the Bohmian interpretation of quantum mechanics has raised the following thought-provoking questions: (a) Why is the pilot wave picture (de Broglie and Bohm's ideas) ignored in textbooks; and (b) Should Bohm's interpretation of quantum mechanics not be taught?

At this stage it would be interesting to consider a possible relationship between Cushing's idea of *contingency* and the historical evolution of the regime of objectivity as presented by Daston and Galison (2007). In other words, it is plausible to suggest that it is perhaps the contingent nature of science (among other factors) that manifests itself in the evolving nature of objectivity. Furthermore, it can be argued that the Copenhagen and the Bohm interpretations of quantum mechanics constitute an example of methodological pluralism in the history of science.

3.2.16 *Historical Narratives and Objectivity*

Kubli (2007) has emphasized the need to go beyond the simple regurgitation of experimental details, and provide students with the historical narratives (stories) which provide the background to understanding progress in science:

Of course, scientific reasoning and laws can be imparted in a completely objective way: they can be reduced to facts and figures without any human element, and indeed, some scientists and even teachers see such *objectivity as the characteristic of true science*. Of course, scientific laws are independent of the specific circumstances of their discovery. They can be "proved" by a reproduction of the basic experiments—which can be repeated whenever there is a need to do so This approach has not disappeared, even among teachers, in spite of engaged discussions in science education. It stands in contrast to the view that, in science teaching, stories are not only justified, but necessary (Kubli, 2007, p. 519, italics added). Classified as Level III.

This presentation shows the need to go beyond the traditional forms of objectivity (and hence its problematic nature) by incorporating the human element involved in scientific progress in the form of science narratives (stories), especially during "science in the making." According to Klassen (2006): "School science lacks the vitality of investigation, discovery, and creative invention that often accompanies *science-in-the-making* ..." (p. 48, italics added).

3.2.17 *History and Objectivity*

According to Matthews (1992):

We know that *objectivity in history is, at one level, impossible*: history does not just present itself to the eye of the beholder; it has to be manufactured. Materials and sources have to be selected; questions have to be framed; decisions about the relevant contributions of internal and external factors in scientific change have to be made. All of these matters are going to be influenced by the social, national, psychological, and religious views of the historian. More importantly they are going to be influenced by the theory of science, or the philosophy of science, held by the historian. Just as a *scientist's theory* affects how they see, select, and work upon their material, so also will a *historian's theory* affect how they see, select, and work upon their material (p. 19, italics added). Classified as Level IV.

Interestingly, in the very first issue of *Science & Education*, Michael Matthews as founder Editor has set the tone for what he expected the journal to promote, espouse, and cultivate. At the end of the citation, Matthews provides the well-known quote from Lakatos (1971), to the effect that if philosophy of science without history of science is empty, then history of science without philosophy of science is blind. Rest of the citation constitutes a preamble and even perhaps a guide to future research on the application of history and philosophy of science (HPS) to science education. It refers to the difficulties involved in recounting any historical episode, and hence the problematic nature of objectivity. Interestingly, he draws a parallel between the *scientist's theory* and a *historian's theory*, as both are theory-laden. It is not farfetched to suggest that in the case of a conflict between the two theories, it is the historian's responsibility to set the record straight. A good example of this conflict is the role played by Holton (1978a, b) in the oil drop experiment that helped to understand Millikan's handling of his published data. Matthews (1992) provides another facet of this conflict by referring to the case of Galileo, who was considered by nineteenth-century philosophers and scientists as an inductivist and empiricist. However, this picture changed in the twentieth century and Galileo came to be considered as a Platonist dedicated to rationalism and thought experiments.

3.2.18 *History of Science and Objectivity*

According to Leite (2002):

Throughout the previous section a few arguments were already put forward to support the idea that the history of science can help students to acquire an adequate image of science. Enabling students to realise that models in science have been altered and modified in order to fit new data and that the same phenomena can be explained by different models, history of science gives students the opportunity to see how scientific knowledge is provisional and uncertain and how, even in science, we cannot find objectivity and truth ... (p. 337). Classified as Level III.

Due to the changing nature of scientific models, this presentation emphasizes the tentative nature of scientific knowledge. Leite then goes beyond by associating

uncertainty in science with difficulties involved in finding objectivity and truth. The essence of the idea expressed in this presentation is quite similar to what Matthews (1992) had referred to previously with respect to objectivity in history.

Lyons (2010) has stressed that we need to do a better job of teaching students about the process of science. The practice of science is not quite the straightforward objective process that many scientists suggest:

The history of science documents that determining *what is a “fact” is continually reevaluated in light of ongoing investigations* More important, a variety of factors contribute to whether a particular idea is readily accepted, from the prestige of the person advocating it to how well it fits in with prevailing social views Nevertheless, objectivity is a value that all scientists strive for in their work. Science is as successful as it is because it has developed a set of standards and a methodology for designing experiments, interpreting results, and constructing effective scientific institutions. This does not prevent scientists from making mistakes, but the various aspects of scientific practice mean that science has enormous capacity to be self-correcting (p. 457, italics added). Classified as Level III.

This presentation attempts to establish a balance between how scientists strive to be objective and that the practice of science shows how various factors are influential in the acceptance of a theory and this often leads the scientists to make mistakes. Science teachers and textbooks generally emphasize that the scientific enterprise is based on “facts.” However, this is more complex than it seems at first sight and Lyons rightly points out that, “what is a fact is continually reevaluated.”

3.2.19 *Marxism and Objectivity*

According to Deng, Chai, Tsai, and Lin (2014):

... Marxism puts less emphasis on the social/cultural influence on science while highlighting the objectivity and rationality of science (Wan et al., 2013). Another possible explanation can be that school science teaching practice pays relatively less attention to the role of society in science. In China, Marxism tends to highlight relatively more the pragmatic values of scientific knowledge than the influence of society on the development of scientific knowledge (p. 853). Classified as Level II.

At first sight, this may appear somewhat counter-intuitive, given the strong relationship between Marxism and changes in society. However, the authors go on to clarify that based on the work of Mao (1986), the concept of “practice” has been emphasized and consequently highly valued in China. Mao even considers practice as the sole criterion for testing truth and value of scientific knowledge (p. 847). Furthermore, besides the work of knowledgeable scientists, the term “practice” includes the work of ordinary people (e.g., workers and peasants). This provides the background for understanding objectivity as a consequence of everyday practice in different endeavors.

According to Wan, Wong, and Zhan (2013):

Since Marxists insist on the necessity to understand phenomena from their surrounding conditions, they also believe that science should be understood in its broad social context.

It is stated that “where would natural science be without industry and commerce?” (Marx & Engels, 1970) However, it should be noted that the emphasis on the influence of the social context on scientific activities does not lead Marxism in the anti-rationalism that characterizes various branches in the contemporary philosophy of science. Instead, the social influence on science is just considered as the opposite of and in a unity with rationality or objectivity of science. (p. 1122). Classified as Level III.

It is interesting to note that the two presentations presented above in this section deal with Marxism and still have some subtle differences. Deng et al. (2014) emphasize the importance of practice in Marxism and thus social and cultural influences are sacrificed or ignored as compared to objectivity and rationality in science. On the other hand, Wan et al. (2013) suggest that although the social influence in China is considered less important it is still considered as part of a unity that includes the rationality and objectivity of science.

According to Skordoulis (2008), Epicurus rather than Hegel emerges as the pivotal figure in Marx’s early development: “Rather than contained within the idealist philosophy of the Hegelian system, Marx’s thesis aimed at formulating an anti-teleological materialism that incorporated the ‘activist element’ of Hegelianism. Building on Epicurus, Marx’s emergent materialism denied neither the objectivity of nature, as Hegel did, nor humans’ active relation to nature and to each other” (p. 565). Classified as Level II. Besides pointing out the relevance of objectivity for Marx, this presentation recognizes its importance for Marx due more to the influence of Epicurus rather than Hegel.

3.2.20 Mathematics Education and Objectivity

Patronis and Spanos (2013) have recognized the role of hermeneutics in mathematics education and consider Lakatos’s (1976) hermeneutical reconstruction of a historical theme (polyhedral, Euler’s formula and related concepts) as an example. Furthermore, they provide the following guideline for classroom practice:

Setting up a “scene” in the mathematics classroom, with a crucial “opening question” in the beginning, may provide a rich field to initiate a dialogue and give the opportunity for knowledge conflicts and negotiation of meaning. As Skovsmose ... indicates by his examples of project work in the classroom, his reformulation of exemplarity may become a link between educational theory and practice, by planning a thematic approach in mathematics education. We need, however, to explore further the nature of “exemplary themes” in mathematics, which we intend to do now, moving towards a theoretical direction which questions the objectivist trend in mathematics education. (Patronis & Spanos, 2013, p. 1997). Classified as Level III.

As a classroom teaching strategy, Patronis and Spanos (2013) suggest the following sequence: setting up of a scene → opening question → dialogue → conflicts → negotiation of meaning. Indeed, this helps to question the objectivist trend not only in mathematics but also in science education (cf. Lee & Yi, 2013; Niaz, 1995a, b). Daston and Galison (2007) provided similar advice based on the dilemma faced by those who tried to understand electroencephalographs using mechanical objectivity based on “a rigid adherence to rules, procedures, and

protocols” (p. 325). Instead, they suggested that the electroencephalographer had to cultivate a new kind of scientific self, one that was more intellectual rather than algorithmic. It is high time that science educators recognize the importance of being “intellectual” in the classroom and ignore algorithmic teaching strategies.

According to Ernest (1991), objectivity of mathematics can be accounted for as socially accepted knowledge, in other words, it is objective by virtue of its acceptance by the scientific community. Rowlands, Graham, and Berry (2011) criticize Paul Ernest’s philosophy of mathematics education and defend teaching of mathematics as a formal, academic system of knowledge.

For Ernest (1991), this is not objectivity in the sense of logical necessity from which the objectivity can be recognised; rather, subjectivity becomes objectivity through consensus. The rationale for this is the failure of the foundationalist programme to establish certainty in the foundations of mathematics: take away the certainty of mathematics then you can take away logical necessity as having any role in establishing what is to be accepted—objectivity merely becomes part of that which is accepted ... What “absolutist” philosophies (Ernest’s term for the foundationalist programme) have failed to establish is not logical necessity but absolute certainty in the foundations, but take away logical necessity (because it cannot be “established”) and you have objectivity as synonymous with consensus in the sense that they are not separate entities from which the former may play a part in establishing the latter. (Rowlands, Graham, & Berry, 2011, pp. 641–642). Classified as Level III.

Rowlands et al. do recognize the criteria used by Ernest for social acceptance, namely mathematical journals and reviewers. However, in their opinion it is not enough to say that objectivity can be equated with acceptance. Furthermore, in order to support their thesis of how objectivity cannot be equated with acceptance, Rowlands et al. (2011) provide the example of the 4-color theorem. This theorem was proven first by Alfred Kempe in 1879 and later by Peter Tait in 1880. However, 10 years later in 1890 it was found that both “proofs” contained fallacies. This episode led Rowlands et al. (2011) to conclude that consensus for proof (1880–1890) did not mean that the theorem was proved and hence objective. Despite the merit of this interpretation one could argue that it was the community that revealed the fallacies in the theorem and hence shows mathematics to be socially accepted knowledge, as suggested by Ernest (1991). This also illustrates Daston and Galison’s (2007) thesis of the evolving nature of objectivity, which is socially conditioned by the scientific community.

Fiss (2012) has analyzed reform movements in mathematics education (based on the documents of the National Education Association, 1894) during the last decades of the nineteenth century that emphasized objective methods of teaching and recommended that rules be derived inductively. Based on this perspective Fiss (2012) concluded:

This language of objectivity and objects was a novel nineteenth-century reinvention of the scholastic distinctions between subjectivity and the objectivity. At this time, its presence signaled a connection to the physical sciences, as well as a sense of a “scientific self” (Daston & Galison, 2007, pp. 191–252). This language, coupled with the argument that students should use the manipulation of physical objects in the world as a substitute for the epistemic authority of a book or teacher, ultimately reframed mathematics as a physical science (p. 1192). Classified as Level III.

According to Daston and Galison (2007, p. 198), in the mid-nineteenth century the “scientific self” was considered to be an obstacle to mechanical objectivity and following measures were suggested to combat subjectivity: self-restraint, self-discipline, and self-control.

3.2.21 Model of Intelligibility and Objectivity

Drawing on the use of a balance, Machamer and Woody (1994) draw implications for the intelligibility of a model:

The model exhibits all and only those properties that are important. This intelligibility and the normative character of the idealized model is what allows for objectivity. If a problem cannot be reduced to these elements, or if a participant in the investigation insists on attending to other aspects, then either the problem falls outside the scope of the model or the participant needs (re-)training about what is important in the problem or what are the allowable procedures. Such disagreements can be used to test the scope and adequacy of models, and sometimes give rise to “revolutions” in intelligibility when people become convinced that something important is being left out (p. 224). Classified as Level III.

This illustrates what Machamer and Wolters (2004) later referred to as “both rationality and objectivity come in degrees.”

3.2.22 Nature of Science and Objectivity

Nature of science is a controversial topic of considerable interest to science educators and had the following five presentations: Talanquer (2013), Irzik and Nola (2011), Wong, Kwan, Hodson, and Jung (2009), Gauch (2009), and Galili (2011).

Based on the work of philosophers, historians and science educators, Talanquer (2013) has contested the Universalist characterization of the nature of science (NOS) and then concluded:

The central claim is that scientists in different disciplines have distinctive epistemic goals, practices, and norms that influence how they conduct their research and how they perceive, communicate, and evaluate their activities and results. Their work relies on unique experimental approaches, particular deployments of instrumentation, different forms of explanation, as well as on distinct conceptions of rationality, standards of objectivity, and modes of argumentation. From this perspective, science educators need to better understand what the various practices of the different sciences look like in order to devise more authentic contexts for the teaching and learning of each of these disciplines in schools. (p. 1762). Classified as Level III.

This presentation calls attention for the need to understand diversity in the scientific enterprise. If scientists use unique experimental procedures in order to solve complex problems then their conceptions of rationality, modes of argumentation, and standards of objectivity would also vary accordingly. Precisely, this also characterizes the evolution of objectivity in the history of science.

According to Irzik and Nola (2011), some of the items mentioned in the consensus view of NOS (this generally refers to Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) lack sufficient systematic unity which leads to a tension among such aspects and then they go on to provide the following example:

For instance, scientific knowledge is said to be theory-laden and subjective. Does this make objectivity of science impossible? If not, why not? If science is socially and culturally embedded, how is it that it produces knowledge that is valid across cultures and societies? Is the influence of society on science good or bad? How do we distinguish between these two kinds of affects? Does science have any means of detecting the bad ones and eliminating them? These are important questions that need to be raised if we want our students to have a sophisticated understanding of NOS (p. 593). Classified as Level III.

After critiquing the consensus view of NOS (nature of science), Irzik and Nola (2011) then go beyond to assert the objectivity of science as experiments are reproducible and the same experiments done under the same conditions do come up with the same results. This is precisely what Daston and Galison (2007) have referred to as mechanical objectivity. Furthermore, this ignores the fact that in the history of science various scientists doing the same experiments and having the same results came up with entirely different theories. In most parts of the world introductory science courses primarily deal with the history of science and “science in the making.” According to Laudan (1996):

The fact is that scientists do not need to study the history of their discipline to learn the Tradition; it is right there in every science textbook. It is not called history, of course. It is called “science,” but it is no less the historical canon for all that. Thus, the budding chemist learns Prout’s and Avogadro’s hypotheses, and Dalton’s work on proportional combinations; he learns how to do Millikan’s oil drop experiment; he works through Linus Pauling’s struggles with the chemical bond. (p. 153)

It seems that Laudan was writing the science/chemistry curriculum. Furthermore, history of science is replete with controversies among scientists (cf. Machamer, Pera, & Baltas, 2000). This obviously leads to a dilemma: which history shall we include in the classroom? One laden with experimental details or the one based on theory-laden nature of observations leading to controversies in the history of science. History of science bears witness to the difficulties involved in interpreting experimental data and that the essence of the scientific endeavor is perhaps characterized by the creativity and imagination of the scientists. Under this perspective, telling students that scientists are “objective” and “rational” would be too simplistic. It would be more motivating to reconstruct the different historical episodes in order to illustrate “science in the making” and how science is practiced by scientists (Levere, 2006; Niaz, 2012).

Later in the same article, Irzik and Nola (2011) state that scientific knowledge, though theory-laden, is nevertheless reliable because it is obtained by subjecting our theories to critical scrutiny, and

Similarly, the fact that science is objective (in the sense that scientific findings are correct independently of individual, social and cultural variations) is a result of the same intersubjective critical process. That scientific experiments are reproducible also contribute to the

objectivity of scientific knowledge. Whoever does the same experiment under the same conditions should come up with the same result regardless of when and where the experiment is carried out. Again, it is not clear in the consensus view how reliability and objectivity of science is to be explained without such considerations. (Irzik & Nola, 2011, p. 602)

Nevertheless, this overlooks the fact that some long-standing controversies in the history of science were difficult to resolve and continue to provide considerable difficulties to students' experiences in the lab. An interesting example is the oil drop experiment (Klassen, 2009) which provides, even at present, very contradictory results in almost all parts of the world even with modern apparatus. Daston and Galison (2007) refer to the resolution of the controversy with respect to the oil drop experiment not due to the reproducibility of experimental data, but as an example of "trained judgement." Also with this background consider Martin Perl's philosophy of speculative experiments. Finally, it seems that Irzik and Nola (2011) follow quite closely Kuhn's (1970) advice to science educators, that is just teach "normal science" (for a critical appraisal of Kuhn's "normal science" see, Niaz, 2011, Chap. 2, pp. 17–33).

Wong et al. (2009) turned crisis into opportunity by using the Severe Acute Respiratory Syndrome (SARS) to understand and teach the theory-laden observations as part of nature of science in the classroom. They used an historical account of the "hunt" for the causative agent of SARS that was infused with several examples of theory-laden nature of observations. In one of the video clips they showed that immediately following the announcement on March 18, 2002, by a group of scientists from Hong Kong and Germany that the virus causing SARS was paramyxovirus, other research groups around the world quickly announced that they had also found evidence that paramyxovirus was the causative agent of SARS. Interestingly,

However, only a few days later, on 22 March 2003, another group of researchers in Hong Kong announced that further evidence showed that coronavirus, rather than paramyxovirus, is the causative agent of SARS. Immediately after this announcement, several laboratories, including Rotterdam, Frankfurt and the Center for Disease Control and Prevention (CDC) in Atlanta, also confirmed the coronavirus theory. This episode illustrates the theory-laden nature of observation and shows how scientists' expectations or predictions influence what they see and how they interpret the data. Acknowledgement of the biased observation of data is in stark contrast to the usual school science curriculum portrayal of scientists as objective and impartial in interpreting data (Wong et al., 2009, p. 110, as part of a section entitled: "Objectivity of scientists and theory-laden observation"). Classified as Level IV.

This episode clearly shows the importance of "science in the making" and how it can facilitate students' understanding of theory-laden nature of observations and that objectivity is an ideal that comes with lot of effort and perhaps only in degrees (cf. Machamer & Wolters, 2004). Furthermore, Wong et al. (2009) consider the initial acceptance of the paramyxovirus as the causative agent of SARS and its replacement by the coronavirus as a consequence of new evidence, as an illustration of the tentativeness of science, which is related to an essential characteristic of good science, such as skepticism and open-mindedness.

According to Gauch (2009):

The Congress of the United States wanted a current assessment of science’s rationality and objectivity, so a 1993 symposium was co-convened by Representative George Brown and the AAAS for the purpose of providing “a philosophical backdrop for carrying out our responsibilities as policymakers” (p. iii). One contributor, influenced by Kuhn, reported that scientists should accept the new picture of science as myth. “Some scientists are still scandalized by the historical insight that science is not a process of discovering an objective mirror of nature, but of elaborating subjective paradigms subject to empirical constraints ... Nevertheless, it is important to understand the nature, function, and necessity of scientific paradigms and other myths ...” (Ronald D. Brunner, in Brown, 1993, p. 6) (pp. 687–688). Classified as Level III.

Gauch (2009) concluded that it is misleading to say that science is tentative, approximate and subject to revision and that some scholars might prefer that policymakers receive a less skeptical and more balanced view of science’s powers and limits (p. 688).

Galili (2011) has pointed out the predicament often faced by science educators in understanding and explaining the essence of objectivity. Consider the following statements:

Thus, the resultant knowledge of *classical mechanics* enabled great technological achievements—a reliable test of objectivity: people walked on the Moon regardless various individual details in the knowledge of the people who created the knowledge required for such enterprise. (p. 1310, original italics)

Many teachers and textbook authors would subscribe to such statements that facilitate an important aspect of the nature of science, namely its objectivity. However, Galili (2011) goes beyond by stating:

Furthermore, in science education, it is important not to confuse various *aspects* of scientific knowledge with its *genus* Confusion of *objectivity* with *universal and unconditional correctness* of knowledge seemingly leads to misconceptions about the nature of science (p. 1310, original italics). Classified as Level IV.

Indeed, conditional correctness of scientific knowledge precisely leads to the evolving nature of objectivity (Daston & Galison, 2007). In other words, just as science advances our understanding also changes, and this shows the need for science educators to understand how objectivity evolves. Indeed, the changing or the tentative nature of scientific knowledge has been recognized as an important part of NOS in many reform documents, and can help to understand objectivity in a historical perspective.

3.2.23 *Observation and Objectivity*

Sievers (1999) critiques Alan Chalmers’ understanding of observation as outlined in his *What is this thing called science?* According to Chalmers when two similar cameras take a picture of the same thing, they produce two identical images.

However, Chalmers argues that when two persons “see” the same thing, there are two different experiences, which may be considered as subjective experiences. Consequently, human beings are unlike cameras as “... an object does not produce in each of us the same subjective experience” (Sievers, 1999, p. 389). After outlining Chalmers position, Sievers (1999) goes on to assert the objectivity of observation in the following terms: “On this view, the objectivity of observation ceases to be a philosophical dogma. We can justify our observations in the face of the subjectivist doubts. In so far as people can be trained to be reliable observers, their perceptual knowledge is objective. Such training is an important part of scientific education” (p. 392). This interpretation in which the objectivity of observation can be restored (based on training) approximates to what Daston and Galison (2007) have referred to as “trained judgment.” Those who work in the lab (both students and scientists) can face a dilemma in which they have to make observations, and it is plausible to suggest that “trained judgment” could be one alternative to reach consensus in the case of differences or controversies with respect to the interpretation of data. Classified as Level IV.

Felipe Folque, a prominent figure in the development of astronomy as a discipline in Portugal, taught astronomy and geodesy at the Lisbon Polytechnic from 1837 to 1856. Students received an intensive training in the use of astronomical instruments and mathematical methods that were believed to be important in their future work. Carolino (2012) has summarized this experience in which engineers received training at the Lisbon Polytechnic, in the following terms:

Historians have stressed the importance that the rise of a culture of precision measurement, from the late eighteenth through the nineteenth century, played in the process of formation of nation-states in Europe and America The same happened in nineteenth century Portugal, where the strengthening of a culture of precision and objectivity was especially visible under the reformist government, from mid-nineteenth century onwards. Normalization of methods, standardization of procedures and culture of objectivity guided the work of the technical staff that worked for the General Board for the Geodetic, Chorographic and Hydrographical Works under Folque’s direction (pp. 126–127). Classified as Level II, as it refers to objectivity as an academic objective.

This historical experience in the teaching of astronomy and geodesy in the nineteenth century corresponds quite closely to what Daston and Galison (2007) have referred to as “mechanical objectivity.”

At this stage it would be interesting to compare the two presentations: Sievers (1999), classified as Level IV, and Carolino (2012), classified as Level II. According to Carolino, students’ work was guided by normalization of methods, standardization of procedures and the culture of objectivity. On the contrary, Sievers emphasizes that objectivity is a consequence of training provided to the observers (trained judgment according to Daston & Galison, 2007). Although, both recognize the importance of objectivity, the difference between the two precisely provides an understanding (Sievers) of the evolving nature of objectivity.

In 1860, Herbert Spencer emphasized the importance of science and scientific knowledge. Based on these ideas, Otis W. Caldwell (1869–1947), a botanist and science educator designed general science courses by emphasizing the role played

by observations. These courses had considerable popularity in the USA, and according to Heffron (1995), this could be attributed to, "... the historical relationship between science and general education, a relationship established in the opening decades of this century, when the authority of science and scientific objectivity was in the minds of most educators unimpeachable" (p. 227). Next, Heffron (1995) presents a critique of the inductive methods and observations in the following terms:

If, as Karl Popper and others have argued, science itself does not advance "solely by inductive methods," that is, by the simple stockpiling and ordering of observations, however repetitious, we cannot expect to make our children (often considered "natural scientists" because of their superior observational skills) better scientists by simply making them more observant. We must first make them more theoretical. For in the realm of science, theories come logically before problems, problems before observations. The latter, in so much as they fail to lead to the falsification of these theories, are actually an aspect of non-science. (p. 245). Classified as Level III.

From a Popperian perspective, Heffron has emphasized that the real test of scientific truth lies not in its obedience to our observations, but in its falsifiability, the belief that scientific truths are only temporarily valid and subject ultimately to falsification. Based on this perspective, Heffron concluded that Caldwell's vision of science in general education was fundamentally unscientific and even miseducative (p. 245). Furthermore, it is important to note that Popper's ideas on falsification have been the subject of considerable controversy in the philosophy of science literature (cf. Lakatos, 1970).

3.2.24 *Piaget's Epistemic Subject and Objectivity*

Piaget's developmental stages have been the subject of considerable controversy in both the psychology and science education literature. Brainerd (1978) has critiqued Piaget's developmental stages on empirical grounds, namely children and adolescents do not acquire the different stages at the ages stipulated by the theory, and hence Piagetian theory has been falsified. This is a very Popperian approach to understand progress and ignores the fact that Piaget's *oeuvre* is based on the *presupposition* that developmental stages correspond to an *epistemic subject*—universal scientific reasoning, ideally present in all human beings (cf. Beth & Piaget, 1966, p. 308). In other words, Piaget was not studying the average of all human abilities, but rather the ideal conditions under which a psychological subject (a particular person) could perhaps attain the competence exemplified by the epistemic subject (for details see Niaz, 1991, p. 570).

Kitchener (1993) has emphasized the important distinction between the epistemic and psychological subject in Piaget's genetic epistemology. In order to understand this distinction he draws on Galilean methodology, a version of the hypothetico-deductive method to indirectly test a hypothesis, in the following terms:

Since a direct empirical test of his hypothetical law was not possible, he [Galileo] used his famous inclined plane experiment to show that as the angle of incidence approximated 90 °

(free fall), the acceleration of objects rolling down an inclined plane increasingly approximated a constant. Hence, by extrapolation, one may assume it is also true of free fall as a limiting case. Here we have an indirect confirmation of a mathematical law which is true only of ideal objects under ideal conditions, a law to which real objects approximate only to certain degrees. (Kitchener, 1993, p. 142)

Based on this understanding of Galilean methodology, Kitchener provides the following perspective for understanding objectivity:

Knowledge is not to be naively equated with mere belief (or the brute factual existence of a cognitive structure): knowledge has an inescapable *normative* dimension, one concerning concepts like evidence, objectivity, rationality, validity, truth, etc These notions are not ... merely *identical* to simple empirical facts like contingencies of reinforcement, nor can they be *replaced* (as in Quine's (1969) naturalistic epistemology) by brute empirical psychological concepts (Kitchener, 1993, p. 141, original italics). Classified as Level II.

Rowell (1993) has endorsed Kitchener's (1993) interpretation of Piaget's epistemic subject and then concluded: "Presumably an epistemic subject would function in this way, but there is considerable doubt that an actual individual would achieve rationality and objectivity in the absence of other social agents (Kitchener, 1981)" (p. 133). Classified as Level III.

It is plausible to suggest that as the epistemic subject does not exist and hence objectivity can only be a possible ideal that can be achieved, provided all the "social agents" required for cognitive development are operative. Kitchener emphasizes that just like validity and truth, objectivity is part of the normative dimension (epistemic subject) and hence cannot be reduced to an empirical psychological dimension (psychological subject). In a sense, both Kitchener (1993) and Rowell (1993) not only recognize the elusive nature of objectivity but also approximate Daston and Galison's (2007) understanding of the evolving nature of objectivity.

3.2.25 *Presuppositions and Objectivity*

School science generally endorses a view that comprises of: (a) Foundationalism, science is built on a foundation of unproblematic true propositions and (b) Logicalism, science has a logical method to determine which of two competing theories is true (McMullin, 1987, p. 50). History of science, however, shows that actual scientific practice is much more complex in which controversies based on the presuppositions of the protagonists play a crucial role. Indeed, controversies play an important role in the dynamics of science, especially before consensus with respect to facts and theories has been achieved (Silverman, 1992, p. 177).

Silverman (1992) has referred to the difficulties involved in understanding science in cogent terms:

Part of the classical perspective of science is that scientists ideally undertake their work without bias or preconception. Objectivity and open-mindedness are indeed integral attributes of science, but not in this naive sense. Rarely does a scientist commence research in the absence of presupposition as to the outcome; objectivity consists not in denying

preconceptions, but in the ability to modify beliefs in the light of emerging evidence. Physicist R. A. Millikan, for example, in his autobiography (1950) expresses his initial grave doubts as to the correctness of Einstein's treatment of the photoelectric effect, a remarkable phenomenon in which light seems to collide with electrons as if it were comprised of small hard corpuscles and not waves. To accept a ballistic interpretation of light:

... was clearly impossible, at least for me, particularly in the Ryerson Laboratory where under Professor Michelson's leadership we were working as continuously and familiarly with the wave-lengths of light as with meter sticks (Millikan, 1950, p. 66)

In regard to testing Einstein's equation, however, he [Millikan] expected that he would surely prove it false, yet he had to conclude:

I spent ten years of my life testing that 1905 equation of Einstein's, and contrary to all expectations, I was compelled in 1915 to assert its unambiguous experimental verification in spite of its unreasonableness (Millikan, 1950, p. 100)

That is objectivity in science. (Silverman, 1992, p. 168, original italics, underline added)

Interestingly, Millikan's opposition to Einstein's hypothesis of lightquanta (despite the acceptance of the photoelectric equation) continued far beyond 1915 and Holton (1999) considers it an irony as it coincides with textbook versions of the experiment. Stuewer (1975, p. 88) goes beyond by considering this adjustment on the part of Millikan as "shocking," considering the fact that even in 1924, in his Nobel Prize acceptance speech, Millikan still questioned Einstein's hypothesis of lightquanta. In a study based on 103 general physics textbooks (published in USA), Niaz et al. (2010a, b) reported that only five mentioned that Millikan's opposition to the quantum hypothesis could be attributed to his prior presupposition and strong belief in the classical wave theory of light. This clearly shows the relationship between how textbooks conceptualize objectivity and the practice of science based on logicalism (McMullin, 1987).

With respect to the determination of the elementary electrical charge there was a bitter controversy between two protagonists (R. A. Millikan and F. Ehrenhaft), and Silverman (1992) recounts this historical episode by considering that: (a) Study of this controversy helps illuminate subtle and complex issues underlying the experimental interrogation of nature; (b) One does not, as often implied by an idealized perspective of science, simply turn on the apparatus, make measurements, and compare with theory; and (c) Questions always arise over such mundane, yet critical, matters such as the sensitivity of apparatus, effects of systematic and random noise, environmental influences, and the reliability and admission of data. Based on these considerations, Silverman (1992) suggested: "How these questions are answered depends on the philosophical attitudes of the experimenter. Millikan scrutinized his measurements to determine where a particular experimental run was 'good'—that is in keeping with his expectations [elementary electrical charge, electron]. Ehrenhaft accepted all measurements in the belief [fractional charges, sub-electrons] that that constituted objective observation. The general philosophical climate of the experimenters' milieu also played an important role" (p. 169). Classified as Level IV.

Again, general chemistry and physics textbooks (published in USA) completely ignore the presuppositions of both Millikan and Ehrenhaft (for details see Niaz,

2009, Chap. 7). No wonder, neglecting the role played by presuppositions leads textbooks to endorse what Daston and Galison (2007) have referred to as “mechanical objectivity.” Silverman’s (1992) conceptualization that, objectivity consists not in denying preconceptions, but in the ability to modify beliefs in the light of emerging evidence—provides not only insight into the dynamics of scientific progress but also approximates to what Daston and Galison (2007) have referred to as “trained judgement.”

3.2.26 *Quantum Mechanics and Objectivity*

According to Hadzidaki (2008a), the understanding of objectivity varies in classical physics from quantum mechanics. For example, in quantum mechanics it is not possible to “... interpret the statements of physics as informing us directly of attributes of the entities under investigation—or, in other words, to judge the objectivity of our knowledge through a comparison with the reality per se ...” (p. 69). Consequently, only a “weak” form of objectivity based on inter-subjective agreement can be invoked. Classified as Level III.

In a section entitled “objectivity and subjectivity,” Pospiech (2003) noted: “Perhaps one of the deepest consequences of uprising quantum theory was the insight that physical truth is not absolute as many people believed after the overwhelming success of Newton’s work. Suddenly there seemingly occurred quantum jumps; results could by principle only be predicted with probability and depended on the acting of an observer. Attempts to explain these phenomena in classical terms were frustrating. The concept of fixed properties independent of any measurement for single quantum objects had to be abandoned. Only the result of many equal measurements on equal objects could be predicted and reproduced” (p. 568). Classified as Level III.

3.2.27 *Romantic Science and Objectivity*

Romanticism as a movement emerged in Germany and spread to Europe in the late eighteenth and early nineteenth century and has been viewed as a cultural and intellectual movement that countered rationalism then considered as the dominant *Weltanschauung* (cf. Cunningham & Jardine, 1990). According to Hadzigeorgiou and Schulz (2014):

The Romantics gave great importance not only to social and political education—since it was through education that human beings became human and a citizen—but also to science, neither of which is well known or typically associated with romanticism. It was “Romantic science,” in fact, while being the development that grew in reaction to eighteenth century Enlightenment rationalism, with its allied mechanistic philosophy (based on objectivity and determinism) that succeeded in actually transforming the latter by emphasizing imaginative/creative thinking and public excitement about scientific work and discoveries ... (pp. 1965–1966). Classified as Level III.

According to the authors, given the pragmatist/utilitarian conception of school science prevalent today, romantic science can in contrast provide food for thought by emphasizing the notion of wonder and the poetic/non-analytical mode of knowledge.

3.2.28 Science in the Making and Objectivity

Nielsen (2013) draws attention to the importance of science as a mode of communication that sustains knowledge. Communication among scientists is what makes knowledge possible, namely technical language, rhetorical resources, peer reviews among others. Consequently, without communication perhaps there would be no science:

Decisions about the topic and resources of ongoing scientific communication involves distinguishing between what Bruno Latour (1987, p. 4) calls “ready-made science,” that is, stabilized scientific knowledge in textbooks, and “science-in-the-making,” that is, scientific knowledge discussed and negotiated in labs, peer reviews, etc. The implication that there is a close connection between the content and the media of (more or less tentative) scientific knowledge is important to our purposes: It is essential for science learners to realize that, despite the appeals to (absolute) objectivity and universality, scientific knowledge does not exist in and of itself; its tentativeness, or its degree of existence, to put it the Latourian way, depends on the ways in which it is involved in scientific communication (Nielsen, 2013, p. 2082). Classified as Level III.

With this background Nielsen (2013) suggests that the following be included as an eighth item of Lederman’s (2007, pp. 833–835, also known as the Lederman seven) list of nature of science topics: science is a mode of communication that enables and sustains knowledge in certain ways (p. 2081). This leads us to understand better the distinction between “ready-made science” and “science-in-the-making.” Ready-made science, of course, refers to stabilized scientific knowledge as presented generally in textbooks. It is plausible to suggest that the communicative structure of science would improve if we discuss in class some of the controversial aspects of “science-in-the-making” and how scientists resolved the controversies. Interestingly, this facet of “ready-made science” is widespread in most parts of the world (cf. Niaz, 2016, Chap. 4, in the context of presentation of atomic models in textbooks).

3.2.29 Science, Religion and Objectivity

Based on his criticism of Good (2001) and Mahner and Bunge (1996), with respect to the religious habits of mind, Gauld (2005) has called for a careful scrutiny of the writings of Christian scientists (e.g., Polkinghorne):

In the above discussion it has been argued that, when one considers a wider range of evidence than Good (2001) has done, the scientific and religious habits of mind are more

similar to one another than he acknowledges. In both cases openness to argument and evidence, skepticism, rationality and objectivity are all held in high regard; in both some ideas are more protected from attack while others are more open to challenge; and in both, at any time, there are various degrees of commitment to theories from skeptical rejection to passionate endorsement. Both habits of mind stem from the same scholarly attitude and any difference between them is probably due to differences in what are counted as appropriate evidence and good reasons. For example, in the Christian religion historical evidence and evidence from human agency and self-awareness are more important than they apparently are in physics (pp. 301—302). Classified as Level II.

This is an interesting example of considering objectivity in scientific and religious habits of mind as academic objectives. Furthermore, it can facilitate a better understanding of both religion and science and also help in teaching controversial topics of the science curriculum, such as evolution.

According to Pennock (2010):

IDC [Intelligent Design Creationism] shows in a striking manner how radical postmodernism undermines itself and its own goals of liberation. If there is no difference between narratives—including no difference between true and false stories and between fact and fiction—then what does liberation come to? Are scientific investigations of human sexuality really no more likely than the Genesis tale of Eve’s creation from Adam’s rib? Those original goals—the overthrow of entrenched ideologies that hid and justified oppression—that motivated the postmodern critique were laudable. But the right way to combat oppression is not with a philosophy that rejects objectivity and relativizes truth, for that guts oppression of its reality (p. 777). Classified as Level III.

Pennock is arguing that the post-modern rejection of objectivity is double edged: on the one hand it espouses liberation from different forms of power structures and at the same time it provides IDC an argument against the prestige of objectively determined knowledge provided by science. Proponents of IDC have acknowledged that it is precisely for this reason that they consider themselves to be deconstructionists and postmodern (cf. Pennock, 2010, p. 759). In this context, it would be helpful to consider some of the ideas introduced by Gauld (2005) with respect to openness to argument and evidence in both science and religion.

3.2.30 *Scientific Literacy and Objectivity*

According to Krogh and Nielsen (2013), in order to achieve functional literacy, “... it is necessary to help students dismantle the naïve view that science is objective and value free, and give the more realistic impression that objectivity is not an all or nothing thing. There are degrees of objectivity” (p. 2061). Classified as Level III. Furthermore, the authors suggested that the inclusion of recent debates within the scientific community based on discipline-specific NOS-insights can help students to understand this facet of science. Machamer and Wolters (2004) have presented a similar thesis with respect to degrees of objectivity.

3.2.31 *Scientific Method and Objectivity*

Based on a framework that emphasizes the technological dimension, Gil-Pérez et al. (2005) have referred to the wide-spread practice in science education of associating objectivity with the scientific method:

For example, in interviews held with teachers, a majority have referred to the “Scientific Method” as a sequence of well defined steps in which *observations* and *rigorous experiments* play a central role which contributes to the *exactness* and *objectivity* of the results obtained. Such a view is particularly evident in the evaluation of science education: as Hodson (1992) points out, the obsessive preoccupation with avoiding ambiguity and assuring the reliability of the evaluation process distorts the nature of the scientific approach itself, essentially vague, uncertain, intuitive (p. 313, italics in the original). Classified as Level III.

Indeed, the ambiguity, uncertainty, creativity, and intuitive aspects of the scientific endeavor are essential if we want our students to understand “science in the making.”

Depew (2010) has referred to the scientific method in the context of Darwinism:

Ironically, so well has the folk version of simplistic empiricism about “scientific method” been internalized into the post-Sputnik public sphere that, rather than reading Kuhn’s *Structure of Scientific Revolutions* as attacking this view of scientific method, students usually read it as expressing mere skepticism about the scientific objectivity with whose norms they are already familiar. Nor do many post-Kuhnian social constructionists do anything [to] counter this impression. In fact, some of them actually play into it. Under such conditions, portraying evolutionary science in any way that seems not to fit the model of well-confirmed science whose rudiments people, including journalists, learned in school generates in most audiences not a more complex conception of scientific inquiry suited to an inherently complex subject, but a sense that Darwinism is not really a science at all, but instead a world view or secular religion (pp. 361–362). Classified as Level III. This presentation could have been classified in Evolution, creationism and objectivity.

It is important to note the difficulties involved in teaching evolution and how at times Darwinism is not considered really a science but perhaps a secular religion. Indeed, to promote the idea that all science is well confirmed is misleading and the inability to discuss this in class leads to the difficulties involved in teaching evolution and understanding Darwinism.

According to Kosso (2009): “The point here is that the scientific method, and the information gained through observation, can be essentially under the influence of what the scientists have in mind, without compromising the objectivity of the method or the information” (p. 38). Classified as Level I. Kosso’s argument is that scientific method is essentially global, in other words any model that describes testing of individual hypotheses, one at a time and in isolation from other theoretical information, is inaccurate (p. 41). However, textbooks generally argue that it is a sequence of steps in a scientific method that makes science objective and this creates difficulties in understanding how science is done.

3.2.32 *Scientific Methodology and Objectivity*

Rusanen and Pöyhönen (2013) have suggested that scientific concepts could be understood as communally shared epistemic tools that scientists use to coordinate their efforts in their common tasks of knowledge production. Working with mechanisms of conceptual change, these authors have reported that: "... the objectivity and correctness of scientific inference are guaranteed by communication and error correction within the research group and within the wider scientific community. Importantly, this picture of scientific concepts applies also in less strongly distributed cases: what is referred to by speaking of scientific concepts are not mental representations of individuals but pieces of scientific knowledge that can be shared by a community of individuals" (p. 1393). Classified as Level IV. This presentation approximates to Daston and Galison's (2007) idea of "trained judgment."

Develaki (2008) first points out that the traditional ethics of science are based on objectivity, empirical control, and precision measurement. Furthermore, scientific knowledge is also projected as autonomous and neutral since it was considered to be substantiated and established exclusively on the basis of empirical and logical criteria. In contrast, critical philosophy focuses on the interaction between science and society:

The view that the evaluation and choice of theories is based (solely) on unambiguous logical rules and empirical criteria has been challenged on the grounds that the development and choice of theories takes place under the deciding influence of concrete world views (e.g., a mechanistic world view for classical mechanics), so that the resulting incommensurability of theoretical and methodological standards of the various theories precludes a neutral, objective and fair framework for comparison and selection among alternative theories (e.g., Toulmin, Hanson, Bohm, Kuhn, and others, see in Suppe, 1977). (Develaki, 2008, p. 875). Classified as Level III.

Comparing the presentations of Rusanen et al. (2013) and Develaki (2008), it can be observed that the former explicitly posits the critical role played by communication within the scientific community, whereas the latter only refers to the problematic nature of objectivity.

3.2.33 *Scrutinized Scientific Knowledge and Objectivity*

Abd-El-Khalick (2013) has clarified the difference between the social and relativistic notions of scientific knowledge in the context of understanding objectivity:

The social NOS, or "science as social knowledge," refers to the epistemic function of these social activities: It refers to the constitutive values associated with those established venues for communication and criticism within the scientific enterprise (e.g., blind review processes), which serve to enhance the objectivity of collectively scrutinized scientific knowledge through decreasing the impact of individual scientists' idiosyncrasies and subjectivities (Longino, 1990). In this specific sense, it should be noted, social NOS refers to

conceptions of science as advanced by philosophers of science such as Helen Longino ... and should *not* be confused with relativistic notions of scientific knowledge (p. 2096). Classified as Level IV.

Ford (2008) has referred to the dilemma faced by a scientist during theory choice, as no set of objective rules can provide guidelines for selecting a theory:

However, it is becoming clear not only in the science studies literature but also in psychology that the information provided by any set of rules or method (i.e., declarative knowledge) is insufficient to account for inquiry. For example, Machamer and Osbeck (2003) elaborated on this point in light of Kuhn's account of how scientists choose among rival theories, noting that no set of objective rules can explain theory choice sufficiently. The key insight offered by Machamer and Osbeck (2003) is that one also needs to know under what circumstances and in what way (and, indeed, it seems, to what end) any posited rules should be applied so their application is appropriate (p. 152). Classified as Level III.

3.2.34 *Social/Cultural Milieu and Objectivity*

According to Cobern (1995):

Colloquial positivism roughly represents a classical view of realism, philosophical materialism, strict objectivity, and hypothetico-deductive method. Though recognizing the tentative nature of all scientific knowledge, colloquial positivism imbues scientific knowledge with a Laplacian certainty denied all other disciplines, thus giving science an a priori status in the intellectual world (p. 299). Classified as Level III.

By colloquial positivism Cobern (1995) is not referring to the philosophical sense, generally referred to as logical positivism or logical empiricism, but rather in the sense of a mythology of school science as referred to by Smolicz and Nunan (1975). Based on this clarification, Cobern (1995) then goes on to critique the traditional practice of science education:

While it may never have been explicit, the goals of science education clearly have been to persuade students that science provides a fairly constant, highly justified, and sufficient understanding of physical phenomena The claim of certainty for scientific knowledge which science educators grounded in positivist philosophy was rendered untenable years ago and it turns out that social and cultural factors surrounding discovery may be at least as important as the justification of knowledge. (p. 287)

Cobern' main concern is to show that discovery in science inevitably takes place in a social and cultural milieu and lacks the certainty school science tries to convey as a dogma (cf. as reproduced in Niaz, Klassen, McMillan, & Metz, 2010b). Interestingly, a recent study has highlighted the importance of the status of certainty/uncertainty of physics knowledge as a means to facilitate conceptual understanding: "The knowledge that has already been acquired allows the researchers to raise new questions because there is uncertainty; a given study aims to decrease this uncertainty and then new questions emerge, again pointing out new uncertainty. This dynamics of uncertainty based on knowledge is a way of developing knowledge. We also consider that, in the students' processes of

construction of knowledge, uncertainty can drive the learning process of knowledge” (Tiberghin, Cross, & Sensevy, 2014, p. 931). This clearly shows that uncertainty with respect to scientific knowledge need not be a constraint in learning science but rather can even facilitate construction of new knowledge. Consequently, questioning the role of objectivity in the “strict” sense has important implications for science education.

3.2.35 *Social Nature of Scientific Knowledge*

According to Howard (2009), “science’s own unreflected pretensions to objectivity” (p. 212) needs to be countered with the social dimensions of knowledge as reflected in the early work (Mannheim, Fleck, Zilsel, & Merton) and more recent work on the social epistemology of science (Longino, Solomon, & Kusch). However, he feels that work on the social dimensions of scientific knowledge has been somewhat peripheral to mainstream work in epistemology and philosophy of science, and that the field has yet to mature. For example, Howard considers (p. 212) Steve Fuller’s intervention unfortunate on behalf of the defendants, hence on behalf of requiring the teaching of intelligent design in public schools, in the *Katzmiller v. Dover* case of 2005. Fuller was the founding editor of the journal *Social Epistemology*, that aspired to be an effective voice in the reform of scientific and social practice affecting science. Classified as Level III.

According to Uebel (2004): “Yet note that the [Vienna] Circle’s intersubjective meaning criterion did not only play a negative but also a positive role (it was not merely an ad hominem device for segregating metaphysics). The notion of intersubjectivity also provided the framework within which it was possible for science to attain its autonomy from philosophy: it opened the possibility for replacing the ‘metaphysical’ idea of objectivity. The objectivity of science did not consist in the provision of distortionless reflections of reality—of ‘views from nowhere’—but in the possibility for intersubjective control of perspectival views and assertions” (p. 54). (Classified as Level III). Based on these considerations, Uebel concluded that the intersubjective perspective required not only the adoption of radical fallibilism but also the recognition of the social character of scientific knowledge.

According to Allchin (1999): “The many cases of bias and error in science have led philosophers to more explicit notions of the social component of objectivity. Helen Longino (1990), for example, underscores the need for criticism from alternative perspectives and, equally, for responsibly addressing criticism. She thus postulates a specific institutional, or social, structure for achieving Merton’s ‘organized skepticism’” (p. 6). Classified as Level III.

It can be observed that the science education literature has shown considerable interest in the social nature of scientific knowledge and consequently its implications for classroom practice, especially for teaching controversial topics.

3.2.36 *Theory-Laden Observation and Objectivity*

Based primarily on the work of Kuhn (1970) and the Duhem-Quine thesis, observations are influenced by the theories/beliefs one holds. In other words all observations are based on some essential theoretical assumptions that may influence the degree to which a scientist may be objective (Godfrey-Smith, 2003). Based on this background, Lau and Chan (2013) designed a study (based on the conceptual change model of Hewson, Beeth, & Thorley, 1998; Posner, Strike, Hewson, & Gertzog, 1982) to explore the effect of theory-laden observations on students understanding of a lab activity:

A discrepant event, the manipulated theory-laden observation, is used to create cognitive conflicts on students' beliefs about the objectivity of observation and science. Then students' practical epistemologies are worked on publicly and explicitly through dialogue, by which the conceptions of theory-ladenness is made intelligible and plausible to students, and as such, conceptual change regarding their formal epistemologies would be likely (Lau & Chan, 2013, p. 2644, original italics). Classified as Level IV.

The lab activity asked students (Grade 9 students in Hong Kong) to investigate whether heating can destroy the vitamin C contents of vegetables. One group of students was told that scientists had found that vitamin C cannot be destroyed by heating and another group was told that vitamin C would be destroyed at high temperature. Lau and Chan (2013) provided the rationale of their study as:

In such way, the students were “biased” by the two theories in opposite directions in the observation of the end points and/or the report of data. But actually the two vitamin C solutions provided are both unboiled! To make certain if the students had really been convinced by the “theory” given in the task sheet, they were asked to *predict* the results before conducting the experiment. About 83% of them made predictions in line with the “theory” given. (p. 2646, original italics)

Results obtained showed that the two groups of students obtained data in line with the predictions from the given “theories” about vitamin C, which shows the role played by theory-laden observations. These results helped the students to understand the idea that observations cannot be entirely objective. Interestingly, some students thought that they were “tricked” by the instructor and one student expressed, “How come you give us something wrong ...” (p. 2650). Finally, most students became more receptive to the idea that observations are not truly objective. Designing such studies can be helpful in facilitating a better understanding of the scientific endeavor.

The role of theory-laden observations and objectivity has been the subject of a study by Park, Nielsen, and Woodruff (2014). On the one hand, these authors recognize the importance of theory-laden observations but still recognize its problematic nature: “Popper ... partially endorsed the notion of theory-free observation when a radical change of theory occurs because past experiences or theories cannot guide scientists to modify the anomalies; rather, objectivity, rationality and elimination of subjectivity lead to new theory. Einstein ..., Heisenberg ..., and Feynman ..., outstanding physicists argue that neither 100% theory-independent,

nor 100% theory-dependent observation really exists” (p. 1172). Later, in this context these authors illustrate their thesis by providing the example of observations provided by the 1919 eclipse experiments: “Without observational and empirical evidence, a theory cannot stand. For instance, when Einstein suggested the special theory of relativity in 1915, he was not a famous physicist at all. After the observation of the 1919 solar eclipse by Eddington, Einstein’s theory was accepted and then, Einstein became famous” (p. 1172). The actual events related to the eclipse experiments were much more complex. Niaz (2009, Chap. 9, pp. 127–137) has argued that if Edington (considered to be a major expert on Einstein’s theory of relativity) had not been aware of the theory, it would have been extremely difficult to interpret observations from the eclipse observations, as providing support for the theory. Classified as Level III.

According to Develaki (2012): “In the philosophy, history and sociology of science was developed a series of documented arguments and disputes that challenged the objectivity of observations and the interpretations of experimental data for principal reasons (and also for practical reasons such as the technological insufficiency of the experimental arrangements), which was noted very early (1928 by Duhem): concretely, given their theory-ladenness and theory-guidedness, experiments cannot, or at least cannot always, identify the erroneous hypothesis within the complex interweaving of auxiliary hypotheses and theoretical principles that lead to a specific prediction that is under examination (e.g. Hanson ...; Suppe ...; Duhem ...; Hume ...; Popper ...)” (p. 867). Classified as Level III. Later Develaki compares the positions of Kuhn, Lakatos, and Giere with respect to theory choice (p. 870) and concludes that only in very favorable circumstances theories are based entirely on logical and experimental grounds.

3.2.37 *Values and Objectivity*

According to Cordero (1992), scientific practice presupposes both theories and values, which does not necessarily destroy objectivity (p. 50). He then goes on to illustrate scientific practice by exploring the intricate relationship between facts and values: “If history shows anything, it is that in science the facts have rarely been loyal to the values which initially led to their identification. When Darwin developed his theory of evolution, he made liberal use of facts that had been gathered by his teleologically oriented predecessors, but he did not respect the valuations which those facts originally carried. In fact, Darwin’s approach turned teleological biology on its head and initiated the destruction of the man-centered and goal-oriented biology then prevalent” (pp. 53–54). According to Cordero this shows the invariance of scientific facts to value change. This, however, may constitute a dilemma for a science educator who believes that science and the values on which it is based are generally objective. Cordero (1992) resolves the dilemma in the following terms:

The way in which science has forged the objectivity of its values is, I suggest, of particular interest to a certain type of person in the contemporary world. I have in mind a person who

agrees that science is acceptably objective, and who cannot honestly take as legitimate any absolute truths or values, let alone ones that are imposed by mere authority. I am referring to a person that has outlived the quest for absolutes, yet one who is aware of his needs and who has managed to develop a sense of reliable access to the world through scientific thought, however limited this kind of access might look relative to previous “philosophical” or “religious” standards. I will call this person the “humane naturalist” (p. 65). Classified as Level III.

Thus a “humane naturalist” would accept science to be objective and at the same time question absolute truths or values—which reflects the problematic nature of objectivity.

Several feminist philosophers, including Elizabeth Anderson, Helen Longino, and Janet Kourany, have argued that feminist values can help increase the objectivity and rationality of scientific reasoning, including decisions about which theories to accept or reject. Based on this premise, Intemann (2008) has concluded:

If feminist (or any social, ethical, or political values) can play a legitimate role in scientific reasoning, then we must not continue to represent science as “value-free” in science education. We must develop more nuanced and sophisticated accounts of concepts such as “bias,” “objectivity,” and “scientific rationality” that reflect the complex interactions between science and values (p. 1078). Classified as Level III.

According to Davson-Galle (2012): “...I will contend that, although science is not and cannot be totally value free, the inescapably involved values are benign, not in the sense that that involvement is not influential but in the sense that it does not affect science’s status as objective” (p. 192). Lack of a critical perspective may lead many science educators to agree with this interpretation of values in science. Classified as Level II.

After considering the events related to the Vietnam War and the Civil Rights Movement in the USA in the 1960s, Cobern and Loving (2008) have referred to the difficulties involved in understanding objectivity in science, especially in the educational context:

Television brought the war home as people saw for the first time the effects of Napalm, Agent Orange and other products of scientific knowledge in the service of political and military needs. Students in particular were prone to change their estimation of science because of what they perceived as an unholy alliance between the community of science and a military-industrial complex that developed and produced such weapons. The rhetoric of values neutrality and objectivity was not tenable when the science community having taken credit for such things as the Green Revolution now denied any responsibility for Agent Orange and Napalm. Science not only lost its luster, it lost its innocence (p. 431). Classified as Level III.

This presentation highlights the underlying tension between scientific progress and the assumptions with respect to its neutrality and objectivity. It is not difficult to see how for a critical student dissonance may lead to tragedy. In order to grapple with such thorny issues science educators will have to reconsider the traditional values associated with the objective nature of science.

This chapter provides examples of research reported in the journal *Science & Education* (35 sections) that facilitate a wide range of perspectives with respect to

understanding objectivity. These examples provide a glimpse of research conducted in various parts of the world over a period of more than 20 years. Conclusions based on these findings along with those of Chaps. 4–6 will be presented in Chap. 7.

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