Introducing Taiwanese undergraduate students to the nature of science through Nobel Prize stories

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Although there is a broad agreement among scientists and science educators that students should not only learn science, but also acquire some sense of its nature, it has been reported that undergraduate students possess an inadequate grasp of the nature of science (NOS). The study presented here examined the potential and effectiveness of Nobel Prize stories as a vehicle for teaching NOS. For this purpose, a 36-hour course, “Albert Einstein’s Nobel Prize and the Nature of Science,” was developed and conducted in Taiwan Normal University. Ten undergraduate physics students participated in the course. Analysis of the Views of Nature of Science questionnaires completed by the students before and after the course, as well as the students’ own presentations of Nobel Prize stories (with an emphasis on how NOS characteristics are reflected in the story), showed that the students who participated in the course enriched their views concerning all aspects of NOS. The paper concludes with some suggestions for applying the novel idea of using Nobel Prize stories in physics classrooms.

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I. INTRODUCTION

The following paragraph is an excerpt from the essay that all of the students participating in the course “Albert Einstein’s Nobel Prize and the Nature of Science” were asked to write. The writer is an undergraduate physics student in the Taiwan Normal University, and is not a native English speaker.

What is the nature of science? I have no idea about it before I take this course. In Taiwan students are trained to be a test machine, learning is merely a process to get a good salary. School teachers never tell students about science (nature of science), “Because this kind of problem never exist in tests. And we are running out of time finishing chapter 6.” This kind of answer can never be too common in elementary school when children ask about the nature of science. Even in university or graduate courses, professors still don’t think that nature of science is more important than reports or papers. Before taking this course, science is fairly unfamiliar to me. Though I major in physics, if someone on the street suddenly asks me what physics is, I will probably run away with a blush. If I must define “science,” I can only say that it is full of calculation, formulas and experiment. And I believe that most people in Taiwan share the same concept with me.

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A. What is the nature of science?

The nature of science (NOS) is often defined in terms of the values and assumptions inherent to scientific knowledge [1]. Although there is no specific definition for NOS [2], there are some characteristics of scientific knowledge that are “widely accepted either in the science standards documents and/or in the philosophy, history and sociology of science and science education literature,” and are therefore “the least controversial aspects of the nature of science” [3]. This is what Irzik and Nola [3] call the consensus approach to the teaching of NOS.

The consensus approach contains the following characteristics of science [1–4]:

- (1) *Scientific knowledge is empirical.* Science, by definition, is limited to naturalistic methods and explanations relying on observations and experiments, and as such it is precluded from using supernatural elements to generate knowledge.
- (2) *There is a distinction between observation and inference.* Science is based on both observation and inference. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations.
- (3) *There is a distinction between laws and theories.* Laws, which are used to express what has been observed and to predict what has not yet been observed, describe relationships, observed or perceived, of phenomena in nature. A theory is defined as an inferred explanation of natural phenomena and associated laws, and of mechanisms for relationships among natural phenomena. Scientists create theories and laws to interpret and describe phenomena. Theories and laws do not progress into

one another, in the hierarchical sense, for they are distinctly and functionally different types of scientific knowledge. They both have substantial supporting evidence, and one does not become the other.

- (4) *Scientific knowledge is reliable but tentative.* On the one hand, scientific knowledge is durable and not easily changed. On the other hand, all scientific knowledge is liable to change in response to new observations and reinterpretations of existing observations. Thus scientific knowledge is never absolute or certain.
- (5) *Scientific knowledge is partly the product of human inference, imagination, and creativity.* Scientific knowledge is a product of the human imagination and of logical reasoning. Typically, as mentioned above, science students are presented with summaries of results lifted out of their context. It is therefore not surprising that students often believe that scientific knowledge is not developed by scientists through a creative and inventive process, but is rather discovered by an accepted “algorithmic scientific method.” Alternatively, they may be “apparently influenced by a classic but erroneous notion that many discoveries occur by accident, a notion heralded in the media and by popular writers of the history of science” (see Ref. [4], p. 566).
- (6) *Scientific knowledge is socially and culturally embedded.* Though contributions to science can and have been made by people the world over, the questions asked, observations made, and conclusions drawn are all influenced to some extent by the locally prevailing state of scientific knowledge, the social and cultural context of the researcher, and the observer’s experiences and expectations.
- (7) *Scientific knowledge is theory laden and subjective.* Observations as well as inferences may be affected by the scientists’ anticipation, beliefs, experiences, and biases.

B. Acquiring an understanding of NOS: Importance and obstacles

For the most part, scientists, science educators, and science education organizations agree that students should not only learn science, but also acquire some sense of these noncontroversial characteristics [2,5–7]. Ryder and Leach [8] provide two main reasons why the development of an adequate understanding of NOS is useful for university science students: first, the development of students’ scientific concepts is dependent on their views on the nature of scientific knowledge; second, an appropriate understanding of NOS will allow students to make more informed decisions on science-based issues in their daily lives.

Despite the importance of NOS at the university level, most of the studies carried out on the understanding of NOS have been aimed at high school and elementary

school teachers and students. Studies on the undergraduate level have been undertaken to a much lesser extent [9]. These studies generally found that undergraduate students, like high school students, lack a broad and deep understanding of NOS [9,10].

According to Ryder and Leach [11], science students acquire scientific knowledge from a variety of sources, such as science magazines and documentaries, formal teaching, or discussions on scientific issues, with the result that views displayed on NOS are often inconsistent and might be dependent on the scientific context under discussion. In addition, undergraduate science students often view science as an objective endeavor, rather than as an action that takes place within a social and cultural context and can be influenced by it [12]. The scientific enterprise is thus regarded as a quest for “truth” and the purpose of the “scientific method” is to prove a hypothesis to be correct. In this context, the process of experimental observation becomes a simple straightforward matter and does not involve human input such as imagination, creativity, and theoretical background. Dagher *et al.* [13] found that, at the beginning of an undergraduate astronomy course, most of the North American undergraduates in their sample regarded scientific theory as a tentative form of explanation for an idea with only some evidence to support it, rather than as a well-founded explanation of phenomena based on rigorous experimentation.

Ibrahim *et al.* working specifically on conceptions of NOS among first year undergraduate physics students, [9] divided their sample into the following four student NOS profiles, which accommodated 86% of their respondents’ views on NOS. They labeled the first group “modelers” (44% of the students in their sample). These held the most appropriate views of NOS, as defined by Lederman [1]. Next were the experimenters (16% of the students), who believe that scientists should strictly use the scientific method, and not their creativity, when doing experiments, and that the results of these rigorous experiments take precedence over theories. The examiners (19% of the students) were those who were convinced that the laws of nature, which are out there to be discovered, are fixed and stable, and that experimental work is essential but not informed by hypotheses or theories and that the results of experiments take precedence over theories. Finally, discoverers (14% of the students) were those who believed that only experiments using the scientific method can be used to discover the laws of nature. They further believed that if experimental data conflict with a previously established theory, then both the theory and the experimental data need to be checked.

The results of Ibrahim *et al.* show that more than half of the physics students participating in this study lacked deep understanding of NOS. We agree with their conclusion that undergraduate physics students should be provided with opportunities to actively consider their views of NOS [9].

Our study therefore examines changes in the views of NOS among Taiwanese undergraduate physics students who participated in a course developed especially for this purpose.

The educational standards in Taiwan advocate that students in schools learn about NOS. In practice, however, NOS is seldom taught in Taiwan's science classes. It seems that the high pressure on teachers to prepare their students for exams focuses all of their efforts on teaching only those subjects relevant to the exam, leaving out the topics that tests regard as "unimportant." This was well expressed by all of the students in this study, who said in their interviews that they had never learned about NOS—neither in school nor at the university (see also the quote at the beginning of the introduction).

The course that was developed for the purpose of this study was based on Eshach's [14] suggestion that NOS could be taught through the histories of Nobel Prize laureates in science. This study takes the theoretical suggestion from Eshach [14], which had not yet been tested in the classroom, and attempts to put it into practice. Gaining insights on how to apply the teaching approach suggested here could make a significant contribution to facilitating the task of teachers, curriculum developers, and textbook writers who are endeavoring to incorporate NOS into the teaching of physics.

C. Teaching NOS via Nobel Prize stories

1. Nobel Prize stories bring narratives to the physics class

Klassen [15] argues that "The only way to interest young students in science is to portray it differently—more realistically from the human and contextual perspective" (p. 56). One way to do this, according to the author, is teaching science through a story. A story is a sequence of events ordered chronologically that describes actions involving characters and includes a plot, which adds a causal or internal element relating the incidents of the story. Klassen [15] argues that "although people naturally use their imaginations and are attracted to good stories and historical accounts, these essential qualities of thought are the very ones that tend to be absent in the study of science and also in science education" (p. 1). Eshach [14] further adds that teaching through the medium of stories implements case-based teaching principles. According to Eshach and Bitterman [16], case-based teaching makes use of case-based reasoning, which is a thought pattern natural to humans [17,18].

2. Nobel Prize stories bring history to the physics class

To learn through Nobel Prizes is to learn the history of science (HOS). It takes the learner back to the time before and after the discoveries that Nobel Prizes recognize, revealing the sometimes wayward path to recognition that they took. Discussing these paths exposes students to

the debates, disagreements, and/or difficulties that accompany the acceptance of new theories. It shows the students that scientific theories are not certain, but are subject to change in light of new evidence or the new interpretation of old evidence. Students may also be brought to realize that facts do not necessarily accumulate linearly, and that some discoveries are genuinely revolutionary, completely changing our way of thinking about how nature works. Many science education researchers hold the view that one of the potential benefits of teaching HOS is that it promotes comprehension of NOS [19–26].

Scientific knowledge is partly the product of human inference, imagination, and creativity. The Nobel Prize stories should help students realize that science—as Einstein [27] himself stated—is no mere collection of laws or catalogue of facts. Rather, it is a creation of the human mind, with its freely invented ideas and concepts. Einstein not only developed his theories at a time when there was no empirical evidence to support them, but also contradicted the wisdom of his time, with the entire scientific community standing opposed to his novel theory. This idea, which Rigden [28] considers a "big idea," was a result of Einstein's imagination and creativity.

II. AIM

The aims of the present study were to (a) examine the potential or effectiveness of teaching NOS via Nobel Prize stories, based on the example of the "Albert Einstein's Nobel Prize and the Nature of Science" course, in enhancing comprehension of NOS, and (b) to formulate suggestions as to this method's applicability. Specifically, we asked the following questions:

- (1) What was the undergraduate students' knowledge of NOS before and after the course?
- (2) Was NOS comprehension evident—and how did it manifest—when students presented Nobel Prize stories of their own?

III. METHOD

A. Participants

The study population consisted of the ten students who registered for a summer course entitled "Albert Einstein and the Nature of Science," which was offered to undergraduates by the faculty of physics in National Taiwan Normal University. Two of the students were women, the remainder men, and for three students this course was the last in their degree. The others were about to enter the last year of their studies.

B. The course: "Albert Einstein's Nobel Prize Story and the Nature of Science"

A 36-hour course was developed for the purpose of this study. Although the course name refers only to Albert Einstein, Einstein's Nobel Prize story was only one of

the stories presented in the course. The course included 12 meetings, each lasting 3 hours. The topics were as follows: Meetings 1–3: Introduction to the Nobel Prize and to the nature of science. Meetings 4–7: Albert Einstein’s Nobel Prize story. Meeting 8: Would Aristotle or Galileo receive a Nobel Prize? Meetings 9–12: Participants’ presentations and course summary.

See this paper’s Supplemental Material [29] for a more detailed account of the course, followed by an elaboration upon how Einstein’s story exemplifies the various elements of NOS.

The decision to start the course with an introduction to NOS was inspired by the work of Abd-El-Kalick and Lederman [30], who suggested that explicit teaching of NOS prior to a course on HOS might increase the likelihood that students’ NOS views will be changed or enriched. This also ensured that the terminology taught during the introduction could be used throughout the course to reinforce the NOS aspects within the context of the Nobel Prize stories.

C. Research tools

(a) *The Views of Nature of Science (VNOS-C) questionnaire.*—This questionnaire was developed and validated for use with the intended participants by Lederman *et al.* (2002), and is widely used. It consists of ten open-ended questions. The open-ended nature of VNOS-C allows respondents to use their own words and examples, without being forced into a choice and/or words that have been chosen for them [6,31]. A week before the course, the students were asked to fill out the questionnaire. An hour later, the interviewer, after reading the answers provided by the students, interviewed them. At the end of the final class, the students were given with the same questionnaire again, and during several days afterwards each student was separately invited to an interview. This process took 5 days and was conducted at times convenient for the students.

(b) *Interviews following administration of VNOS-C.*—Schwartz *et al.* [6] suggest conducting an interview following administration of VNOS-C. In the interview the

participants were confronted with their own VNOS-C responses and asked to state whether their views are different from those they expressed in the questionnaires, and also to further explain their answers. The aim of these questions is to identify any misinterpretations of questionnaire items and clarify ambiguous responses, thus helping us to draw up faithful representations of participants’ understanding of the NOS (Schwartz *et al.*) [6].

(c) *Participants’ presentations.*—As part of the course requirements, each participant was asked to illustrate the NOS by presenting the history of a Nobel Prize laureate and to explicitly discuss with the class the way that the story reflects NOS characteristics, as taught during the course.

The way each participant incorporates the NOS characteristics in the story is expected to reflect their understanding of the NOS characteristics described above.

Figure 1 describes the research tools that were used for each of the research questions.

D. Data analysis

The main categories, which were the consensus characteristics of the NOS as described in the literature, were predefined. Comparisons were drawn between these characteristics of the NOS and the participants’ views, as these appeared in the pretests and posttests, and in the transcripts of the students’ presentations. To identify subcategories, an inductive analysis [32] was performed on the students’ views for each of the NOS characteristics, in which patterns, themes, and categories were extracted from the data. The analysis started with the research team forming tentative individual impressions by reading and rereading the questionnaires, the interview transcripts, and students’ presentation transcripts separately [33]. As part of verification methodology [34] the research team then repeatedly reread the data together and initial categories were revised as a result of several rounds of discussion. Then a summary was generated for each participant that expresses their understanding of each category, based on the inductive analysis of each of the aspects of the NOS before, during, and after the

FIG. 1. Research tools for research questions 1 and 2.

course. All the data sources were subjected to a similar analysis. The left column of Table I summarizes the main categories and subcategories yielded by the analysis process.

IV. RESULTS

Table I summarizes how many students expressed each of the categories and subcategories before and after the course. As can be seen from the table, the students improved and enriched their understanding of all the aspects of the NOS that we tested.

In what follows, students' views for each of the NOS characteristics will be presented, first as they appeared in the students' pre- and postquestionnaires and interviews, and then as they appeared in the students' presentations and in their class discussions.

A. Science is empirically based

1. Questionnaires and interviews—pre vs post

As Table I shows, before and after the course all ten students connected science with experiments and explained that what distinguishes a scientific theory from nonscientific theory is the fact that scientific theories should be supported by experimental data. After the course, all of the students also understood that scientific theories may emerge in the absence of any empirical data too, and yet, that science is empirically based. Here are few typical examples from the prequestionnaires:

Without experiments how can we know that our theories are real? Scientific knowledge needs experimental proof (S1).

TABLE I. Students' views of the NOS characteristics, according to the inductive analysis yielded themes, before (B) and after (A) the course.

Aspects of the NOS and their subcategories	B	A
<i>1. Empirically based</i>		
1.1. Scientific theories should be supported by experiments	10	10
1.2. Scientific theories emerge from empirical data	10	10
1.3. Theories may emerge in the absence of experimental evidence but experimental proof is crucial	0	10
<i>2. Observe or infer</i>		
2.1 Inferring is a direct result of what we see	10	0
2.2. Different explanations may fit the same observation	0	10
<i>3. Theories or laws</i>		
3.1. Theories become laws. Laws are truth.	7	4
3.2. Laws are the mathematical part of a theory	1	0
3.3. Theories consist of laws. Theories are truth.	2	0
3.4. They constitute different types of knowledge	0	10
<i>4. Tentativeness</i>		
4.1. Scientific theories do not change after they are proved by many experiments	10	4
4.2. Scientific theories do change due to technological improvement	10	10
4.3. Scientific knowledge accumulates	10	10
4.4. Scientific knowledge change may be revolutionary	0	10
<i>5. Creativity and imagination</i>		
5.1. Not used	3	0
5.2. Used by only great scientists	1	0
5.3. Used only by ancient scientists	1	0
5.4. Used mainly in planning and designing experiments	3	0
5.5. Used mainly in identifying anomalous data	2	0
5.6. Used in developing mathematical equations	1	0
5.7. Used in all scientific inquiry stages	0	10
<i>6. Social and cultural</i>		
6.1. Science is universal	5	0
6.2. "Scientists are human"	4	0
6.3. Scientific research questions reflect needs of society	2	10
6.4. Social and cultural values influence scientists' views and thinking	0	10
<i>7. Theory laden</i>		
7.1. When only limited data are available, scientists may be influenced by their own theories	4	0
7.2. Scientists may be influenced by their own theories	0	10

Experiments are important because they allow us to find a theory (S5).

Scientists observe nature and then, from what they observe they build hypotheses. They then use experiments to prove their hypotheses, otherwise hypotheses remain just hypotheses (S9).

The latter two of these three quotes reflect the general impression conveyed by the students that observation and experimentation must come first, *before* the emergence of a theory. This impression had changed by the end of the course, as these typical examples from the postquestionnaires and interviews show:

Creativity and imagination are used to create a guess/hypothesis, which are then tested through observations and experiments. Like de Broglie who thought of the wave nature of electrons, even though there was no experimental evidence for this. Also, the experiments can be done later, not necessarily by the same scientist (S5).

Theories can be developed without any experiments... Einstein didn't do any experiment, ... But experiments are important because we need to prove our theories. We cannot rely on theories that were developed by only thinking. We must do experiments (S9).

The sentiments expressed above, taken from the interview with S9, were very common among the other students too. Students did understand that although science theories may or may not be developed based on experiments, being a scientific theory demands that a theory be supported by empirical evidence.

2. Student presentations and class discussion

During the course it was hard for students to bridge the gap between the idea that science seeks experimental evidence and the fact that theories may be the result of creative thinking. The story of Louis de Broglie's Nobel Prize (1929) illustrates this difficulty. Student 5 said in his presentation that de Broglie's wave-particle duality theory, while endorsed by Einstein, was met with skepticism by others because there was no empirical evidence to support it. It was only in 1927 that Davisson, Germer, and Thomson empirically confirmed, in their electron diffraction experiments, that an electron does have wave properties.

The fact that theories not always develop in light of existing data led some students, including the student (S5) who presented de Broglie, to mistakenly believe that these cases show that science is *not* empirically based. For instance, the student who presented de Broglie said during the part of his presentation that discussed how the story reflects the NOS characteristics that "de Broglie did not do

experiments and didn't work in the laboratory," and claimed that "this shows that science is not always empirically based." This statement led to class discussion and the lecturer asked the other students whether they agree with this claim. Only one student (S6) said that "scientists sought to prove de Broglie's theory with experiments and this is what makes science empirically based." The student reminded the class that in the case of Einstein it had also seemed that his theory was not empirically based, but that we had shown that experiments were necessary to prove it. Indeed, we discussed how important experiments are and that they always have a role in verification.

One point of difficulty was the seeming similarity between the theories of "modern" scientists and those of "ancient" scientists. One student (S1), for example, noted that we had said of Aristotle and Democritus that they formulated theories without experimentation, and asked, "So, what's the difference [between them and Einstein]?" Indeed, we had previously discussed the idea that these ancient Greek scientists developed what we called, "the logos" method, according to which scientists observe nature and use their logical thinking to provide explanations that obey this logic. It was therefore necessary to repeat that while the ancient Greeks had used their logical thinking method, they had also used creativity and imagination as today's scientists do. The difference, though, is that today's scientists, unlike the ancient scientists or philosophers, would not be satisfied with a theory unless it was supported by empirical evidence.

The fact that students reached a wrong conclusion—namely that since scientific theories are sometimes developed in the absence of the relevant empirical data, science is "not always empirically based"—indicates that the whole idea of science being empirically based was not a trivial one for students to understand. Furthermore, dealing with ancient science caused some confusion regarding the roles of pure thinking, creativity, imagination, and experiments, in the development of scientific theory. By the end of the course, as the posttest results show, this point was clear to all of the students. This was probably due to the many opportunities to further elaborate on this point that came up in other students' presentations too.

In other Nobel Prize stories, such as in Rutherford's, the theories were developed based on empirical data. Bohr's story is interesting since, as the student who presented him (S6), said: "Bohr based his atom's model on Rutherford's empirical data, but he was troubled by the fact that this model was not coherent with the wave theory, according to which accelerating electrons would have to radiate electromagnetic waves and thus collapse to the atom nucleus. Then his creativity enabled him to combine Rutherford's model with the brilliant idea posited by de Broglie. Thus, Bohr developed his theory in light of both existing data and a theoretical idea." To this, the lecturer added that, although Bohr's model of the atom

emerged from empirical data, empirical data by itself does not guarantee that we reach the best powerful explanations. This is another example demonstrating that being empirically based does not mean that theories necessary directly emerge from experimental data. Sometimes no experimental data exist, as we saw in the Einstein and de Broglie stories. Sometimes theories emerge directly from experimental data, as in the case of Rutherford, but sometimes, as in the case of Bohr's story, the development of theories is indeed based on empirical data, but not exclusively, because it also involves scientists' highly creative input.

B. Observation vs inference

1. Questionnaires and interviews—pre vs post

As Table I shows before the course all students saw observations and interpretations as being directly linked—you explain what you “see.” This view was expressed, for instance, in reference to the question concerning the certainty of the atom model as presented in the textbook (question 6 in the VNOS-C questionnaire). All of the students believed that the atom model described in textbooks is certain. After the course (see Table I) all of the students understood that there might be different explanations for the same observations. Typical explanations given by the students in the pretests were as follows:

“Scientists saw the atom” (S1), “Scientists used microscope to see the atom” (S2), “They did experiments... I think Rutherford showed that the nucleus is in the middle Mmmm, I don't remember” (S5). Two students did not provide any answer, saying rather that they believe it is certain but they “don't know why.”

The idea that inference is the direct or exact interpretation of what we see is probably the reason that most of the students (6) (such parenthetical numbers from this point on are used to represent the number of students) in responding to the question about the extinction of the dinosaurs (question 8) believed that both of the two events suggested as causes of the dinosaurs' extinction (i.e., a huge meteorite hitting the Earth and a massive and violent volcanic eruption) must have occurred. Otherwise, most of the students explained, “the two groups of researchers could not [have] reach[ed] different conclusions” (S2). In other words, if we give an interpretation of what we observe, our interpretation, according to that view, must be the only possible correct interpretation, because it directly reflects what we “see.”

When told that the two groups of researchers had access to the same data, and asked again why they believed that there are two different hypotheses and why, if indeed the two events happened, the two scientist groups did not reach that conclusion, the typical answer was “they just prefer to look at only one set of data. It is easier for them.” Two students expressed the view that “each scientist wants to prove what they believe in. So probably each group

believed in different theory” (S4). This point also belongs to the theory-laden NOS characteristic. The other three students thought that such a lack of consensus can occur only when there is not enough data. In such cases scientists need to decide which theory they prefer or they “just guess” (S10, S3, S7).

After the course, most of the students answered the dinosaur extinction question by explaining that two different explanations for a single phenomenon *are* possible, as exemplified by the following excerpt from the postinterview with S5:

S5: People may look at things through their own “glasses.” Different scientists may look at the same data and interpret it differently; based on what “glasses” they wear.

Researcher: You wrote the term “glasses” in the questionnaire. What do you mean by that?

S5: I mean that we can look at the same data, but you and I may have different knowledge and experience and this is why we can give different explanations.

2. Student presentations and class discussion

The difference between observations and interpretation was raised by several students' presentations. For instance, the student (S2) who presented the topic “Would Newton win a Nobel Prize” discussed the simple fact that the same observation of falling bodies was explained differently by Newton and Aristotle. In the presentation of Thompson's story, the student (S9) discussed the idea of cathode rays and described Thompson's experiment, where he deflected the rays with an electric field. While Thomson saw this experiment as confirmation of his hypothesis that the cathode rays were composed of very light negatively charged particles, his interpretation was not the only one. Supporters of the ether theory, though accepting of the possibility that negatively charged particles are produced in Crookes tubes, believed instead that these are a mere by-product rather than a basic component, and that the cathode rays themselves are immaterial. This, the student said, is an example of two different interpretations of the same data.

One interesting issue that was discussed by the lecturer was the comparison between Millikan's and Rutherford's interpretations of the results obtained from their experiments. Rutherford could arrive at the atom's model because he wisely managed to account for deviant observations (outliers). In contrast to Rutherford, Millikan managed to calculate the electron's charge only because he ignored such outliers. So the issue discussed with the students was the point that the way we analyze data may also influence our interpretation and that different analysis

of the same data may yield different explanations. The students found this point quite surprising.

C. Theories vs laws

1. Questionnaires and interviews—pre vs post

As Table I shows, before the course, all of the students saw laws and theories not as separate types of knowledge, but rather as some kind of hierarchy, related as follows:

- (a) Theories become laws. Laws are truth (7):

If a theory is proved over many experiments it becomes a law (S1)

Scientific law is what really exists, e.g., the Sun rises every morning. Scientific theories are hypotheses. Hypotheses that were proved by experiments become laws. They do not change. They are the truth (S6).

- (b) Theories consist of laws. Theories are truth (2).

- (c) Laws are the mathematical part of a theory (1).

In all three cases, it seems that the element placed higher in the hierarchy, whether it is a law or a theory, is considered to be the truth. All of the students explained “truth-ness” as being the law or a theory that is supported by “many” experiments.

After the course, all ten students expressed the view that theories and laws are different types of knowledge. Here are some examples from the questionnaires and interviews:

Different scientists may look at the same data and interpret it differently. Theories are just explanations and explanations may be influenced by the “glasses” the scientist wears. His experience, his background, also, how smart and creative he is (S1).

Theories are human explanations like Thomson’s “plum pudding model” of atoms. Theories are subjective. Laws are description of observations and experiments. They are not subjective. Like Newton’s law of motion (S9).

However, only seven students after the course deeply understood this point. In the case of the other three students (S4, S6, S7) it was clear that some progress in their views had occurred, and they did indeed explain that “theories and laws are different types of knowledge.” However, in addition to their declarative use of the term “different types of knowledge,” they also simultaneously used the idea that “some” theories “which were proved by many experiments and have mathematical explanations can become a law” (S6), and thus these theories are durable and “do not change,” they are truth. So it seems that these three students still believe that some (and not all, as was thought in the pretest) theories become laws, which are higher in the hierarchy, and which are truth.

2. Student presentations and class discussion

This NOS characteristic was reflected by only two student presentations. Student S9, whose presentation addressed whether Newton would win the Nobel Prize, discussed Kepler’s laws and said,

Kepler’s laws obtained from his observation are just laws describing the behavior of the planets. They describe how the planets move, but they are not a theory. They just describe mathematically the observation’s results, they do not explain it. Newton’s idea of gravity is a theory (S9).

Presenting Newton was also an opportunity to discuss Newton’s second law and ask whether it is a theory. It is surprising that at this stage, where the class had already discussed the difference between laws and theories several times, three students (S4, S6, S8) answered “yes” when asked “Can Newton’s second law be considered a theory?” One student said that “if the gravitation law is a theory, then the second law should be a theory as well.” This led to a deeper discussion of the idea that the gravitational law is not the theory, but rather that the *explanation* that bodies attract each other is the “gravitational theory.” This point was not easy to grasp. It was the comparison between the two that enabled a deeper understanding.

The difference between theories and laws was also emphasized by student S3, who presented Max Plank. This student pointed out that Plank, when introducing the notion of the quantum in his 1900 equation for the energy density per unit volume of blackbody radiation at frequency f and temperature T , “used the quantum idea only mathematically” in deriving his formula, since he was unaware that light comes in quanta, or photons. For him, the “energy elements” were not physically real, but a mathematical means to his objective. This, she said, points to the difference between a theory of light quanta and Plank’s law.

D. Scientific knowledge is reliable but tentative

1. Questionnaires and interviews—pre vs post

As Table I shows before the course students expressed the following views: (a) scientific theories do not change after they are proved by many experiments (10); (b) scientific theories do change due to technological improvement (10), and (c) scientific knowledge accumulates (10). No student expressed the view that change in scientific knowledge may be revolutionary. After the course, the students expressed richer views concerning the change of theories. Furthermore, they used terms that were discussed during the course, such as “tentative,” “self-correcting,” and “truth” to express their views.

The following excerpt from the pretest interview with student S10 reflects the students’ overall pretest position:

S10: Yes, theories change. We once thought that the Earth is flat.

Interviewer: And how did this theory change?

S10: Well, today we have technology that allows you to see that the world is not flat. That it is a sphere.

Interviewer: You gave an example of a very ancient theory. And what about the theories we know today? Do you think that they might change?

S10: Well, they might. But I do not think so. Today we have very good experimental tools.

As the above example shows, the student does know that theories over the years have been changed. However, these changes in her view occurred mainly because of lack of appropriate technology. She also believes that today's theories are not expected to change since we already have good technology.

In another example, regarding the question about the atom's model, all of the students before the course thought that scientists are certain of the model and that it will not change. This shows that students view scientific theories as certain, unchangeable, and "the truth," a term that was often used. Here are examples from the questionnaires:

Of course, the scientist saw the atom. We know that electrons surround the nucleus (S1).

The scattering experiment is proof that the positive charge of the atom is in its middle. We can be sure! (S4).

In response to the "influence of culture and society" question in the VNOS-C questionnaire (question 9) many students expressed the idea that science is not influenced by culture and society because science theories are truth (seven students: S2, S3, S5, S7, S8, S9, S10). Though their answers to this question did not address the tentativeness issue directly, seeing science as representing truth suggests that they do not believe that theories, once consolidated, change.

After the course, all of the students expressed the view that science is tentative in nature and that changes may occur due to new technologies, a broadening knowledge base, or new, revolutionary ideas:

Theories do change. Scientific claims are not truth. They are concepts in the human mind...we always discover new things, so explanations should always be modified or totally changed (S10).

Science is self-correcting. Wrong theories will eventually be changed (S8).

Because the time changed and we have better experimental tools science is changing. Also, people in different times think differently because we have more knowledge to be based on, so, we can change old theories. Also, scientists can suggest some brilliant idea that will be different from what we think now (S1).

Most of the students (7) also applied their view concerning the tentative nature of science to other VNOS-C questionnaire questions. For instance, here are some typical postcourse explanations for the atom question:

Scientists are still not certain about the structure of the atom. All atomic models are merely possible explanations. We cannot be sure (S10).

Even now we are not really sure of what is there inside the atom. The models we have are just possible explanations, they aren't the truth (S8).

Despite the clear change in many of the students' perceptions, four students though they claimed explicitly that science is tentative, nevertheless failed to apply this idea to other VNOS-C questionnaire questions. In a typical example of this, one student (S7) said, "*Theories do change. Maybe the previous views were not correct at all...Scientific theories may even change our view in 180°.*" This same student, however, said in answer to the atom structure item in the questionnaire that "*scientists are certain about the atom's model. They did so many experiments, all confirmed this model.*" This finding suggests that for these four students scientific theories can change, but that this change is not in science's essential nature.

2. Student presentations and class discussion

The tentative nature of science was easy for students to show in their presentations. All of the presentations began with the description of why the Nobel Prize was given to the scientist who won the prize. This required the student to assess whether the discovery they presented replaced an old theory, like Einstein's theory, or whether it was of a cumulative nature, adding something new to old known theories. The Nobel Prize stories provided opportunities to discuss both situations. For instance, the student who presented de Broglie (S5) pointed to the former, stating that "*de Broglie thought of something completely new. He changed our minds about the way we think of material objects like electrons. To think that they (electrons) have wave nature is something that no one thought before.*" In the case of J.J. Thompson, the presenting student (S2) pointed to the cumulative. Student S2 noted that the idea that atoms are not the smallest particles preceded Thomson, since this had already been hypothesized by physicist William Prout. However, Thomson's experiments on cathode rays did *confirm* Prout's theory, and lead him to the novel conclusion that the fundamental particles of which atoms are composed of are negative charges and that they are much smaller than the atomic size, over 1000 times smaller than an atom. Thus, the student said Thomson's case, though based on an existing hypothesis, is still "*an example of a discovery that changed what was previously known, that the atom is a fundamental particle.*"

The student who presented Rutherford cited his case as another example “of a theory that changed the previous theory we had.” Rutherford, the student explained “*who was Thomson’s student, wanted to prove his mentor’s theory. However, his results didn’t agree with his mentor’s model and he needed to think of another explanation.*” In contrast, the student who presented Millikan’s Nobel Prize story (S4) pointed out that though “Millikan was brilliant because he suggested a sophisticated experiment to measure the electron charge,” his work “didn’t change any previous known theory” because “everyone knew that electrons exist and that they have a negative charge. They didn’t know, though, its magnitude.”

E. Creativity and imagination

1. Questionnaires and interviews—pre vs post

As Table I shows before the course students only narrowly associated creativity and imagination with science. Three students (S2, S5, S7) did not believe that scientists use creativity and imagination at all before the course. One student (S10) expressed the view that only a few “great” scientists, such as Einstein and Newton, use imagination. Another student (S1) expressed the view that imagination and creativity were used “only in ancient times.” Two students (S3, S4) connected imagination only with planning and designing experiments and two other students (S6, S8) said that scientists use imagination and creativity when they identify a problem. One student (S6) also said that imagination and creativity are necessary to developing mathematical equations. None of the students could provide any examples for their ideas:

Imagination, no, I think that I would use this term to describe the work of musicians and artists. In science...well, maybe, I am not sure (S2).

Mmm...imagination definitely no. It would be quite bad if this was the case. Science should be accurate, you cannot imagine. It is not like writing a story. It is equations. Creativity, mmm...I don’t know. I guess they do (S5).

The two examples above show that the students did not associate scientists with creativity and imagination. For student S2, creativity and imagination “belongs” to artists, not to scientists. Student S5 distinguished between creativity and imagination. According to this distinction, science, which must be “accurate,” cannot be associated with imagination, but might make use of creativity—though student S5 could not explain or give any example of how or where creativity is used.

Student S1 expressed the view that imagination and creativity were used “*Only in ancient times,*” citing these as a necessary alternative to the absence of technology. “*The Greeks,*” said the student, “*had no technological*

means to measure reality so they needed to use their creativity and imagination [but] after the industrial revolution good technology was developed and we can see and measure the nature.” This comparison suggests the student’s assumption that since we now have the tools to “measure” nature, we no longer need to use creativity and imagination.

After the course, all of the students expressed the view that scientists, in all stages of their research, use creativity and imagination (see Table I). This new perspective is exemplified in the following student’s answer:

I believe that scientists use imagination and creativity in all the stages of their inquiry. When planning and designing investigations scientists must come up with some controlled system to get proper data. They have to think creatively how to prevent errors. After data collection scientists use their imagination to put those data into some sort of conclusion or see if there is a law behind (S2).

2. Student presentations and class discussion

Each of the students could easily explain how imagination and creativity were used by the Nobel Prize laureate they presented. Naturally, some focused on the creativity and imagination that were required in designing experiments while others focused on theory development with the absence of any experimental data. Here are some examples:

The student (S9), whose topic was “should Newton get a Nobel Prize,” showed a video depicting apples falling from a tree as well as the Moon and stars in the sky, in which the narrator explains that Newton understood that the reason why objects fall was the same as the reason for the attraction of the Moon to the Earth—the force of gravity. The students then discussed the idea that imagination and creativity were necessary for Newton to reach the abstract idea of gravity. “*No one sees gravity. No one had ever expressed the idea of gravity before Newton.*” The students pointed out that, unlike Newton, Kepler spent most of his life observing the stars, but was unable to make the imaginative leap and formulate a theory explaining his own laws.

Millikan’s story served as an example of the role creativity can play, not just in the formation of a theory, but in the composition of an experiment. Student S4, who presented Millikan, first introduced the fact that the electron concept was found and verified by Thomson before Millikan’s oil drop experiment. Then the students discussed the idea that no one before Millikan had an idea of how to measure the electron’s charge, although “they knew about its existence.” He then presented the Millikan experiment’s design and showed how on the one hand the experiment is simple, but on the other hand, how “brilliant” it was to use such a simple apparatus to discover the electron charge.

A good example of how creativity and imagination are needed to develop a theory when experimental data is lacking is de Broglie's Nobel Prize story. Thinking of an electron as behaving like waves was in those days an interesting, novel and provocative idea. Student S5 said in his presentation that "the world of physics, which had to struggle and adapt to the idea that light is a particle had now to confront the opposite idea, that electrons are waves."

One interesting idea that was raised during the discussion is the question of whether the scientific theories discovered by the different scientists would still be discovered if these particular scientists had not existed. For instance, would the gravity theory have been developed without Newton? Would the idea of light quanta have been developed without Einstein? In art one may think that without Shakespeare the world would never have Romeo and Juliet and without da Vinci we might not have the Mona Lisa. The students reached the conclusion that while science theories may have been developed even without the existence of specific scientists like Einstein and Newton, the creativity and imagination of these specific great scientists were used to enhance our knowledge.

F. Social and cultural influence

1. Questionnaires and interviews—pre vs post

Before the course, four students expressed the view that science is universal (S3, S6, S7, S8) and not influenced by cultural and social values. Four students (S2, S4, S5, S9) said that "scientists are human and therefore science is influenced by culture and society," but could not give an example of such influences. Only two students (S1, S10) held the view that science is influenced by culture and social values and could provide examples to support their views. After the course, all of the students understood that science is influenced by culture and society. Six students (S1, S2, S3, S5, S8, S9) mentioned as an example the fact that Lenard was a Nazi and how his belief in the existence of "German physics" influenced his scientific thinking. Three students (S7, S8, S10) mentioned Marie Curie as an example of how social and cultural values influenced her work and recognition as a scientist. During the interview they all said that they do not believe that a woman researcher today would suffer from the same problems. However, they also added that the cultural influence might manifest itself by the fact that "much less girls will choose to study science." The reason they gave was that "women in Taiwan do not really think that it is for them to study science."

Examples from interviews and questionnaires.

Before the course the students stated the following:

If scientific theories can be tested and proved they are universal. There should be no cultural influences (S3). Science is and should be objective; otherwise people could have different views based on their culture (S8).

People's faith can influence scientific interest. For instance, the Germans develop less biotechnology because they are Christians while in Taiwan which is multireligion country, we develop more such technology (S10).

Whether this last statement is correct or not is not the issue. What is important here is that the student did recognize that culture, in this case religion, influences science.

After the course the students stated the following:

I think that science is universal and also reflects social and cultural values. For me, the beginning of science development is more tend to social and cultural values, like Aristotle, but as time goes by, it becomes more and more universal, less influenced by culture and society. Scientists from different countries can have the same ideas and work on the same topics (S6). Chinese people, 200 years ago, did not like the west. Thus they were not interested in its science and did not know it (S1).

The differences between the "before" and "after" quotes indicate a certain softening of the students' position regarding the absolute universality and objectivity of science, but they by no means indicate a complete understanding of what social and cultural embeddedness entails. First, most students could not provide examples for cultural and social influences other than those which were discussed in the course. Second, the "after" quotes concede that social and cultural influence is *possible*, but suggest that it has receded over time and that science is moving *towards* the objective ideal described in the "before" quotes.

2. Student presentations and class discussion

Social and cultural influences on science were only seriously discussed in two Nobel Prize stories—Philipp Lenard and Marie Curie. Student S8, who presented the Philip Lenard Nobel Prize story, revealed an interesting cultural aspect: During the Nazi regime, Lenard, who was an active member of the National Socialist Party, declared that Germany should rely on "Deutsche physik," and ignore what he considered the fallacious and deliberately misleading ideas of "Jewish physics," by which he meant mainly the theories of Albert Einstein, including "the Jewish fraud" of relativity. The student who presented this story said "Imagine that Lenard would not accept only the Jew physics, but rather also the Taiwanese's physics as well." Many students expressed their feelings by saying things like, "How can such a distinguished scientist like him have such a stupid thinking?," "I do not believe that scientists have such thoughts," "It's terrible," "they should take from him the Nobel Prize."

In the case of Marie Curie, student S10 presented the difficulties she faced, being a woman, in becoming a scientist. The student also mentioned the irony in the fact that Curie ultimately received two Nobel Prizes, one in physics and the other in chemistry. This gave the students an opportunity to discuss in class whether a female scientist would have difficulty working in science today, and whether this particular cultural bias is still in effect. Thus the two stories were a good lesson to teach that scientists are human, and as such they may be influenced by cultural and social values. They can envy, they can hate, and they can be prejudiced.

G. Scientific knowledge is theory laden and subjective

1. Questionnaires and interviews—pre vs post

This view was expressed before the course by only four students (S3, S6, S1, S7), who also thought that this is the case only when limited data are available (see Table I). For instance, in responding to the dinosaurs question in NOSV-C questionnaire (question 8), student S7 explained that “the two groups arrive at different explanations because when they (scientists) are not sure due to lack of data. They need to decide what is more reasonable, based on what they know.” As can be seen from this example, which also reflects the responses of three other students, students do not view science as being theory laden in essence, assuming rather that in special situations or occasions, such as when there is not “enough data,” researchers are influenced by their knowledge and experience.

After the course, all of the students expressed the view that scientists work in light of the theory they know. Here are some examples from questionnaires and interviews for the dinosaurs question in NOSV-C questionnaire (question 8):

Both groups of scientists could draw different conclusions from the same data because they are influenced by their different background and experiences (S3).

The two groups actually can reach the same ideas. However, each group prefers its own explanation because it better fits the theories they believe in (S2).

2. Student presentations and class discussion

The characteristic of science being theory laden was hard for the students to deeply understand, as one student said when discussing the fact that Millikan opposed Einstein’s theory even though his results supported it:

I don’t understand. But the results of his own experiment show that Einstein was right, no? How can that be?

Another student said the following:

I do not get it, if the results show that the theory is working they should accept it. It is science, how can someone say, look, I do not believe that this is true. But we show him that it is true.

The idea of science being theory laden was further illustrated in several Nobel Prize stories by some student presentations. In some cases, the existence of a previous theory was an obstacle, as shown in the stories of Einstein and Thomson. Student S2, who presented Thomson, said that he developed his idea about the atom being composed of smaller particles when it had already been suggested by Prout that the atoms are composed of hydrogen atoms, which are the basic fundamental parts. Those who opposed Thomson’s idea of cathode rays being electrons had an alternative theory and did not accept Thomson’s theory. In other cases, however, previously known theories could help scientists develop their own. Student S1 showed that Rutherford, for example, made his investigation in light of his mentor’s “plum pudding model,” and that later on Bohr suggested *his* atom model based on Rutherford’s as well as de Broglie’s theories.

V. DISCUSSION

The present study aimed at examining Eshach’s [14] suggestion that the use of Nobel Prize stories is an efficient or effective method of helping students gain a deep understanding of NOS. The findings show that the students who participated in the course “Albert Einstein’s Nobel Prize Story and the Nature of Science” enriched their views concerning all the NOS consensus aspects. The results of this study show that before the course the students had a naïve image of what the nature of science is. This image was probably compiled by these students based on various impressions gleaned from the many science courses they had already taken. We thus agree with Clough [35] that

science courses cannot escape conveying an image of the NOS to students. Teachers’ language [28,36–38], cookbook laboratory activities, textbooks that report the end products of science without addressing how the knowledge was developed, misuse of important words having special meaning in a science setting, and traditional assessment strategies are just some of the ways students develop conceptions about the NOS. Ever present in science content and science teaching are implicit and explicit messages regarding the NOS. The issue is not whether science teachers will teach about the NOS, only what image will be conveyed to students (p. 464).

The naïve image of science that the students had before the course can be summed up as follows: scientists first observe nature and identify a problem by noticing new data that were not previously seen, or by looking at phenomena

that were already explored in the past, but with new technologies. Then they try to explain these phenomena by using existing theories. If no theory exists and/or the old theories cannot explain the data obtained from the observations, they offer new hypotheses, which then they test with experiments. If these hypotheses are experimentally confirmed, they become theories. If the theories find support from other experiments and observation, they become laws. Laws are truth.

The students' initial conceptions of the role of the experiment in science were somewhat simplistic and partial. On the one hand, their naïve image acknowledged the important role of experiments in providing evidence to support theories. This understanding in itself is not misguided, because as Feynman *et al.* [39] point out, "The principle of science, the definition almost" is that "the test of all knowledge is experiment [and] experiment is the sole judge of scientific 'truth'" (p. 1). On the other hand, however, the naïve views that students held before the course also indicate a simplistic view, one which assumes that scientific theories can emerge only from observation and experiments, and that this is done in the following two possible ways: (a) noticing data that were previously ignored before, or (b) using new technologies that enable the identification of anomalous data that is not compatible with the existing theories.

The students' precourse views also indicate a perception of scientific knowledge as something that accumulates. They did not understand that sometimes theories may emerge even in the absence of data, as speculations in the creative scientists' mind, and that these theories may be of a revolutionary nature. The students also viewed scientific theories as directly and accurately describing observations, and did not consider creativity as part of the scientist's work. Most students did not connect creativity and imagination to science, and if they did, it was only in special conditions that limited its use to ancient times, great scientists, or specific stages of the scientific inquiry.

After the course, the students showed a broader understanding of all aspects of NOS. First, they understood that, in addition to identifying new phenomena that were previously unnoticed or reexamining old theories with new technologies, theories can also emerge in the absence of any experimental data. Second, they understood that although theories may arise as speculation in scientists' creative minds, they still require empirical evidence, and that this seeking after empirical evidence is what makes science in essence empirically based. Having said this, however, it is worth noting that this point was hard for students to grasp. Students thought that the fact that some scientists have raised theories speculatively means that science is *not* "always" empirically based. To understand this point, several discussions with the students, accompanied by examples, were needed.

In Taiwan's schools and universities, theories are usually presented to the students first, and then the students do the experiments to confirm them. It is interesting to note that although the theories are presented to students before they do experiments, the theories are described as yielded *from* the experiments. As a result, the students get the impression that theories always begin with empirical data that must be explained, and that these explanations must then be tested more rigorously in experiments.

After the course, the students were able to distinguish between observations and theories, understanding that these are different types of knowledge, and that different theories may explain the same set of data. However, not all of the students fully understood that theories are never unchangeable and certain. Four out of the eleven students, though they explained in different answers to the VNOS-C questionnaire that theories and observations are two types of knowledge, still could not apply this idea to the case of the atom model.

It is important to note that the use of Nobel Prize stories, while it carries many benefits, can also generate some misconceptions. Although the study showed that, in general, the students improved and enriched their understanding of NOS, the fact that the scientist got a Nobel Prize, and the fact that the Nobel Prize is given after theories obtained experimental support, probably caused some students to think that some theories are not changeable—their developer got a prestigious prize, after all. This point should be clarified to the students in future utilizations of the unit. Perhaps students should be asked to write an essay on a case in which a theory for which a Nobel Prize was awarded was ultimately displaced by a later, opposing theory. In any case, this point should be reinforced during such a course.

While the "Albert Einstein Nobel Prize and the Nature of Science" course clearly did improve the students' understanding of NOS, it is important to ask: what specifically made the course a success? One significant contributing factor may have been the fact that the course, based as it is on historical cases, introduced the students to HOS. This possibility supports other research findings, according to which using HOS is an efficient way to teach NOS [21,40]. However, the effectiveness of using HOS to teach NOS is controversial and we would like to add more on this issue. Abd-El-Khalick and Lederman [10] found that participating in HOS courses had only minimal influence on students' NOS views. They also claim that their finding does not lend empirical support to the assertion that course work in HOS would improve students' NOS views. They further claim, based on their findings, that one HOS course is not likely to enhance students' NOS views in any substantial way.

In light of the findings of Abd-El-Khalick and Lederman, we believe that HOS alone cannot account for the changes in our own students' views of NOS. Rather, the

success of our approach can be attributed to a *combination* of history of science, contextual learning, explicit teaching, and the use of stories. We cannot, of course, wholly separate the contributions of each of the components to the course. In this sense the whole is bigger than its parts.

Though this particular study has produced no concrete evidence to explain the specific contribution of teaching NOS in the context of the real historical Nobel Prize stories, we believe that this approach was particularly helpful in illustrating the complex relationships in science between evidence and theory. Nobel Prize stories give rise to discussion of this key issue in NOS almost “naturally,” because the tension and interaction between theory and evidence—and the various forms it can take—are an inherent part of their narratives. In this case, the “real” stories can be excellent examples with which to contextualize and conceptualize issues that are hard for some students to grasp. For instance, our comparative discussion of the various Nobel Prize stories helped students to bridge the difficult gap between (a) the idea that science by nature seeks experimental evidence and (b) the fact that theories may also be the result of creative thinking and emerge in the absence of empirical evidence too. Moreover, the real context of Nobel Prize stories—its inclusion of the trials leading up to being awarded one and of dissent that may continue even afterwards—also illustrated the idea that empirical evidence does not always guarantee the acceptance of a theory.

The explicit teaching of NOS as an independent topic, taught using acknowledged NOS terms [15,20], was critical for achieving changes in the students’ views. Indeed, Abd-El-Khalick and Lederman [10] also found that changes in NOS views were evident in relatively

more participants who entered the HOS courses after taking a course on NOS. The fact that the students in our course were first introduced to the NOS literature, and the fact that the terms learnt at this introductory part were used throughout the course, also explains the promising findings of our study. Moreover, the discussion of the ideas of NOS in Einstein’s Nobel Prize story, as well as in each of the stories presented by the students, allowed us to deliberately scaffold classroom experiences, and allowed the students to develop their NOS understanding back and forth along the continuum of the learning process, which according to Clough [35] is more effective.

We conclude with that, as the results of this study show, the Nobel Prizes, which according to Feldman [41], “are the most coveted and most potent awards of our time” (p. 1), may be an inspiration not only for scientists or those who wish to become scientists, but also for educators who work hard to bring science and NOS to the young generation. According to Eshach [14], the Nobel Prize stories can *introduce glory into the physics class*, and the glamour and glitter of the Nobel Prize can induce young people to take a look at the frontiers of science and, perhaps, continue to develop a genuine interest in scientific ideas. However, Nobel Prize stories may mistakenly be taken as if they are the be all and end all of being a physicist. To address this concern, teachers who would like to use Nobel Prize stories will probably also need to present students with good stories regarding physicists who did not receive a Nobel Prize, but were still fruitful. This point confronts students with the fact that the judgment of scientific significance is open, at many junctures, to human fallibility, as any judgment invariably is.

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