Introduction

The physicist Richard Feynman is credited with having said, "Philosophy of science is about as useful to scientists as ornithology is to birds". However, the study of the scientific enterprise by outsider philosophers and sociologists of science occasionally yields works of great influence even to scientists themselves (Kuhn, 1970). Indeed, understanding how the enterprise of science operates is considered so important by practicing scientists that inquiry has become a major goal of science education reform (National Research Council, 2005).

Epistemology is a branch of philosophy that concerns itself with what qualifies as knowledge in a discipline and how that knowledge comes into being. For science, epistemology
considers the process by which scientists generate, evaluate, and negotiate the meaning of observations of natural phenomena from biochemical structures to astronomical events. These are creative processes that occur through the lens of existing paradigms in the field and that scientist’s experiences, values, and beliefs. These aspects of science have come to be known in science education as Nature of Science (NOS) (Lederman, 2007). Although the definition of Nature of Science varies, there is wide agreement that scientific knowledge is *durable but subject to change*. Furthermore, scientific knowledge is *empirically-based*, but *subjective* due to interpretation being influenced by current models, in other words *theory-laden*. As a human enterprise it necessarily involves *inference* and *creativity* and is *socially and culturally embedded*. These are aspects of NOS that science students should come to understand implicitly or explicitly as a result of their education.

During a scientist’s education from undergraduate to researcher, s/he comes to understand NOS as a result of immersion in the discipline, first in classrooms and teaching labs and later in authentic research. It is not clear which among a student’s vast set of experiences contribute most to epistemological growth, or how they interact. Even authentic research experiences do not reliably improve NOS understanding (Bell, Blair, Crawford, & Lederman, 2003; Morrison, Raab, & Ingram, 2009) and practicing scientists themselves have diverse views that are not always consistent with target NOS understanding (Schwartz & Lederman, 2008; Wong & Hodson, 2009). Surprisingly, even courses in the History and Philosophy of Science do not reliably improve NOS status (Abd-El-Khalick, 2005), and upper level courses for science majors do not improve NOS status much more than general education science courses (Miller, Montplaisir, Offerdahl, Cheng, & Ketterling, 2010).

Other approaches can be used to teach NOS. Science educators have advocated using stories from the history of science to convey the numerous cultural, personal, and technical variables that come to bear on the development of an idea (Clough, 2010; Tao, 2003). A source of such stories appropriate for undergraduate students is science trade books commercially produced for the general public. Three years ago the first author established an optional book club for students enrolled in her first year biology lecture course. Each spring up to half of the students choose book club as their weekly homework option. The assigned books, *Genome* (Ridley, 1999), *Why We Get Sick* (Nesse & Williams, 1994) and *Good Germs, Bad Germs* (Sachs, 2007), were selected because they relate the major topics of the course, genetics, evolution, and ecology, to human biology and medicine. These narrative expository works can be considered lessons in the history of science because they document the development of thought and paradigms with respect to genes, illness, and microbes, respectively. This genre is distinct from other science nonfiction genres such as reference books, biographies, field guides and how-tos. Although there has been recent attention to the value of adapted primary literature (Ford, 2009), no reports have been found in the literature that evaluate the benefit of including popular science nonfiction in undergraduate science courses.

The book club originally was established to offer an additional enrichment activity to broaden interest in biology and connect biology to medicine. At the outset there was no goal of stimulating or measuring NOS growth. However, anecdotal evidence in the first year of book club suggested a more sophisticated understanding of NOS than the first author expected of freshmen. To document whether growth had indeed occurred, and whether it was related to book club participation, surveys and interviews were conducted and documents were collected the following academic year. The VNOS-C survey was administered to all students at the start and end of the year. Post-course focus group interviews were conducted with
students who had and had not been in book club, using the VNOS-C questions as probes. Learning artifacts such as book club homework and optional exam questions were also considered. Students showed significant growth with respect to NOS status, but book club (BC) students had slightly more informed views than non-BC students. However, students who later participated in book club had a slightly higher NOS status at the start and end of the year than the class as a whole, suggesting that book club attracts, rather than produces, students with higher NOS status. Nonetheless, the improvement in NOS status for both groups was significant, indicating that the sum of their experiences in their first year of our program contribute significantly to their epistemological growth.

Method

Instructional Context

Students in this study were in their first year of an intensive two-year pre-medical program at Weill Cornell Medical College’s branch campus in Qatar. Admission is selective (average Math SAT 682) and heavily dependent on motivation for medicine. Most students use English as a second language but received secondary education in English medium schools using diverse curricula including the AP (Advanced Placement, USA), IB (International Baccalaureate Diploma Programme), A-levels (UK), and national curricula from India, Pakistan, Lebanon, Qatar, and others. Few are products of systems that emphasize inquiry or hands-on investigations. The first author is the sole instructor of both of the required first year biology lecture courses. There is attention to research throughout the course, although there were no specific lessons addressing NOS explicitly.

In addition to three lectures per week, students are required to attend a one-hour review session each week. Two different review sessions are offered, and students are free to choose the one they prefer. One is a traditional review with problem solving and extensions such as case studies and passages from the MCAT (Medical College Admissions Test). The other option is a book/journal club. Other than the associated homework assignments, book club (BC) and non-book club (non-BC) students attended a common lecture and were assessed by common exams. Book club was neither established nor modified for the purpose of this study.

The Book Club

The book club met weekly for one hour to discuss the assigned readings, usually about one-fourth of the book. The books were chosen because they were favorably reviewed works that directly relate biology to medicine. To encourage participation, book club fulfilled the literature requirement for a separate extracurricular certification of research-related activities (ASTER). Book club also was a requirement for eligibility for the grade of A+ in the course. Some stated they initially joined for A+ eligibility and ASTER certification but stayed even when the A+ grade was out of reach. Book club members’ grades were only slightly higher than the class as a whole (3.36 for BC vs 2.97 for non-BC on 4.0 scale, \( p = 0.065 \)). The first author was a participant observer and co-authors were observers. The book club sessions were videotaped but not further considered for this study. Students provided informed consent prior to participating.
The book club first read *Why We Get Sick: The New Science of Darwinian Medicine* (Nesse & Williams 1994) in which the authors argue that it is essential that physicians consider illness and disease from an evolutionary perspective, and this should become an important part of their medical education. Beginning with fever and inflammation, the authors take a fresh look at the adaptive significance of pathogens, injury, blood type, toxins, allergy, and even mental illness. At the time we read this book, the class had not yet studied the mechanisms of natural selection and speciation, however, evolution had been introduced as an overarching theme in the first semester and revisited in nearly every topic studied to that point.

At the same time we were studying genetics, book club read *Genome* (Ridley, 1999), subtitled *Autobiography of a Species in 23 Chapters*. This national bestseller was written when the human genome was first mapped: “by picking one newly discovered gene from each pair of chromosomes and telling its story, Matt Ridley recounts the history of our species and its ancestors from the dawn of life to the brink of future medicine” (cover summary). Beginning with the 5S rRNA gene on chromosome 1, he chose a gene purposefully from each the remaining 22 chromosomes to ponder history, fate, self-interest, and disease via stories as old as the prebiotic soup and as new as epigenetics.

By the time we studied ecology, we were reading *Good Germs, Bad Germs: Health and Survival in a Bacterial World* (Sachs 2007), which “explores our emerging understanding of the symbiotic relationship between the human body and its resident microbes” (cover summary) in its recounting of the history of sanitation, antibiotics and resistance, the human microbiome and the emerging hygiene hypothesis.

**Views of the Nature of Science (VNOS) instrument**

Researchers use a variety of methods to assess the NOS status of a learner, including closed- and open-ended survey instruments and interviews. The *Views of Nature of Science Questionnaire* version C (VNOS-C) is the open-ended instrument used in this study (Appendix A) (N. G. Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The VNOS-C was designed to be used with a follow-up interview to assess NOS status holistically. A newer, stand-alone questionnaire, *The Student Understanding of Science and Scientific Inquiry* (SUSSI) (Liang, et al., 2009) was not available at the time of the pre-course survey. The VNOS-C was administered during scheduled class time as a pre-test to the cohort of entering students (n = 60) in the first week of the academic year (pre-course) and again near the end of the academic year (post-course). Approximately 40 minutes were allowed for completing the survey. All students selected for the focus group interviews completed the VNOS-C at the start of the interview.

No scoring rubric has been published for the VNOS-C, therefore, one was devised for this purpose by adapting a rubric used for the open-ended questions of the SUSSI survey (Miller, et al., 2010). VNOS-C questions do not correspond one-to-one to each of the stated NOS aspects as does the SUSSI. Furthermore, neither the VNOS-C nor the SUSSI elicit all aspects of NOS understanding. For example, no VNOS-C question explicitly prompts the respondent to distinguish observation from inference, therefore, it is unlikely that a student’s response will convey his/her understanding of the inferential aspect of NOS. Likewise, no item specifically asks about the theory-laden nature of science or the myth of the scientific method, although it is possible that a response could provide clues to that learner’s status. Therefore, only the NOS aspects that were specifically elicited by the VNOS-C questions
were scored: empirical NOS, tentative NOS, theories and laws, social/cultural NOS, and creative NOS. However, evidence of status with respect to validity of observational data, inferential NOS, theory-laden NOS and the myth of the scientific method were considered when distinguishing between transitional and informed views. For example, only respondents who specifically mentioned that not all evidence must come from experiments were scored as informed for empirical NOS. Likewise, transitional status was assigned to a respondent who understood the tentative nature of theories but did not explicitly say that change is not necessarily due to technology or that old data are revisited in light of new theories. The criteria for each level and examples from questionnaires are provided in Table 1 and explained further in the Results and Discussion.

In the VNOS-C, a single NOS aspect can be assessed by evaluating more than one item on the questionnaire. Therefore each questionnaire was evaluated holistically for each of these five aspects of NOS. A score of 1, 2 or 3 was assigned for naïve, transitional and informed views, respectively. Overall NOS status was determined as an average of these five scores. Unclassified or blank responses were not scored, and NOS status for these questionnaires was based only on the number of questions receiving a score. Questionnaires with two or more un-scored items were excluded. Evaluations were low-inference; no additional meaning was ascribed to a student’s understanding beyond the words on the page. To minimize bias during scoring, information about book club membership and date of administration was masked in a code and the order of questionnaires was randomized prior to analysis. Focus group participants were selected before blinding to allow purposeful sampling of the interviewees.

Table 1. Rubric for scoring VNOS-C responses with illustrative examples from the questionnaires, modified from (Liang, et al., 2009)

<table>
<thead>
<tr>
<th>Target NOS aspect</th>
<th>Naïve view</th>
<th>Transitional view</th>
<th>Informed view</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Empirical NOS</strong></td>
<td>Science is based only on objective observations that lead to discovery of facts. This can only be arrived at by experimentation. <strong>Science is a way of displaying facts and analyzing them, in contrast to religion and philosophy</strong></td>
<td>Science knowledge is based on observations of natural phenomena directly or indirectly. Ideas are tested with experiments or investigations. <strong>Two scientists may have opposing ideas on how something works. If science did not require the validation of these ideas then any...journals written on the subject matter are not so much advances... as they are personal perspectives.</strong></td>
<td>Science deals with theories, which are explanations of observations in nature. Observations can occur using experimental or naturalistic approaches. <strong>Science...relies heavily on evidence...experiment is a means to prove, justify or simply observe a physical, biological or chemical phenomenon...</strong></td>
</tr>
<tr>
<td><strong>Tentative NOS</strong></td>
<td>Theories do not change unless the original experiment was wrong <strong>They are extremely certain (about textbooks). They use things like spectrophotometers and the properties of elements</strong></td>
<td>Theories can change, for example when new technology becomes available <strong>Science is never complete. Every year thousands of discoveries are made in science and a lot of these updates are crucial to understand the world we live in.</strong></td>
<td>Theories get updated or modified as new information accumulates; it also can change when existing evidence is reinterpreted <strong>...Scientists don’t intend to falsify a theory, but if their findings oppose a certain theory it would have to change. If such a finding was discovered it usually drives the scientist to look at the theory in a different aspect...</strong></td>
</tr>
<tr>
<td><strong>Nature of Theories and Laws</strong></td>
<td>Laws are more certain than theories or theories become laws when proven</td>
<td>Theories are explanations; laws are relationships</td>
<td>Theories are explanations (hows and whys) of observed phenomena whereas laws are statements of</td>
</tr>
</tbody>
</table>
A law was supported a longer time than a theory. Scientific theory is mainly a generalization with some defects that might occur, e.g., theory of evolution. Scientific law is something concrete that is evident and not possible to argue on, e.g., law of gravity. Relationships between them (usually mathematical) observed directly. Laws are accepted as facts and can be expressed in terms of mathematical equations...A theory is more complex and describes a group of related phenomena.

| Social/Cultural NOS | Science is a search for universal truth and fact which is not affected by culture or society. Science is the same everywhere in the world, while religion or philosophies of individuals differs from one individual to the next. Society or culture determines what or how science is conducted or accepted. Science is universal. No matter where you come from, a theory will still be a theory. It’s just the usage and interpretation of these theories varies depending on your background and social norms of your own culture. Society or culture affect how a scientist interprets her/his data, including existing paradigms. -Science is universal—its explanations can be used to explain phenomena across cultures and countries. Science, however, may be slightly affected by these values because they may affect how a scientist thinks, because people are affected by their environment. -...many important discoveries were reached through detaching the mind from the boundaries of following a fixed method... |
| Creative NOS | Scientists do not use creativity because it affects their objectivity. No, they can’t use imagination. Scientists use creativity in designing experiments but not interpreting data, or vice versa. Scientists start their research using their imagination...but this creativity stops whenever the idea is proved wrong, illogical or inapplicable. Scientists use creativity throughout their investigations, including interpretation. Yes, scientists do use creativity and imagination in experiments, I think they have to be creative in all the stages mentioned above...At every step he/she must think outside the box to get somewhere! |

Focus Group Interviews

Near the end of the second semester, two focus group interviews were conducted, one with eight book club members (BC) and the other with eight students who had not participated in book club (non-BC). The class cohort was sampled purposively to compose the focus groups. First, only students for whom pre- and post-course questionnaires could be matched were considered. Among these, two groups of eight were selected that were balanced for gender ratio and for biology grades to that point in the course. The latter measure was taken to validate that any improvements in NOS understanding could be attributed to book club, not simply academic ability. In the end, the average course grade of non-BC students chosen for the focus group was marginally higher than BC focus group students (3.46 vs. 3.17 on 4.0 point scale, p = 0.13).

The selected students were invited by e-mail, and all who were invited participated. The role of book club in the focus group composition was not revealed. The interviewers made no mention of book club in the interviews. The interviews began by explaining that a focus group interview is one in which a question is posed in order to initiate a conversation among the participants. There were no right or wrong answers, and there was no need to come to a consensus. Interview questions were paraphrased from the VNOS-C. A five second-wait time was observed before moving to a new question. Additional questions were posed ad hoc to redirect the conversation or to explore ambiguities. The book club focus group was longer than one hour, however the videotape ended before the final question about creativity was discussed (Table 4). Focus group interviews were videotaped then imported, transcribed and
coded using NVivo 8 software (QSR International). Transcripts were initially parsed/coded by NOS aspect: empirical, inferential, tentative, creative, social/cultural, theory-laden, myth of scientific method, nature of theories and laws vs. theories, with the addition of categories as novel examples or exceptions, were noted.

**Statistical Analysis**

Variables were summarized using means and standard deviations. Differences between the pre and post scores for the total sample were assessed using the independent t-test and for the focus group sample using the Wilcoxon rank sum test after computing the differences between pre and post as these data were linked by student names. Post score comparisons between all students in the book club and those who did not participate in the book club were made using the independent t-test. A p-value of 0.05 or less was declared significant. All analyses were done using IBM-SPSS.

**Document Analysis**

Homework assignments and exam essay questions by BC students were included in the analysis. The weekly assignment for book club participants was to complete a reflective journal entry about that week’s readings; particular attention was paid to sections in which students identified at least three new insights you had while reading this section and at least three passages or ideas that are still confusing to you or new questions that emerged as a result of this reading. On each exam students answered one of three essay questions, of which one was about the book club, for example, *Using three relevant examples presented in Ridley’s Genome, discuss several insights you had about the human genome or insights about science in general, and relate them to your understanding of genetics prior to reading the book.* Approximately 50 graded homework assignments and eleven exam essay responses were analyzed post facto for evidence of understanding of NOS using criteria in the rubric (Table 1). Neither task was designed to assess NOS status, as most of their responses discussed biology, not NOS. Nonetheless, some comments were identified as being indicative of NOS status.

**Validation Measures**

Although the first author’s role in the course and the book club could be a source of bias, all reasonable post facto measures were taken to minimize that possibility. Her pedagogical content knowledge from over 25 years as a science faculty member with an education specialty may have influenced some interpretation and drew attention to NOS during instruction. Masking, randomization, and scoring by a single evaluator provided a measure of internal validity that allowed comparisons within this population, but scores generated here cannot be compared to other groups or by other evaluators. Findings based on numerical scores were triangulated by qualitative data from interviews and document analysis.

**Human Subjects**

This project was granted exemption from oversight by the Institutional Review Board of the Weill Cornell Medical College in Qatar. Students were allowed to exclude their homework and exams from consideration for research purposes but none did so.
Results and Discussion

Questionnaires, interviews, and documents provided qualitative evidence of NOS status for book club and non-book club students at the beginning and end of the academic year. Open-ended responses were evaluated and scored to determine whether book club participation improved NOS status. These scores were compared several ways. First, comparison of pre-course and post-course NOS scores for the entire class showed a significant difference from the beginning to the end of the academic year ($p < 0.001$), indicating that NOS understanding improved for the class as a whole in their first year of our pre-medical program. Since pre-course and post-course questionnaires could not be matched except for those students in the focus groups, it cannot be claimed that each and every student’s NOS status improved. Although there was overall improvement, the NOS scores of BC participants at the end of the year did not differ significantly from non-BC students (2.00 vs 1.89, $p = 0.32$).

Most students included their names on the pre-course questionnaire, allowing us to identify questionnaires completed by students who eventually participated in book club. When the BC students’ pre-course questionnaires were compared to those of non-BC students, NOS status of future BC students was marginally higher even before book club began (1.68 vs 1.55, $p = 0.11$), and their improvement from pre- to post- was not significantly different than the improvement shown by non-BC students (0.29 vs. 0.40, $p = 0.32$). Therefore students who were attracted to book club were already at a slightly higher NOS status at the start of the course. These data show that book club alone is not likely to be the main reason for the improvement. Rather, the entire set of first-year experiences, including attention to NOS in the biology course and to critical reasoning in the first-year writing seminar, seem to contribute to NOS growth. To assess whether the higher NOS status of BC students could be attributed to higher academic ability, final grades in the biology course were compared. Book club members’ grades were only slightly higher than the class as a whole (3.36 for BC vs 2.97 for non-BC on 4.0 scale, $p = 0.065$). However, the opposite was the case for students in the focus groups (3.17 for BC vs. 3.46 for non-BC on 4.0 point scale, $p = 0.13$), yet the NOS results were very similar to those for the class as a whole. Therefore we consider any difference in overall academic ability to be less of a factor in the pre and post- difference than other variables that were not examined here, such as high school curriculum. Post-course questionnaires completed as part of the focus group interviews (BC and non-BC) had higher NOS scores than those collected outside the focus groups, which may reflect a more authentic engagement with the task by interviewees than by students who would not be asked to discuss their responses afterward.
Table 2. Pre- and post-course NOS scores of BC and non-BC students.

<table>
<thead>
<tr>
<th></th>
<th>All students</th>
<th>pre</th>
<th>post</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>book club</td>
<td>1.68</td>
<td>2.00</td>
<td></td>
<td>0.01*</td>
</tr>
<tr>
<td>non book club</td>
<td>1.55</td>
<td>1.89</td>
<td></td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>p-value</td>
<td>0.11</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Pre- and post-course VNOS-C scores of all BC and non-BC students.

Table 3. Pre- and post-course NOS scores of eight BC and eight non-BC students who participated in focus groups.

<table>
<thead>
<tr>
<th>Focus Groups</th>
<th>pre</th>
<th>post</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Book Club</td>
<td>1.72</td>
<td>2.28</td>
<td>0.008*</td>
</tr>
<tr>
<td>Non Book Club</td>
<td>1.49</td>
<td>2.01</td>
<td>0.005*</td>
</tr>
<tr>
<td>p-value</td>
<td>0.20</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2: Pre- and post-course VNOS-C scores of eight BC and eight non-BC students who participated in focus group interviews.

NOS Aspects

Final NOS scores are averages of scores for each of the five different NOS aspects measured: empirical NOS, tentative NOS, theories and laws, social/cultural NOS, and creative NOS. BC students scored higher than non-BC students with respect to understanding of the empirical NOS, tentative NOS, social/cultural NOS, and creative NOS (Figure 3). Non-BC students as a group scored higher only on the distinction between theories and laws in the pre-course questionnaire (Figure 3). There was improvement from pre-course to post-course on all aspects of NOS regardless of book club participation. Of the five aspects of NOS assessed on the questionnaires, all students seemed most informed about the creative aspect of NOS. This was triangulated by independent comments such as this made in the non-BC focus group:

Interviewer: You’re allowed to be creative when you’re interpreting the results?
Student: You have to be, that’s how your mind works, creativity, you can’t just like [turn it off]. It’s not an exact process, that’s why people have different views of the same things.

Students also understood the empirical nature of science, but few were scored as informed. Most cited the importance of evidence to back up claims and said that experiments are necessary. But very few went beyond the question before them to state that qualitative observations are as valid as quantitative data generated by experiments. These responses were scored as transitional. The distinction between observational and experimental data was addressed early in the year when introducing students to the range of inquiry in biology, including inductive, discovery-based approaches and deductive, hypothesis-based approaches. However, it was not possible to rule out the possibility that students conflated experiment in question 2 with investigation. This claim is supported by questions posed during the BC focus group interview: I was just wondering, when you make observations, like when you’re seeing stuff, is it an experiment? Another asked is a study considered an experiment? While another concluded So studies and experiments are the same thing. Therefore the scores may underestimate the students’ understanding of the empirical aspect of NOS.
With respect to tentative NOS, nearly all students responded that theories do change over time. Responses stating that theories only change when proven wrong were scored as naïve. Most who said that theories do not change said that a record or memory of the theory would not cease to exist even after a better theory became favored. This interpretation was scored as transitional rather than naïve. A response was scored as naïve if they said in question 2 that theories change but contradicted that in questions 5 and 6 by saying that scientists are very certain of information of textbooks. In both focus groups the response to the question was quick and unanimous. When asked about whether scientists are certain about information in textbooks, the reply was that they were as certain as can be: *it’s the best they’ve got at the time*. One BC focus group participant mentioned information in the textbook about changes from the sandwich model to the fluid mosaic model of the cell membrane; another commented about additions of information to each new edition, such as about aquaporin protein channels we had studied in class. None mentioned examples from the book club readings. Responses that cited technology as the main reason for changes to theories were scored as transitional. In response to such a view expressed in the BC focus group, a student with a more informed view said:

A lot of times it’s not technology, it could be things like culture because a lot of things, like you said in lecture, a lot of the greatest achievements ever were as plain as the noses on our faces, it just took someone to point it out.

The few responses that specifically mentioned reviewing old data in light of new theories were also scored as informed, for example:

…Scientists don’t intend to falsify a theory, but if their findings oppose a certain theory it would have to change. If such a finding was discovered it usually drives the scientist to look at the theory in a different aspect…(emphasis added)

In the biology course there was significant attention paid to how we know what we know, from the explication of classical experiments to exposure to research news at the start of every lecture. This may explain why book club could not be isolated as a cause of NOS improvement, but that together, lecture and book club may have contributed to students’ understanding of the tentative and social/cultural nature of science more than the other aspects. Biology lecture also contributed to an understanding of the role of consensus in building models. For example, in response to VNOS-C question 6 about the definition of a species, several students wrote that scientists are very certain about it because they invented the definition themselves, suggesting an informed understanding that species is a human construct. Species concepts had been discussed in the lectures about new views of classification. Understanding of social/cultural NOS was also enhanced in other courses, such as the First-year Writing Seminar in which epistemology, the nature of objectivity and theoretical lenses are discussed. In response to VNOS-C question 7 about dinosaurs, one student in the BC focus group recognized a parallel with literature and the role of personal experience and agenda in data interpretation.

Whatever the scientist uses, they have their own interpretations and sometimes they put their own kind of personal agenda. And they’ll look at the data in a way to support what they think happened, and another scientist will interpret in a different way…Science becomes a lot like literature, like it’s how you interpret the data. Like we could all read the same book or the same poem and we would all see it in different ways according to what we want to see. (BC focus group)
Others recognized the impossibility of complete objectivity.

It’s not intentional to factor in social or…, like intentionally factor those into your model. It just happens…People can’t be completely objective ever because you always have the element of their upbringing…(BC focus group)

How our mind processes information and gives us an outlook, it depends on past experience. It can’t just be based on the data. Even if you think it’s just based on the data, unconsciously we are influenced by our past experience, which includes social, cultural…(Non-BC focus group)

One BC student recognized the theory-laden aspect of science, another feature of the social/cultural NOS. This was the only comment made in any interview that cited an example from book club:

I think to some extent we can have social construction in science. In book club we did the part where for a long time they thought we had 24 chromosomes, and people kept seeing 24 just because one person said 24, even though more people conducted experiments they kept believing 24. So there was social construction there and they were just following previous scientists… (BC focus group)

In interviews and questionnaires, many responses about social and cultural influences were about government policy and business decisions regarding research grants or drug development for tuberculosis, for example. Responses that did not connect how these influence theories were scored as transitional. Recalling an example from that day’s research report in class, one BC focus group student commented that public naïveté about the meaning of scientific findings exacerbates this influence:

I believe that experiments are not [socially or culturally influenced], like once the results get released I think there is pressure, like public pressure. Like what you said this morning, when scientists for example say ‘this is what the data supports’, and politicians say, ‘but it’s not proven.’ I guess that it’s kind of like there is this little gap between the way scientists think and the way the public thinks…(BC focus group)

Most comments in the VNOS-C about the social/cultural aspect of NOS, however, were about religious influence. The majority of students in our program are Muslim, and many VNOS responses cited religious influence on cloning, stem cell research, and/or beliefs in evolution. Several of these responses conveyed optimism by saying that the objectivity of science is a welcome improvement over past religious influence in the practice of science. Such responses were scored as transitional with respect to the social/cultural NOS.

The lowest score for both groups at the beginning and end of the year was the distinction between theories and laws. However, there was not a separate VNOS-C item that asked explicitly for the definition of a theory, only to distinguish theories from laws. This question was left blank more often than others in the VNOS-C. Although most correctly described theories as current best explanations, most thought laws could not change, and very few students were able to explicitly state what a scientific law is. Transitional status was assigned to responses mentioning mathematics or relationships or observations, but very few responses were considered informed. As reported in the literature, the common response in both focus groups and in questionnaires was that theories that are proven true become laws over time. In
both focus groups, the immediate response was similar to this conception, but this was followed by doubt and debate. Long pauses and a questioning tone suggested they had not been asked to consider the distinction before. In the BC focus group, one student gave evidence of an informed view: *Laws are just observations, and theories are explanations of those observations.* This student was a lone voice among the BC focus group until another student agreed, saying *I think laws are observations,* and another followed with *Laws are actually an attempt to understand nature. Someone makes a law to make it easier to understand the natural phenomenon going on.* There was less progress in the non-BC focus group: *A law is more proven, has more basis behind it, but a theory is just accepted but it may not have solid evidence behind it.* Some responses mentioned facts as a rationale for accepting a law. Although *facts* can be defined as empirical observations, it was not assumed that the respondent used the word in this way. Special attention was given in the course to the nature of theories but the nature of scientific laws was not discussed in either the course or the book club. Therefore it was not surprising that the low score did not improve much over the year. This is also evidence that studying numerous laws in their first-year chemistry and physics courses did not clarify this distinction either. The naïve view was also found to be widespread in other undergraduate students (Miller, et al., 2010) and scientists (Wong & Hodson, 2009), which begs the question of whether this goal is an important one for being successful in science.

![Aspects of NOS](image)

**Figure 3.** Pre- and post-course scores of BC and non-BC student with respect to five aspects of NOS: Emp = empirical, Tent = tentative, Laws = theories vs laws, Cult = social/cultural influences, Cre = creative
Table 3. Comparison of BC and NonBC focus group comments closest to target

<table>
<thead>
<tr>
<th>VNOS-C Question</th>
<th>BC Focus Group</th>
<th>Non BC Focus Group</th>
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| Empirical/validity of non-experimental approach | Is a study considered an experiment?  
No an experiment you have to change something  
What’s the difference between a study and an experiment? Can an experiment be a study?  
It can be part of study  
I: Is an experiment the only way to gain scientific knowledge?  
It’s the only way to prove it  
If a study and experiment are different, then no, but if they’re the same thing, then yes.  
Manipulate or work off of already (existing data), how nature manipulates the variable, then you will just (use) opportunistic sampling or something (natural experiment) | But an experiment can also be an observation, it doesn’t necessarily have to be a controlled environment  
An experiment might use observable data so we should go to nature and see that or to see the cell in the microscope  
Yeah like in the butterfly, was it the monarch butterflies? The one with the trees, that wasn’t experiments, that was from observations... look at different environments, he didn’t change anything.  
Some observations, you don’t need to do actual experiments, you just observe and interpret what you observe  
Actually she is right, that was not an observation. If it’s observational then just look at the environment the way it is, you can’t change anything |
| Tentative | I think when something is revised it’s not wrong. Even when publishing, the scientific community accepts it and even if it turns out to be wrong I don’t think they label it wrong. They label it, like he said, the best they had at the time. They wouldn’t say it’s like completely wrong. | But you have some theory that some accept it. You can have it for some time then someone does a new experiment and realize it’s wrong  
I: Do theories every change?  
Several: Definitely |
| Theories and Laws | Laws are just the observations and theories are the explanations of those observations  
I think laws are observations  
Laws are actually an attempt to understand nature. Someone makes a law to make it easier to understand the natural phenomenon that is going on  
I thought laws are looking at quantitative, I think if we could just plug in numbers and test whether we are right or wrong. And theories are more qualitative, speculations, you make models | I: Once a theory becomes very accepted is it still a theory?  
No it’s a law (quickly, but then smiles doubtfully and says) It goes hypothesis to theory to law to…right?  
A law is more proven, has more basis behind it, but a theory is just accepted but it may not have solid evidence behind it |
| Social/Cultural | 65 million years ago is so long ago that the data is not as precise as some data that we have from two years ago so that way it’s kind of wrong and whatever the scientist uses they have their own interpretations | How our mind processes information and gives us an outlook, it depends on past experience. It can’t just be based on the data. Even if you think it’s just based on the data, unconsciously we are influenced |
and sometimes they put their own kind of personal agenda and they’ll look at the data in a way to support what they think happened, and another scientist will interpret it in a different way.

Science becomes a lot like literature like it’s how you interpret the data. Like we could all read the same book or the same poem and we would all see it in different ways according to what we want to see by our past experience, which includes culture, social.

For example if you have two different scientists in two different societies, one of them like compares bacteria to like humans, finds a really close relationship. If his religion allows him he can say that this originated from this. For example the other one he knows in his religion it says that God created this and God created this, so he would say they originated differently. They’re similar but they didn’t evolve one into the other.

I: What about something non religious?

Culture can also affect science, for example you are doing research about drugs, you would study drugs … more related to your country (national priorities, policy).

Focus group interviews made it possible to explore nuances of NOS understanding that were not explicitly elicited by the VNOS-C. Although the VNOS differences between BC and non-BC were not statistically significant, the conversations in the focus groups were starkly different. The level of questioning and debate and the sophistication of examples were greater in the book club focus group, particularly when seeking clarification about the definition of experiment and law. Comments closest to the target understanding in the BC and Non-BC focus groups are summarized side-by-side for the purpose of comparison (Table 3).

Some NOS views in the literature were not observed in either the VNOS or the focus groups. For example, other studies suggest that the myth of the scientific method is common (Abd-El-Khalick, 2004). However, there was no mention in the focus groups and only one mention in 150 questionnaires of a stepwise approach to science from hypothesis to conclusion. Therefore this myth either was not elicited by the survey or it is not a significant barrier to understanding NOS in this population. Likewise, no explicit observations suggested that students could not distinguish observation from inference (inferential NOS).

Neither the book club homework option nor the exam essay question directly prompted consideration of any aspect of NOS, therefore these data from BC students are taken as evidence of informed NOS views that are implicit rather than explicit (Table 4). There are no comparable documents to compare with non-BC students. These qualitative data suggest that reading and discussing science non-fiction trade books may hold value as a curricular adjunct even if the effect of book club participation could not be measured against the background effects of a program that attends to epistemology across the curriculum. It is fortunate that an improvement was measured at all, given that there has been little change observed in college students in other studies (Abd-El-Khalick & Lederman, 2000; Miller, et al., 2010).

A comparison of these data with responses cited from upper level students enrolled in a History of Science course (Abd-El-Khalick, 2004) showed similar strengths and weaknesses. There was widespread recognition that science knowledge is based on evidence, unlike other

*Evidence of creative NOS was not for BC focus group therefore not compared with non-BC here.
disciplines, but also that science requires experiments. As in the other study, some undergraduates continue to use prove, right and wrong when referring to validity of ideas. They also held naïve views that laws are stronger theories. Students in this study likewise cite technology as the reason theories change. However, one area in which our students were more informed was that they were aware that theories are best current explanations, not opinions. Based solely on these comparisons, we assert that these pre-medical students’ NOS understanding is as informed as that of upperclassmen and graduate students interviewed in that study. In summary, as a group, these pre-medical students showed epistemological growth during their first year in the pre-medical program regardless of book club participation. This may be due to a variety of features of our program, including attention to NOS in the biology lecture course itself and/or to epistemology in the First-year Writing Seminar. It would be difficult to predict whether these findings could be replicated in other settings given the size and life science orientation of our program.

Even in a program with a very focused curricular goal, narrow admissions criteria, and a regional student body, there is considerable heterogeneity among our students with respect to academic propensities for extracurricular academic activities such as creative writing, debate, lab research and even attraction to book club. Book club was initially offered to extend the learning opportunities for high achieving students without imposing additional burden in a compressed curriculum. However, because of the insightful and engaging presentation of the ideas in these three books, even academically at-risk students continued to participate even after they had the opportunity to change. Several said that book club showed them that the genre is accessible even to novice science students, more accessible than primary literature, but a satisfying alternative to popular fiction. Book club also introduced a new genre of literature to students who said they didn’t know it existed and would never have picked up such a book to read for pleasure. It is hoped that along with discovering a new pastime, these future doctors will retain what they learned about the biology of medicine and the nature of science.
<table>
<thead>
<tr>
<th>Quote</th>
<th>Source</th>
<th>Significance/NOS aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>…the notion of the genome as a battlefield between two powers: parental and childhood genes, has greatly affected the philosophical foundations of biology. (regarding genetic imprinting)</td>
<td>Insight in homework about Genome</td>
<td>Nature of theories: how knowledge accretes to generate new big ideas</td>
</tr>
<tr>
<td>…Maybe the use of hand sanitizers in our daily lives is not such a good idea. After all we are robbing skin of a vat of bacteria that could be performing some unknown function we are unaware of?...</td>
<td>Insight in homework about Good Germs, Bad Germs</td>
<td>Tentative NOS. Even health practices can change as theories change</td>
</tr>
<tr>
<td>…Ridley also discussed the history of eugenics. Prior to reading this book, not only did I have no knowledge of many 20th century European [practices], I also had a very limited perspective pertaining to it...Ridley showed me the errors of my ways. Eugenicism can take a more integrated and disguised form in society than one would think. In the early 1900s many Europeans were prevented from the right to reproduce, based on genetic prejudice. According to some, their bad genes were plaguing society...</td>
<td>Exam response, regarding Genome</td>
<td>Theory-laden and social/cultural NOS</td>
</tr>
<tr>
<td>(same student)...Although Ridley did not so much as take a position based on irrefutable evidence, I realized that maybe he couldn’t. That maybe science is limited and people have different ways of interpreting the world so maybe they use different branches of science as well....</td>
<td>Inspection in homework about Genome</td>
<td>Inferential NOS</td>
</tr>
<tr>
<td>…There are so many aspects of science in which it is sometimes difficult to differentiate between cause and effect...</td>
<td>Inspection in homework about Genome</td>
<td>Empirical, inferential, social/cultural aspect of NOS</td>
</tr>
<tr>
<td>…Most importantly, the book taught me that after all it doesn’t matter if we believe that evolution is true or not, but we must acknowledge the fact that many aspects of sickness and medicine make much more sense in the light of evolution.</td>
<td>Inspection in homework about Why We Get Sick</td>
<td>Tentative NOS: hypotheses, even naïve ones, have value</td>
</tr>
<tr>
<td>I like Thomas Huxley’s quote about how error is better than being vague in the chapter about allergies. It is better to speculate than to completely ignore something and I think it is an interesting and productive way of thinking.</td>
<td>Inspection in homework about Why We Get Sick</td>
<td>Tentative NOS: recognizing a medical idea in transition</td>
</tr>
<tr>
<td>(elsewhere in same homework) Do people with allergies have an immunological advantage? Does this mean that there is a misconception that allergies are a sign of a weak immune system?</td>
<td>Inspection in homework about Why We Get Sick</td>
<td>Tentative NOS: spotting an outdated view by the authors and wondering which current views could change in the future</td>
</tr>
</tbody>
</table>
"All truth passes through three stages: First, it is ridiculed; Second, it is violently opposed; Third, it is accepted as self-evident." Arthur Schopenhauer

Cited by several students as a favorite quote opening a chapter of Genome

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References


Appendix: VNOS-C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment? Does the development of scientific knowledge require experiments? If yes, explain why. Give an example to defend your position. If no, explain why. Give an example to defend your position.

3. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? If you believe that scientific theories do not change, explain why. Defend your answer with examples.

If you believe that scientific theories do change: (a) Explain why theories change; (b) Explain why we bother to learn scientific theories. Defend your answer with examples.

4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
5. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

6. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?

7. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

8. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

   If you believe that science reflects social and cultural values, explain why. Defend your answer with examples. If you believe that science is universal, explain why. Defend your answer with examples.

9. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations? If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate. If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.