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Mendelian Genetics as a Platform for Teaching About Nature of Science and Scientific Inquiry: The Value of Textbooks

Megan F. Campanile · Norman G. Lederman · Kostas Kampourakis

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Abstract The purpose of this study was to analyze seven widely used high school biology textbooks in order to assess the nature of science knowledge (NOS) and scientific inquiry (SI) aspects they, explicitly or implicitly, conveyed in the Mendelian genetics sections. Textbook excerpts that directly and/or fully matched our statements about NOS and SI were labeled as explicit and excerpts that partially and/or indirectly matched our statements about NOS and SI were labeled as implicit. There was a running count of each NOS and SI aspect that was identified in the textbooks and the instances were noted to be either implicit or explicit. There were 365 instances of NOS and SI aspects counted in 140 textbook excerpts. Of the 365 instances, 237 (65 %) were NOS aspects and 128 (35 %) were SI aspects. The analysis also revealed far more implicit than explicit instances of NOS and SI. Of the 365 instances, 362 (99 %) were implicit and three (1.0 %) were explicit. The three explicit instances were all SI aspects. In conclusion, the Mendelian genetics sections demonstrated a multitude of opportunities to teach NOS and SI explicitly, although what was included in textbooks was virtually all implicit. This study demonstrates the importance and value for science educators to examine how teachers use instances of NOS and SI in textbooks. Understanding how teachers use instances of NOS and SI would provide information that could be immediately implemented into professional development programs. Lastly, this research would provide textbook developers with compelling information to update the supplemental instruction materials provided to teachers.

M. F. Campanile (✉)
Department of Mathematics and Science Education, Illinois Institute of Technology, Chicago, IL, USA
e-mail: mfaurot@hawk.iit.edu

N. G. Lederman
Department of Mathematics and Science Education, Illinois Institute of Technology, Chicago, IL, USA
e-mail: ledermann@iit.edu

K. Kampourakis
Biology Section and IUFE, University of Geneva, Geneva, Switzerland
e-mail: konstantinos.kampourakis@gmail.com

1 Introduction

Scientific literacy as a specified instructional outcome has been around for over a century (Central Association for Science and Mathematics Teachers 1907) and its connection to an understanding of nature of science knowledge (NOS) and scientific inquiry (SI) was, perhaps, most formalized by the work of Showalter (1974) and by a National Science Teachers Association position statement on science-technology-society (NSTA 1982). Others have also contributed to the conceptualization of what it means to be scientifically literate (Laugksch 2000; Orpwood and Alam 1984; Roberts 2007). In general, scientific literacy was always at least partially associated with an individual's ability to make informed decisions about scientifically-based personal and societal issues. To make such decisions, individuals need to know science subject matter, how it is developed (i.e., inquiry) and the characteristics of knowledge necessarily derived from the way knowledge is produced (i.e., nature of science) (Lederman and Lederman 2011).

For an individual to be considered scientifically literate requires that he/she understands subject matter, NOS, and SI. Although the meaning of subject matter is familiar to teachers and science educators, the meanings of NOS and SI are not always clear to teachers and often are contentious within the science education and science communities. Consequently, a discussion of the meaning of these constructs follows. It is important to note, when understandings of SI and NOS are viewed as instructional outcomes, that the audience of interest is K-12 students. Hence, one must consider developmental appropriateness, empirical evidence that students can learn the constructs and a justification that knowledge of such constructs is necessary for scientific literacy (or the general citizenry). Using this lens, the often contentious debates about what constitutes SI and NOS disappear (Lederman et al. 1998).

Gregor Mendel is an exemplar case: most biology textbooks include a description of his work and of his "laws". The usual description is that of a heroic monk, working alone in his garden with the aim to understand heredity, performing numerous experiments the significance of which his contemporaries unfortunately failed to appreciate. However, a careful study of the history of science shows that this story is wrong (see Allchin 2003 for this and other similar cases). Mendel was not the only one studying heredity during his time. In contrast there was a whole community of naturalists who were studying heredity and Mendel was rather an outsider to this community because his work had a different focus (Kampourakis 2013). Furthermore, his study of *Pisum sativum* and the conclusions made of it about dominance and recessiveness of characters, currently presented as the norm, is actually a special and exceptional case. Weldon had shown from the beginning of the twentieth century that variability in *Pisum* was much larger than what Mendel had assumed. Peas were not either green or yellow but there was a continuum of phenotypes from greenish yellow to yellowish green (Jamieson and Radick 2013). It is also important to note that the empirical research does not support the intuitive assumption that students come to understand SI and NOS implicitly (Lederman 2007).

In this article we analyze seven widely used textbooks in order to assess the NOS and SI aspects they, explicitly or implicitly, convey. This is done in the light of a more careful study of the history of science and in particular of Mendel's work and background. Mendel is often presented as an exemplar case in most biology textbooks and so most students come to learn something about his life and work. Consequently, it is interesting to examine how Mendel and his work are portrayed in textbooks.

2 Conceptualizing Nature of Science Knowledge

The seven characteristics of scientific knowledge that has guided this research are not meant to be an exhaustive list. There are certainly other characteristics of scientific knowledge that others consider important, and we have no quarrel with the substance of other lists. The aspects investigated here with respect to their appearance in selected textbook explanations of Mendelian genetics were chosen for the following reasons: (1) developmental appropriateness; (2) empirical support that students can develop adequate understandings; (3) meaningfully connected to the existing science curricula; (4) not contentious; and (5) predominate the empirical literature base.

The characteristics of scientific knowledge that meet these five criteria are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws (Lederman 2007).

Again, it is important to note that these aspects of NOS are not meant as a comprehensive listing. There are other aspects that some researchers or reform documents include or delete (Abd-El-Khalick et al. 1998; Chiappetta and Fillman 2007; Matthews 1994; Irzik and Nola 2011; Achieve, Inc. 2013; Osborne et al. 2003; Smith and Scharmann 1999). There is no definitive listing of the aspects of NOS.

3 Conceptualizing Scientific Inquiry

Although closely related to science processes, SI extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. From the perspective of the *National Science Education Standards* (NRC 1996), students are expected to be able to develop scientific questions and then design and conduct investigations that will yield the data necessary for arriving at answers for the stated questions.

The *Benchmarks for Science Literacy* (AAAS 1993) is a bit less ambitious as it does not advocate that all students be able to design and conduct investigations in total. Rather, it is expected that all students at least be able to understand the rationale of an investigation and be able to critically analyze the claims made from the data collected. Scientific inquiry, in short, refers to the systematic approaches used by scientists in an effort to answer their questions of interest. Pre-college students, and the general public for that matter, believe in a distorted view of SI that has resulted from schooling, the media, and the format of most scientific reports. This distorted view is called *THE SCIENTIFIC METHOD*. That is, a fixed set and sequence of steps that all scientists follow when attempting to answer scientific questions. The visions of reform, as well as any study of how science is done, are quick to indicate that there is no single fixed set or sequence of steps that all scientific investigations follow. The contemporary view of SI advocated is that the research questions guide the approach and the approaches vary widely within and across scientific disciplines and fields (Lederman et al. 1998).

Scientific inquiry has always been ambiguous in its presentation within science education reforms. In particular, inquiry is perceived in three different ways. It can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation. It can also be viewed as a cognitive outcome that students are to achieve. In particular, the current visions of reform (e.g., NRC 1996) are very clear (at least in written words) in distinguishing between the performance of inquiry (i.e., what students will be able to do) and what students know about inquiry (i.e., what students should know). Although the processes that scientists use when doing inquiry (e.g. observing, inferring, analyzing data, etc.) are readily familiar to most, knowledge *about* inquiry, as an instructional outcome is not. This is the perspective of inquiry that distinguishes current reforms from those that have previously existed, and it is the perspective on inquiry that is not typically assessed. In summary, the knowledge *about* inquiry included in current science education reform efforts includes the following (NRC 1996):

- Scientific investigations all begin with a question, but do not necessarily test a hypothesis.
- There is no single set and sequence of steps followed in all scientific investigations (i.e., there is no single scientific method).
- Inquiry procedures are guided by the question asked.
- All scientists performing the same procedures may not get the same results.
- Inquiry procedures can influence the results.
- Research conclusions must be consistent with the data collected.
- Scientific data are not the same as scientific evidence.
- Explanations are developed from a combination of collected data and what is already known.

Again, these are cognitive instructional outcomes targeted by science instruction, as opposed to the performance of inquiry skills.

There currently is a vigorous research effort to discern the most effective ways to facilitate students' conceptions of NOS and SI. One perennial factor impacting the nature and quality of science instruction is the textbook used by teachers and students. Although teachers use textbooks to varying degrees (e.g. as a resource, as a specific guide to instruction), the textbook still remains a significant influence on what constitutes the science curriculum and/or the topics comprising a science course. Consequently, the purpose of this investigation was to analyze a variety of the most widely used biology textbooks, with a specific focus on the topic of Mendelian genetics and the relative frequency of explicit and implicit references to NOS and SI.

4 Methods

Seven textbooks were analyzed for the presence of the aspects of NOS and SI (i.e., explicit or implicit) in the sections on Mendelian genetics. The most recent editions of seven textbooks were retrieved for this study. *Glencoe Biology* (Biggs et al. 2009), *Miller & Levine Biology* (Miller and Levine 2010), *BSCS Biology: A Human Approach* (Resch 2011) and *Holt McDougal Biology* (Nowicki 2012) were selected because they are commonly used for introductory high school biology courses in the United States. *Pearson Baccalaureate Higher Level Biology* (Ward et al. 2008) and *Biology for the IB Diploma Coursebook* (Walpole et al. 2011) were selected because they are commonly used in the International Baccalaureate Diploma Programme all over the world. *Campbell Biology*

(Reece et al. 2012) was selected because it is commonly used for advanced placement high school biology courses in the United States. The sections on Mendelian genetics were analyzed in the seven textbooks for explicit and implicit references to NOS and SI. There was a range in the lengths of the sections on Mendelian genetics. *BSCS Biology: A Human Approach* had the shortest section on Mendelian genetics and consisted of only two pages and the textbook by Nowicki (2012) had the longest section which consisted of 42 pages.

The Mendelian genetics sections from the seven textbooks were analyzed for both explicit and implicit instances of the NOS and SI aspects. Three researchers independently analyzed each Mendelian genetics section using the content analysis method. The researchers identified excerpts in the sections that related to our statements about NOS and SI. These were defined to be paragraphs, sentences, table headings, and figure headings. Excerpts that directly and/or fully matched our statements about NOS and SI were labeled as explicit and excerpts that partially and/or indirectly matched our statements about NOS and SI were labeled as implicit. The three researchers kept a running count of each NOS and SI aspect that was identified in the textbooks and the instances were noted to be either implicit or explicit. Actual examples of implicit and explicit instances of NOS and SI from the Mendelian genetics sections will be concretely illustrated in the results section. In general, explicit instances of the NOS and SI aspects were those presented in a manner that would not require further explanation from the teacher and implicit instances were potential opportunities that teachers could use to explicitly teach NOS and SI aspects. The three researchers met regularly to share, discuss, and negotiate their analysis of the Mendelian genetics sections. There was a 90 % level of agreement measured across the three researchers.

There were seven aspects of NOS and eight aspects of SI used in the textbook analysis. The seven aspects of nature of science were NOS 1) *observation versus inferences*; NOS 2) functions and relationship of *theory and law*; NOS 3) *empirically-based*; NOS 4) *creativity*; NOS 5) *subjectivity*; NOS 6) *socially and culturally embedded*; and, NOS 7) *tentativeness*. The eight aspects of scientific inquiry were SI 1) scientific *investigations all begin with a question*, but do not necessarily test a hypothesis; SI 2) there is no single set and sequence of steps followed in all scientific investigation (i.e., there is *no single scientific method*); SI 3) inquiry *procedures are guided by the question asked*; SI 4) all scientists performing the *same procedures may not get the same results*; SI 5) inquiry *procedures can influence the results*; SI 6) *research conclusions must be consistent with the data* collected; SI 7) *scientific data are not the same as scientific evidence*; and, SI 8) *explanations are developed from collected data and what is already known* (Lederman and Lederman 2012).

5 Results

In the seven textbooks analyzed, there were a total of 140 excerpts that were coded with NOS and SI aspects. In total, there were 365 instances of NOS and SI aspects counted in the 140 excerpts. There were more instances of NOS aspects than SI aspects counted in the seven textbooks. Of the 365 instances, 237 (65 %) were NOS aspects and 128 (35 %) were SI aspects. The 237 instances of NOS were coded in 124 of the 140 excerpts. The 124 excerpts were coded with one to four of the NOS aspects. There were 40 (32 %) excerpts coded with one NOS aspect, 59 (48 %) excerpts with two NOS aspects, 17 (14 %) excerpts with three NOS aspects, and 8 (6 %) excerpts coded with four NOS aspects. The 128 instances of SI were coded in 97 of the 140 excerpts. The 97 excerpts were coded with one to three SI aspects. There were 63 (65 %) excerpts with one SI aspect, 28 (29 %) excerpts with two SI aspects, and six (6 %) excerpts with three SI aspects. There were 77 excerpts that were coded with both NOS and SI aspects simultaneously, however, the NOS and SI results are presented separately.

The analysis revealed far more implicit than explicit instances of NOS and SI. Of the 365 instances, 362 (99 %) were implicit and three (1.0 %) were explicit. The three explicit instances were all SI aspects. The SI aspect explicitly addressed one time in the textbook analysis was *procedures can influence the results* and the other SI aspect explicitly addressed two times was *the same procedures may not get the same results.* In the following sections, the results on the explicit and implicit instances of NOS and SI aspects in the Mendelian genetics sections will be presented with actual excerpts from the textbooks.

5.1 Nature of Science

There were 237 instances of NOS aspects in the textbook analysis and all of them were implicit (Table 1). No explicit instances of the NOS aspects were identified in the seven textbooks analyzed for this study. Reece et al. (2012) addressed all seven NOS aspects; Nowicki (2012), Ward et al. (2008), and Walpole et al. (2011) addressed six NOS aspects; Biggs et al. (2009) addressed four NOS aspects; and, Miller and Levine (2010) and *BSCS Biology: A Human Approach* addressed three NOS aspects. The NOS aspects that were most often addressed in the textbooks were *empirically-based* (37 %), *observation versus inference* (28 %), and *theory and law* (14 %). The less common NOS aspects in the textbooks were *tentativeness* (6 %), *creativity* (6 %), *socially and culturally embedded* (5 %), and *subjectivity* (5 %) (Table 1).

Table 1 NOS aspects counted in the analysis of the seven textbooks

Textbook	NOS aspects							Total NOS incidences
	NOS 1	NOS 2	NOS 3	NOS 4	NOS 5	NOS 6	NOS 7	
Glencoe biology (Biggs et al. 2009)	11	3	13	1	0	0	0	28
Miller and Levine biology	11	0	18	0	0	1	0	30
BSCS biology (Resch 2011)	2	2	2	0	0	0	0	6
Holt McDougal biology (Nowicki 2012)	14	9	18	2	0	1	6	50
Higher level biology (Ward et al. 2008)	3	1	4	0	1	2	1	12
Biology for the IB diploma (Walpole et al. 2011)	1	5	3	0	5	5	1	20
Campbell biology (Reece et al. 2012)	25	14	28	11	5	2	6	91
TOTAL	67	34	86	14	11	11	14	237
Implicit	67	34	86	14	11	11	14	237
Explicit	0	0	0	0	0	0	0	0

Instances of NOS aspects in the 7 textbooks analyzed for this study. The seven aspects of nature of science analyzed were NOS 1) *observation versus inferences*; NOS 2) *theory and law*; NOS 3) *empirically-based* NOS 4) *creativity*; NOS 5) *subjectivity*; NOS 6) *socially and culturally embedded*; and, NOS 7) *tentativeness*

5.1.1 Empirically-Based

The most common NOS aspect in the Mendelian genetics sections of the textbooks was *empirically-based*. Of the 237 instances of NOS aspects, 86 (37 %) were instances of *empirically-based*. There were no explicit instances of *empirically-based* in the seven textbooks analyzed. The textbooks with the most implicit instances of *empirically-based* were by Reece et al. (2012) with a total of 28 instances and Miller and Levine (2010) and Nowicki (2012) both had 18 instances. The other four textbooks analyzed in this study had less than 15 instances of *empirically-based* (Table 1). The aspect of e*mpirically-based* was often coupled with the aspect of *observation versus inference*. There were 87 textbook excerpts coded with *empirically-based* and 67 excerpts coded with *observation versus inference*. Of the 87 textbook excerpts coded with *empirically-based*, 23 (26 %) were coded without *observation versus inference* and 64 (71 %) were coded with *observation versus inference*. Excerpts that were coded with *empirically-based* and not *observation versus inference* and excerpts coded with both *empirically-based* and *observation versus inference* will be presented in this section.

The implicit instances of *empirically-based* focused on the association between Mendel's experiments and the development of his principles of inheritance. This first set of excerpts presented were coded with *empirically-based* and not *observation versus inference*. The following excerpts were from the three textbooks with the most instances of *empirically-based*:

> One was the physicist Christian Bopple, who encouraged his students to learn science through experimentation and trained Mendel to use mathematics to help explain natural phenomena (Reece et al. 2012, p. 263);
> Mendel wondered if alleles for one trait affected the alleles from another trait. To find out, Mendel set up a cross that enabled him to study two different genes at the same time (Miller and Levine 2010, p. 269); and,
> Mendel performed many dihybrid crosses and tested a variety of different combinations (Nowicki 2012, p. 176).

This next set of excerpts presented were coded with both *empirically-based* and *observation versus inference*. These excerpts were also from the three textbooks with the most instances of *empirically-based*:

> Mendel developed a model to explain the 3:1 inheritance patterns that he consistently observed among the F2 offspring in his pea experiments (Reece et al. 2012, p. 265);
> Whenever Mendel performed a cross with pea plants, he carefully identified and counted the offspring. So he had plenty of data to analyze. He noticed trends whenever he crossed two plants that were hybrids for stem height (Tt), about three fourths of the offspring were tall and about one fourth were short. (Miller and Levine 2010, p. 266); and,
> Mendel did not cross only two plants, however, he crossed many plants. As a result he was able to observe patterns (Nowicki 2012, p. 169).

This final set of excerpts presented comes from the other textbooks with fewer instances of empirically-based. The following excerpts presented were coded with *empirically-based* and not *observation versus inference:*

> Once Mendel established inheritance patterns of a single trait, he began to examine simultaneous inheritance of two or more traits in the same plant (Biggs et al. 2009, p. 280);
> When Gregor Mendel was performing his experiments in the mid 1800s, he did not know anything about meiosis because it had not been discovered (Ward et al. 2008, p. 270); and,
> It was fortunate that Mendel chose these two characteristics for his crosses. Seed colour and height are unlinked genes on different chromosomes. Had they been on the same chromosomes and linked, the results would have been different (Walpole et al. 2011, p. 242).

5.1.2 Observation Versus Inference

The second most common NOS aspect in the Mendelian genetics sections of the textbooks was *observation versus inference*. Of the 237 instances of NOS aspects, 67 (28 %) were instances of *observation versus inference* (Table 1). Only implicit instances of *observation versus inference* were found in all seven textbooks analyzed. The textbooks with the most implicit instances of *observation versus inferences* were Reece et al. (2012) with 25 instances, Nowicki (2012) with 14 instances, and both Biggs et al. (2009) and Miller and Levine (2010) with a total of 11 instances. The other three textbooks analyzed in this study had three or less instances of *observation versus inference* (Table 1). As mentioned, it was observed that when the aspect of o*bservation versus inference* was identified it was often coupled with the aspect of e*mpirically-based.* The majority of the 67 excerpts coded with *observation versus inferences* were also coded with *empirically-based*. There were only three (4 %) excerpts that were coded with *observation vs. inference* that were not also coded with *empirically-based*.

Observation versus inference was commonly addressed in the textbooks' descriptions of the various traits and crosses of pea plants that Mendel performed. The following excerpts were the three instances that were coded with *observation versus inference* and not *empirically-based.*

> Remarkably, Mendel made this deduction without knowing about the role, or even the existence of chromosomes (Reece et al. 2012, p. 265);
> Mendel himself realized that he could not explain the more complicated patterns he observed in the crosses involving other pea characters or other plans (Reece et al. 2012, p. 271); and,
> Mendel explained how a dominant allege can mask the presence of a recessive allele (Biggs et al. 2009, p. 277).

The remaining excerpts were instances that were coded with both *observation versus inference* and *empirically-based*. Furthermore, in the textbooks there were implicit instances that addressed observation or inference separately and others that addressed both observation and inference simultaneously. Implicit instances that described Mendel's experimental observations, included:

> Mendel, a shrewd mathematician, bred thousands of plants, carefully counting and recording his results (Nowicki 2012, p. 167); and,
> Mendel used very large sample sizes and kept accurate records of his results: 705 of the F2 plants had purple flowers, and 224 had white flowers (Reece et al. 2012, p. 264).

An implicit instance that described one of Mendel's inferences about inheritance, included:

> Mendel found that an individual's characteristics are controlled by factors that are passed from parents to offspring (Miller and Levine 2010, p. 263).

Implicit instances that described Mendel's observations and inferences simultaneously, included:

> By carefully studying what happens in a cross, Mendel began to figure out how genetic information is inherited (Miller and Levine 2010, p. 266).
> From his data, Mendel correctly predicted the results of meiosis long before chromosomes were discovered (Nowicki 2012, p. 167).

Observation versus inference was the most addressed NOS aspect by Ward et al. (2008). In this textbook there were a total of 14 implicit instances of NOS and four of these were related to *observation versus inference*. The implicit instances focused on Mendel's observations of seed color and seed shape and were presented as figures and bulleted lists with the actual number of different seed types Mendel observed in his experiments. One of the instances was the following excerpt:

> The F1 generation is made up exclusively of plants which give round yellow peas. When these peas were planted, grown into adult plants and allowed to self pollinate, Mendel expected some of the recessive traits to show up again (Ward et al. 2008, p. 272).

Examples of implicit instances of *observation versus inference* from the other three textbooks, included:

> Mendel noticed that certain varieties of garden pea plants produced specific forms of a trait, generation after generation (Biggs et al. 2009, p. 277);
> He studied several traits in peas, including pod color and pod shape (Resch 2011, p. 636); and,
> Over a period of seven years, he cultivated and texted different pea plants and studied their visible characteristics (Walpole et al. 2011, p. 86).

However, it is critical to emphasize that just using the words observation and inference, separately or together, does not explicitly address this NOS aspect. Again, all the instances of *observation versus inference* were implicit because they only partially and/or indirectly matched our statement about this NOS aspect.

5.1.3 Theory and Law

The third most common NOS aspect in the Mendelian genetics sections of the textbooks analyzed was the function and relationship of *theory and law*. Of the 237 instances of NOS aspects, 34 (14 %) were instances of *theory and law*. There were no instances of *theory and law* that were explicit. All seven textbooks analyzed presented implicit instances of *theory and law*. The textbooks with the most implicit instances of *theory and law* were by Reece et al. (2012) with a total of 14 instances and Nowicki (2012) with 9 instances. The other five textbooks analyzed in this study had five or less instances of *theory and law* (Table 1).

In all the textbooks, implicit instances of *theory and law* were excerpts that described Mendel's development of his theory and laws related to inheritance. An issue related to this NOS aspect was the interchangeable use of the terms theory and law in the textbooks and this could easily lead to student misconceptions. Therefore, teachers would need to first address the misuse of terms related to this NOS aspect before using the implicit instances in these textbooks as context to explicitly teach about *theory and law*. The term "theory" was used in only two of the seven the Mendelian genetics sections analyzed. The following two excerpts are how the term "theory" was used:

> Mendel developed his theory of inheritance several decades before chromosomes were observed under the microscope and the significance of their behavior was understood (Reece et al. 2012, p. 262); and,
> Mendel's theory of inheritance cannot explain all patterns of inheritance (Nowicki, 2012, p. 170).

The term "law" was used in all the textbooks. The following three excerpts are examples of how the term "law" was used:

> Mendel's quantitative analysis of the F2 plants from thousands of genetic crosses like these allowed him to deduce two fundamental principles of heredity, which have come to be called the law of segregation and the law of independent assortment (Reece et al. 2012, p. 264);
> Mendel developed the law of segregation and the law of independent assortment (Biggs et al. 2009, p. 282); and,
> In 1866, he published a paper on inheritance of characteristics in pea plants, which he call 'Experiments on Plant Hybridization', in *The Proceeding of the Natural History Society of Brunn*. In it he set out his two laws of inheritance (Walpole et al. 2011, p. 86).

The same reasoning used with *observation versus inference*, it is critical to emphasize that just using the words theory and law, separately or together, does not explicitly address the relationship or the differences between theory and law. Again, all the instances of *theory and law* were implicit because they only partially and/or indirectly matched our statement about this NOS aspect.

5.1.4 Less Common NOS Aspects

T*entativeness*, *socially and culturally embedded, creativity*, and *subjectivity* were the four NOS aspects that were less common in the Mendelian genetics sections in the seven textbooks (see Table 1). All 50 instances of the four less common NOS aspects were implicit. There were 14 instances of both *creativity* and *tentativeness* and 11 instances of both *subjectivity* and *socially and culturally embedde*d. *BSCS Biology: A Human Approach* was the one textbook that had no instances of *tentativeness* and *socially and culturally embedded.* Implicit instances of *tentativeness* focused on what Mendel and other scientists of the time did not know about science. *Tentativeness* was identified in the following two excerpts:

> Scientists of the time commonly thought that parents' traits were blended in offspring, like mixing red and white paints. But this idea failed to explain how certain traits remained without being diluted (Nowicki 2012, p. 167); and,
> Mendel figured out much about heredity, but he did not know about chromosomes. As it turns out, he only studied traits produced by genes on autosomes. Now we know about sex chromosomes and we now that the expression of genes on sex chromosomes differ from the experssion of autosomal genes (Nowicki 2012, p. 188).

Socially and culturally embedded was identified in a question at the end of one of the Mendelian genetics sections. The question was as follows:

> Do you think Mendel's work was ignored because it was not widely published or because he was not a well-known scientist, or for some other reason? (Walpole et al. 2011, p. 86).

However, this *socially and culturally embedded* instance refers only to scientific culture. It is critical to emphasize that NOS is not limited to the influence of the scientific culture but is influenced by the larger culture. Scientific culture is part of the larger culture of society.

Creativity and *subjectivity* were the two least common NOS aspects addressed in the seven textbooks analyzed for this study. Two examples of implicit instances of *creativity,* included:

> Mendel's fresh approach allowed him to deduce principles that had remained elusive to others (Reece et al. 2012, p. 263); and,
> He made three key choices about his experiments that played an important role in the development of this laws of inheritance: control over breeding, use of purebred plants, and observation of "either-or" traits that appeared in only two alternate forms (Nowicki 2012, p. 167).

Examples of an implicit instance of *subjectivity*, included:

> Although Mendel sent copies to well-known biologist, his ideas were rejected; and, For the next 35 years, his paper was effectively ignored yet, as scientists later discovered, it contained the entire basis of modern genetics (Walpole et al. 2011, p. 86).

The following was the one excerpt identified in the textbook analysis that implicitly addressed *creativity* and *subjectivity* simultaneously:

> Mendel's fresh approach allowed him to deduce principles that had remain elusive to others (Reece et al. 2012, p. 263).

5.2 Scientific Inquiry

There were 128 instances of the SI aspects in the Mendelian genetics sections of the seven textbooks analyzed for this study (Table 2). There were no instances of *no single scientific method* in any of the seven textbooks analyzed. Reece et al. (2012), Biggs et al. (2009), and Nowicki (2012) addressed six SI aspects; Ward et al. (2008) addressed four SI aspects; and, Miller and Levine (2010) and Resch (2011) addressed three SI aspects; and, Walpole et al. (2011) addressed two SI aspects. Of the 128 instances of SI aspects, there were three explicit instances and the other 125 were implicit instances (Table 2). The SI aspect explicitly addressed one time in the textbook analysis was *procedures can influence the results* and the other SI aspect explicitly addressed two times was *the same procedures may not get the same results.*

The SI aspects that were most often addressed in the textbooks were *procedures can influence the results* (37 %), *conclusions must be consistent with the data* (30 %), and *procedures are guided by the question asked* (14 %). The less common SI aspects in the textbooks were *investigations all begin with a question* (7 %), *explanations are developed from collected data and what is already known* (6 %), *the same procedures may not get the same results* (3 %), and *scientific data not the same as scientific evidence* (3 %) (Table 2).

5.2.1 Procedures Can Influence the Results

The most common SI aspect in the Mendelian genetics sections in the textbooks analyzed was the influence that inquiry procedures can have on the results. There were instances of this SI aspect in five of the textbooks. Of the 128 instances of SI aspects, 47 (37 %) were instances related to *procedures can influence the results*. Only one of the instances was

Table 2 SI aspects counted in the analysis of the seven textbooks

Textbook	SI Aspects								Total SI Incidences
	SI 1	SI 2	SI 3	SI 4	SI 5	SI 6	SI 7	SI 8	
Glencoe biology (Biggs et al. 2009)	3	0	7	0	9	6	1	3	29
Miller and Levine biology	4	0	4	0	0	9	0	0	17
BSCS biology (Resch 2011)	0	0	0	1	1	1	0	0	3
Holt McDougal biology (Nowicki 2012)	1	0	2	1	10	7	0	3	24
Higher level biology (Ward et al. 2008)	0	0	1	2	2	1	0	0	6
Biology for the IB diploma (Walpole et al. 2011)	0	0	0	0	2	2	0	0	8
Campbell biology (Reece et al. 2012)	1	0	4	0	23	12	3	2	45
TOTAL	9	0	18	4	47	38	4	8	128
Implicit	9	0	18	2	46	38	4	8	125
Explicit	0	0	0	2	1	0	0	0	3

Instances of SI aspects in the 7 textbooks analyzed for this study. The eight aspects of scientific inquiry were SI 1) *investigations all begin with a question*; SI 2) *no single scientific method*; SI 3) *procedures are guided by the question asked*; SI 4) *same procedures may not get the same results*; SI 5) *procedures can influence the results*; SI 6) *conclusions must be consistent with the data*; SI 7) *scientific data are not the same as scientific evidence*; and, SI 8) *explanations are developed from collected data and what is already known* explicit and the remaining 46 instances were implicit. There were instances of this SI aspect in six of the textbooks. The textbooks with the most implicit instances of *procedures can influence the results* were by Reece et al. (2012) with a total of 23 instances, Nowicki (2012) with 10 instances, Biggs et al. (2009) with 9 instances. The other three textbooks had less than three instances of *procedures can influence the results* (Table 2).

The one explicit instance of *procedures can influence the results* focused on how the pea traits Mendel selected to examine influenced his results. The explicit instance was identified in the following excerpt:

> "It was fortunate the Mendel chose these two characteristics for his crosses. Seed color and height are unlinked genes on different chromosomes. Had they been on the same chromosome and linked, the results would have been different" (Walpole et al. 2011, p. 242).

This excerpt explicitly demonstrates how Mendel's decision to examine color and height directly influenced the data he gathered from his investigations. This instance was categorized as explicit because it directly matched our statement about *procedures can influence the results.*

There were implicit instances of *procedures can influence the results* counted in five of the textbooks (Table 2). Implicit instances associated with Mendel's decision to use peas to study inheritance, included:

> Other advantages of using peas are their short generation time and the large number of offspring from each mating. Furthermore, Mendel could strictly control mating between plants (Reece et al. 2012, p. 263); and,
> Mendel was successful in sorting out the mystery of inheritance because of the organism he chose for his study (Biggs et al. 2009, p. 277).

Implicit instances related to Mendel's methods to obtain the appropriate true-breeding peas to conduct his crosses, included:

> To get the seeds he needed, Mendel crossed true-breeding plants that made only round yellow peas with plants that produced only wrinkled green peas (Miller and Levine 2010, p. 269); and,
> He made three key choices about his experiments that played an important role in the development of his laws of inheritance: control over breeding, use of purebred plans, and observation of 'either-or' traits that appeared in only two alternate forms (Nowicki 2012, p. 167).

Lastly, other implicit instances of *procedures can influence the results* associated with Mendel's decision to follow traits for multiple generations, included,

> Mendel usually followed traits for at least the P, F1, and F2 generations. Had Mendel stopped his experiments with the F1 generation, the basic patterns of inheritance would have escaped him (Reece et al. 2012, p. 264); and,
> When he allowed the F1 generation to self-fertilize, Mendel showed that the recessive allele for green seeds had not disappeared but was masked (Biggs et al. 2009, p. 279).

Interestingly enough, these instances are often used in textbooks to indicate Mendel's creativity or ingenuity in uncovering the laws of heredity. Mendel is presented to have carefully designed and prepared his experimental procedures and this is why, textbooks imply, he succeeded where others did not. However, what this actually shows is that Mendel studied a very special case and this is why his results were far from generalizable, and could not for example be obtained in his experiments with *Hieracium* (see Kampourakis 2013). What Mendel actually did by obtaining true breeding varieties is that he almost eliminated all variability in peas, allowing what seemed to be two distinct phenotypes for each of the traits he studied, which nevertheless were the two extremes in a continuum of phenotypes (Jamieson and Radick 2013).

5.2.2 Conclusions Must be Consistent with the Data

The second most common SI aspect in the Mendelian genetics sections in the textbooks analyzed was *conclusions must be consistent with the data* collected. Of the 128 instances of SI aspects, 38 (30 %) were instances related to *conclusions must be consistent with the data*. There were no instances of this SI aspect that were explicit. All seven textbooks had instances of *conclusions must be consistent with the data*. The textbooks with the most implicit instances of this SI aspect were by Reece et al. (2012) with a total of 12 instances, Miller and Levine (2010) with 9 instances, Nowicki (2012) with 7 instances, and Biggs et al. (2009) with 6 instances. The other four textbooks had less than three instances of *conclusions must be consistent with the data* (refer to Table 2).

The implicit instances of *conclusions must be consistent with the data* were associated with descriptions of Mendel's conclusions drawn from his experiments. Even the following two excerpts that used the term "conclusion" were viewed as implicit:

> Mendel concluded that the green-seed form of the trait did not show up in the F1 generation because the yellow-seed form of the trait is dominant and masks the allele for the green-see of the trait (Biggs et al. 2009, p. 279); and,
> Mendel's second conclusion explains why some of the traits seemed to disappear in the offspring (Miller and Levine 2010, p. 263).

The reason these excerpts were considered implicit instances was it is not entirely clear that these conclusions were made using the data Mendel collected in his experiments. Other implicit instances of *conclusions must be consistent with the data,* included,

> Mendel continued to find this approximately 9:3:3:1 phenotypic ratio in the F2 generation, regardless of the combination of traits. From these results he realized that the presence of one trait did not affect the presence of another trait (Nowicki 2012, p. 176); and,
> Mendel's quantitative analysis of the F2 plants from thousands of genetic crosses like these allowed him to deduce two fundamental principles of heredity, which have come to be called the law of segregation and the law of independent assortment (Reece et al. 2012, p. 264).

5.2.3 Procedures are Guided by the Question Asked

The third most common SI aspect in the Mendelian genetics sections in the textbooks analyzed was *procedures are guided by the question asked*. Of the 128 instances of SI aspects, 18 (14 %) were instances related to *procedures are guided by the question asked*. There were no instances of this SI aspect that were explicit. Five of the textbooks had instances of *procedures are guided by the question asked*. The textbooks with the most implicit instances of this SI aspect were by Biggs et al. (2009) with a total of 7 instances and both Miller and Levine (2010) and Reece et al. (2012) had four instances. The other three textbooks had less than three instances of *procedures are guided by the question asked* (Table 2).

The implicit instances of *procedures are guided by the question asked* suggested that there was a question being investigated, however, exactly how the question was used to develop the procedure was often not explained. Implicit instances of this SI aspect that were associated with how Mendel figured out the procedure for cross-pollination, included:

> In order to understand how these traits are inherited, Mendel performed cross pollination by transferring male gametes from the flower of a true-breeding green seed plant to the female organ of a flower from a true breeding yellow-seed plant. To prevent self-fertilization, Mendel removed the male organs from the flower of the yellow-seed plants (Biggs et al. 2009, p. 277); and,

Mendel wanted to learn more about how traits are passed from parent to offspring. So, he used pollen from one stock of plants to fertilize the female parts of flowers from other stocks of plants (Miller and Levine 2010, p. 263).

There were other implicit instances of *procedures are guided by the question asked* that focused on how Mendel figured out how to set up his crosses to understand the inheritance of traits. The following two excerpts demonstrate this use of the SI aspect:

Once Mendel established inheritance patterns of a single trait, he began to examine simultaneous inheritance of two or more traits in the same plant (Biggs et al. 2009, p. 280); and,
Mendel wondered if alleles for one trait affected the alleles for another trait. To find out, Mendel set up a cross that enabled him to study two different genes at the same time (Miller and Levine 2010, p. 269).

5.2.4 Less Common SI Aspects

Investigations begin with a question (7 %), *explanations are developed from collected data and what is already known* (6 %), *same procedures may not get the same results* (3 %), and *scientific data are not the same as scientific evidence* (6 %) were the four SI aspects that were less common in the Mendelian genetics sections in the seven textbooks (Table 2). As mentioned, there were no implicit or explicit instances of scientific *investigations all begin with a question* in any of seven sections. In total, there were 25 instances of the four less common SI aspects counted in the textbook analysis. Two of the instances were explicit and remaining 23 instances were implicit.

The two explicit instances addressed *same procedures may not get the same results.* One of explicit instances was found in the margins of the textbook by Ward et al. (2008). The excerpt stated,

"When examined closely by experts in statistics, some of Gregor Mendel's results seem too good to be true. His numbers do not show the expected variations which are typically found by farmers and researcher when breeding plant. What happened?" (Ward et al. 2008, p. 97).

Another explicit instance of *same procedures may not get the same results* identified in the textbook analysis was identified in the following excerpt:

"Punnett and Bateson, like Mendel, studied dihybrid crosses of pea plants. But their results differed from the 9:3:3:1 phenotype ratios that Mendel observed" (Nowicki 2012, p. 197).

Both of these instances were categorized as explicit because they directly matched our statement about *procedures can influence the results.* The first excerpt explains that even though farmers and other researchers follow the breeding procedures as Mendel did their results tend to be different. Similarly, in the later excerpt, Punnett, Bateson, and Mendel gathered different results on phenotype ratios even though they were making observations of the same type of plant.

Respectively, the following three excerpts were coded with *investigations begin with a question, explanations are developed from collected data and what is already known*, and *scientific data are not the same as scientific evidence*:

Mendel wanted to learn more about how traits are passed from parent to offspring. So, he used pollen from one stock of plants to fertilize the female parts of flowers from other stocks of plants (Miller and Levine 2010, p. 263);
Mendel allowed F1 pea plants with the genotype YyRr to self-fertilize in a dihybrid cross. Mendel calculated the genotypic and phenotypic ratios of the offspring in both the F1 and F2 generations. From these results he developed the law of independent assortment (Biggs et al. 2009, p.280); and,
Many biologists remained skeptical about Mendel's laws until there was sufficient evidence that these principles of heredity had a physical basis in chromosomal behavior (Reece et al. 2012, p. 286).

6 Discussion

In conclusion, the Mendelian genetics sections analyzed in the seven textbooks for this study demonstrated that there are a multitude of opportunities to teach NOS and SI explicitly, although what was included in textbooks was virtually all implicit. Combined there were 365 instances of NOS and SI aspects counted in 140 excerpts from the seven textbooks analyzed for this study. Of the 365 instances, 237 (65 %) were NOS aspects and 128 (35 %) were SI aspects. In addition, to identifying instances of NOS and SI aspects this study categorized the instances as either being explicit or implicit. Of the 365 instances, 362 (99 %) were implicit and three (1.0 %) were explicit. Previous research has reported that explicit instruction is required to effectively teach the NOS and SI aspects (Lederman 2007). An overwhelming number of the instances of NOS and SI were implicitly addressed in the Mendelian genetics sections.

The results from the textbook analysis could be interpreted as either positive or negative with respect to the teaching of NOS and SI. Both the positive and negative perspectives will be discussed. From the negative perspective, in the seven textbooks analyzed there were only three explicit instances in the Mendelian genetics sections. There was not even one NOS aspect that was explicitly addressed in any of these sections. Of the eight SI aspects, the only two aspects explicitly addressed were *procedures can influence the results* and *same procedures may not get the same results*. Textbooks are the primary curriculum resource used in high school science courses (Chiappetta et al. 2006; Weiss et al. 2001; Chiappetta et al. 1991). If the textbook was the only resource used to guide the teachers' instruction on NOS and SI, these results would be a cause for concern in science education. Not only are there few explicit instances, but, there are no explicit instances for any of the seven NOS aspects and for only six of the eight SI aspects.

The 362 implicit instances would not be useful to the development of students' understanding of NOS and SI, based on the prior research on explicit instruction and student learning of NOS and SI (Lederman 2007). Therefore, if the textbook was the only resource of NOS and SI instruction, students' exposure to NOS and SI aspects would be extremely limited and incomplete when learning about Mendelian genetics. From a positive perspective, the results of this study indicate that textbooks are valuable resources of NOS and SI aspects. As mentioned, there were 237 instances of the NOS aspects and 132 instances of the SI aspects. Each of these instances can be viewed as a learning opportunity for teachers to teach NOS and SI aspects. Four of the seven textbooks were found to have more instances of both NOS and SI aspects in their Mendelian genetics sections—*Campbell Biology, Miller & Levine Biology, Glencoe Biology, and Holt McDougal Biology* (refer to Tables 1 and 2). These results suggest that these four textbooks would be the best choices to combine instruction on Mendelian genetics and NOS and SI aspects.

There are many other factors that need to be considered and addressed to expect the implicit instances in the textbooks can be used to explicitly teach the NOS and SI aspects. First, teachers would need to possess knowledge of the NOS and SI aspects. Second, they would need to be able to identify implicit instances of NOS and SI aspects in textbooks. Third, they would need to have the pedagogical content knowledge to effectively and explicitly teach the NOS and SI aspects.

The approaches used to address these factors would be different for in-service and pre-service teachers. For in-service teachers, professional development programs to educate science teachers on the NOS and SI aspects would be the most effective approach to address these factors. These professional development programs would need to demonstrate how to identify both explicit and implicit instances of NOS and SI aspects in textbooks. In addition, they would need to model teaching strategies to explicitly teach NOS and SI aspects to high school students. For pre-service teachers, modifications could be made to teacher education programs to specifically address NOS and SI and instructional approaches to facilitate student understandings. Based on the lack of explicit instances of NOS and SI aspects in textbooks, it can be assumed that textbook developers are not aware of the research on NOS, SI, and explicit instruction. Another plausible reason for the lack of explicit instances in textbooks is that the textbook developers are not interested in stressing NOS and SI. This is clearly the case when the objectives for the chapters are reviewed and there is no mention of the NOS and SI aspects. This highlights the ongoing issue related to the translation of educational research and current visions reflected in reform documents into educational practices. If research on explicit instruction is applied to the development of textbooks, the outcome might be more explicit instances of NOS and SI embedded in textbooks.

7 Misrepresenting the History of Science

The main concern behind all this is that, no matter whether it is intended or not, NOS and SI aspects are portrayed in textbooks. Consequently, attention should be given to ensure that this is done as accurately as possible. Another main concern has to do with the attention that textbook authors pay to details. When it comes to the use of case studies from the history of science, the contribution of expert historians is crucial in order to refrain from constructing or preserving myths. One important problem is that textbook authors do not seem to pay the required attention to the details of history of science and as a result the latter. Unfortunately, this was the case in the textbooks sampled for our analysis. In this section, we will briefly provide some examples and comment on the problems caused by not studying history of science in some detail. We do not aim to provide an exhaustive analysis of these textbooks in terms of how the history of science is misrepresented; we rather show some illustrative examples of this.

Textbooks often refer to Mendel as the father of genetics. For example, in one textbook it is stated that: “The study of genetics which is the science of heredity, began with Mendel, who is regarded as the father of genetics” (Biggs et al. 2009, p. 277). However, this is far from true. Mendel’s 1866 paper became the foundational document of genetics after its “rediscovery” in 1900 and certainly had an influence since then. However, Mendel was not the person who initiated the study of heredity. The publication of the *Origin of Species* (Darwin 1859) placed the study of heredity at the centre of biological thought, as Darwin’s theory of natural selection lacked a complementary theory of heredity which would explain the origin and inheritance of variations. Consequently, Charles Darwin himself, as well as Herbert Spencer, Francis Galton, William Keith Brooks, Carl von Nägeli, August Weismann and Hugo de Vries developed theories of heredity under an evolutionary perspective, having all been influenced by each other in various ways. Mendel was an outsider to this active group, and certainly was not the first to develop such a theory. What is more important is that Mendel may not have intended to study heredity in general but only hybridization in particular, something that has been debated among historians (see Kampourakis 2013 for an overview).

Another myth besides that Mendel was the first to study heredity, was that his important work did not become widely known or was not appreciated by his contemporaries. In one textbook it is stated that: “When Darwin developed his theory of evolution, he did not know how heredity worked. Mendel's studies were published while Darwin was alive. But no-one understood the importance of Mendel's work" (Miller and Levine 2010, p. 406). In another textbook the following statements were made: "Although Mendel sent copies to well-known biologists, his ideas were rejected. […] For the next 35 years, his paper was effectively ignored yet, as scientists later discovered, it contained the entire basis of modern genetics" (Walpole et al. 2011, p. 86). Then the following questions are asked: "(1) Why is the work of some scientists ignored while that of others becomes readily accepted? (2) How important is it for a new theory to be presented in a famous journal or at a well-attended meeting? (3) Do you think Mendel's work was ignored because it was not widely published, or because he was not a well-known scientist, or for some other reason?". Similar statements are included in another textbook, "Is it acceptable that a scientist's new ideas are not adopted just because he or she is not a well-known person with an established reputation? Inversely, should the new ideas of a well-known person scientist be embraced solely because he or she has a solid reputation?" (Ward et al. 2008, p. 98). While it is certainly the case that some scientists may be more influential than others and that their status may matter on how their views are considered, or that where one's work is published may have influence on how widely or not it is read, this is not exactly what happened in Mendel's case. Nägeli, who was indeed the only prominent scientist of that time who became aware in some detail of Mendel's work through a long correspondence from 1866 to 1873, actually referred to Mendel's 1866 paper in 1885 and to Mendel's work on Hieracium in 1891. There also were other references to Mendel's paper before 1900, some of them in books which were widely read by naturalists. In addition, several copies of the Brno Natural Science Society journal in which Mendel's paper was published were sent out to Berlin, Vienna, USA and to Great Britain (the Royal Society and the Linnaean Society) (see Olby 1985; see also Kampourakis 2013 for an overview and further reading). Thus, it was not simply the case that no-one learned about Mendel's work, or that those who read it failed to understand its importance. Rather, the paper may have been not considered of any importance at that time as it focused on hybridization.

Another problem has to do with the description of discontinuous variation in peas. In one textbook, it is mentioned that: "Mendel studied characters that could be classified on an either-or basis, such as purple versus white flower color" (Reece et al. 2012, p. 274). Similarly, in another textbook it is stated that: "And, as Mendel observed, different alleles can produce different phenotypes, such as white flowers or purple flowers" (Nowicki 2012, p.188). This is actually something stated in most textbooks. What is not mentioned here is that Mendel himself was rather responsible for this. In analysis of the work of W.F.R. Weldon, it has been argued that he tried to show that Mendel's "laws" do not actually work even for *Pisum*. Weldon studied inheritance in peas himself and concluded that they could be green or yellow, but that they could also have colors ranging from greenish yellow to yellowish green. Thus, it seems that the classification of characters on an either-or basis does not accurately represent what one can find in nature, which is actually a continuum of colors. Nor would it be reasonable to suggest that one factor or allele produces one particular phenotype. The influence of DNA sequences is more complicated than this on some traits and in some other cases we still do not know which sequences are implicated (Reid and Ross 2011). It seems that Mendel (consciously or not) simplified his studies "looking where the light is better, rather than where the keys are—the keys that unlock the most profound mysteries about inheritance" (Jamieson and Radick 2013). This is a very important point because Mendel is often praised for his experimental methods. We do not mean to undermine his contribution here, but it seems that Mendel tried to make general conclusions by studying a very special case, and not the norm as is usually described in textbooks.

Finally, it is problematic to attribute to Mendel an understanding of meiosis. In a textbook it is mentioned, "Another of Mendel's discoveries was that chromosome pairs separate independently during meiosis" (Resch 2011, p. 636). In fact, Mendel had no idea about chromosomes and meiosis. He could have been able to infer that a process like meiosis could have been taking place, but it was the work of Edouard van Beneden, Oscar Hertwig and August Weismann in the late ninenteenth and that of others during the early twentieth century that clarified these phenomena. This is very important because otherwise Mendel is portrayed as possessing knowledge about chromosomes and meiosis which was unavailable at his time (see Churchill 1970; Hamoir 1992). What actually happened is that once knowledge about this became available Mendel's work was "rediscovered" and was read in that new context and happened to fit nicely into it (Kampourakis 2013). It is one thing what a scientist knew and thought and another what, in hindsight, we may think that he knew and thought. Even in the exemplar case of Charles Darwin, whose extensive writings and correspondence are available and have been studied for the past 40 years by historians, there still are questions about how he developed his theory of evolution by means of natural selection which remain unanswered. Imagine then how difficult it is to make firm conclusions about Mendel by studying his one paper.

In order to use cases from history of science to teach about SI or NOS, one should study history of science in some detail. This does not entail that one should become a professional historian of science, nor necessarily refer to professional journals of the discipline. What one should do though, would be to consult some valid and reliable resources on the history of science. Some general books on history of science are available for this purpose (especially Bowler and Morus 2005; Gribbin 2003; Dear 2007 may also be useful). However, it is best that one refers to more specialized books on history of biology (Mayr 1982; Moore 1993; Sapp 2003; Endersby 2007), or even on the history of specific disciplines (e.g. Olby 1985, 1994; Keller 2000; Kay 2000; Bechtel 2006; Bowler 2009). Of course, working with historians of science would be ideal, but this will not be possible for all science teachers and educators.

Now given how widespread are presentations of Mendel's work in biology textbooks, this could become an exemplar case for explicitly teaching about SI and NOS. In what follows we provide some examples of how Mendel's story could be used to illustrate the NOS aspects already discussed in this article. That Mendel conducted numerous experiments on different characters which yielded particular ratios could be used to illustrate that science has an empirical basis. Or that Mendel observed particular ratios and then performed a mathematical analysis through which he made the inference to the *Faktoren* could be used to illustrate that observation and inference are distinct. Then, by explaining why Mendel's simple model of inheritance is no longer accepted as the norm, it could be illustrated that scientific knowledge is never absolute or certain. Another useful point would be that even if Mendel developed his "laws", he had no theory to explain the patterns he observed, which shows that laws and theories are distinct and not hierarchically related. Mendel performed a statistical analysis of his results and he also studied the phenotypic ratios of various characters separately from others, which can be used to illustrate that science involves imagination and creativity. How Mendel considered his results with *Hieracium*, which yielded different results from those obtained with *Pisum*, can be used to show that scientific knowledge is subjective. Finally, why exactly Mendel's work did not have an impact on the 1860s but had one in the 1900s can be used to show that science is a human enterprise that is practiced in the context of a larger culture.

8 Implications for Research and Practice

Preparing teachers to effectively use existing textbooks will occur much more quickly than making changes to textbooks. This study demonstrates the importance and value for science educators to examine how teachers use the implicit and explicit instances of NOS and SI in textbooks, like those found in the Mendelian genetics sections analyzed here. Understanding how teachers use instances of NOS and SI would provide information that could be immediately implemented into professional development programs. The results of this research would provide textbook developers with compelling information to update the supplemental instruction materials provided to teachers. For example, teachers' margin notes could highlight references to NOS and SI and also provide instructions to guide teachers to explicitly address these important constructs.

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