The Effect of Explicit versus Implicit Instructional Approaches during a Technology-Based Curriculum on College Students' Understanding of the Nature of Science (NOS)

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Abstract*: The purpose of this study was to examine the effect of explicit versus implicit instructional approaches on students' understanding of the nature of science (NOS). The study emphasized the inferential and tentative NOS. The control group consisted of 97 students, 64 female and 33 male, and the experimental group consisted of 143 students, 92 female and 51 male. A quantitative analysis of students' pre-intervention NOS views revealed that there was no statistically significant difference between implicit and explicit groups in both targeted NOS aspects, However, the same analysis indicated a statistically significant difference for post-intervention between implicit and explicit groups, A qualitative analysis of students' pre-intervention views of the target NOS revealed that the number of informed NOS responses was not considerably different. However, analysis of post-intervention NOS views indicated that more students in the explicit group demonstrated informed views of the target NOS than in the implicit group. The findings of the study demonstrated firstly, the effectiveness of the explicit approach when teaching aspects of the NOS and secondly, that this teaching could be accomplished through short intensive discussion. (****Keywords****: Explicit instruction, Implicit instruction, Nature of science (NOS), Inferential NOS, Tentative NOS).*

تأثير الأسلوب التدريسي التصريحي مقابل الأسلوب ألتدريسي الضمنيّ باستخدام منحى علمي يعتمد إستخدام التكنولوجيا في فهم طلاب المرحلة الجامعية لطبيعة العلم

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ملخص: هدفت هذه الدراسة إلى اختبار أثر الأسلوب ألتدريسي التصريحي مقابل الأسلوب ألتدريسي الضمني بإستخدام منحى علمي يعتمد على إستخدام التكنولوجيا في فهم طلاب المرحلة الجامعية لطبيعة العلم. وركزت الدراسة على الاستدلالية والتجريبية للمعرفة العلمية. وشملت عينة الدراسة على 97 طالبا (64 انثى و33 ذكرا) للمجموعة الضمنية و143 طالبا (92 انثى و51 ذكرا) للمجموعة التصريحية. ولقد كشف تحليلُ كمّي لآراء الطلاب حول طبيعة العلم قبل التدخل البحثي عدم وجود فارقٍ دال إحصائياً بين المجموعتين المصرح بها والضمنية في كل من السمتين المستهدفتين في طبيعة العلم، إلا أن التحليل نفسه أشار إلى وجود فرق ذات دلالة إحصائية بين الآراء بعد التدخل البحثي بين المجموعتين المصرح بها والضمنية، وأشارت نتائج التحليل النوعي إلى جانب مقابلات شبة مقننة لوجهة نظر الطلبة قبل التدخل البحثي إلى عدم وجود فارق كبير في آراء الطلاب الواعية للسمتين المستهدفتين في الدراسة و لكن بعد التدخل البحثي أصبحت آراء الطلبة الواعية في المجموعة التصريحية أفضل من نظرائهم في المجموعة الضمنية. خلصت نتائج الدراسة الى ان الأسلوب التصريحي هو الأسلوب الأمثل في تدريس طبيعة العلم وان تدريسة ممكن تحقيقة في فترة زمنية قصيرة من خلال مناقشات مكثفة لطبيعة العلم. (**الكلمات المفتاحية:** الأسلوب ألتدريسي المصرح بة، الأسلوب ألتدريسي الضمني، طبيعة العلم، طبيعة العلم الاستدلالية، طبيعة العلم التجريبية)

Introduction

Science education reforms call for building a scientifically literate society. This education is vital in order to enable people to appropriately confront global problems such as population growth, destruction of tropical forests, extinction of plant and animal species, scarce natural resources, and nuclear war (American Association for the Advancement of Science (AAAS), 1990, 1993; National Research Council (NRC), 1996). In order to achieve scientific literacy, which is the central theme of recent science reforms, science educators must acknowledge that science instruction faces many challenges which impede science reform movements (AAAS, 1990).

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To achieve scientific literacy, schools must equip students with an education that encourages a deep understanding of the nature of science, mathematics, and technology, and how these subjects operate both independently and together (AAAS, 1990, 1993; NRC, 1996). One of the most consistent themes of these science reform documents is that developing deep understanding of the NOS and scientific inquiry will lead to better understanding of science content, concepts and scientific literacy (NRC, 1996).

There is general agreement among researchers and science educators that teachers and students do not hold adequate understanding about aspects of the NOS (e.g. Lederman, 1992; Abd-El-Khalick & Lederman, 2000). Despite the many attempts to improve this understanding, little success has been realized. This is mainly due to the implicit approach used in teaching the different aspects of the NOS (Abd-El-Khalick & Lederman, 2000). This approach emphasizes that students will develop an adequate understanding of aspects of the NOS aspects by merely being involved in inquiry-based activities, reading about significant historical stories and events or important investigations in the history of science, or being involved in open discussion about their personal beliefs and experiences regarding science. The major drawback to this instructional approach is the absence of straightforward discussion of the particular aspects of the NOS.

Although there have been many studies that adapted the explicit approach to enhance K-12 students' understanding of the NOS (e.g. Lederman, 1992; Lederman et al., 2001; Khishfe & Abd-El-Khalick, 2002) very few have focused on post-secondary students' understanding. Additionally, to date, the literature provides very little evidence of attempts to teach aspects of the NOS embedded within a framework of content-related activities with explicit instruction connection. Furthermore, technology as an authentic tool to teach NOS has been seldom used, even though it could play a major role in helping students develop a deeper understanding of the NOS (Abd-El-Khalick, 2002; Bell, 2001). This study contextualizes aspects of the NOS into inquiry-based activities during a technology-oriented laboratory project with college students.

Theoretical Perspective

Approaches to Learning the NOS

Many approaches have been developed since the early 1950s to help students and teachers improve their views of the NOS (Lederman, 1992; Abd-El-Khalick & Lederman, 2000). These attempts are categorized as historical, implicit, or explicit approaches (Lederman, 1992; Khishfe & Abd-El-Khalick, 2002). Some studies that exemplify each approach are stated below with the definitions of these approaches following later in the text.

Historical Approach

Abd-El-Khalick and Lederman (2000) used Views of the NOS Questionnaire-Form C (VNOS-C) to assess the effectiveness of three History of Science courses on college students' and pre-service teachers' understanding of the NOS. The study emphasized the tentative, inferential, and empirical nature of science; the myth of the scientific method; the experimental approach; the distinction between theories and laws; and creative, imaginative, and theory-laden aspects of scientific knowledge. The three history courses served as an intervention and included: (1) "Studies in Scientific Controversy", a survey course that dealt with the controversy surrounding scientific discoveries; (2) "History of Science", a survey course that spotlighted the relationship between scientific concepts and social and cultural aspects; and (3) "Evolution and Modern Biology", centered around the origin and development of the theory of evolution by Charles Darwin.

A total of 181 college students and pre-service teachers comprised the sample of the study and were given pre- and post-test questionnaires. Pre-test analysis of the study indicated that participants generally held naïve understanding of the target aspects of the NOS. Post-test analysis indicated very little change in the participants' conceptions of the target aspects of the NOS. The study concluded that incorporating elements from history of science had nominal influence on participants' understanding of the NOS. Other studies (e.g. Tamir 1972; Aikenhead 1979) have also concluded that the historical approach does not positively affect students' understanding of the NOS.

The Implicit Approach

Moss, Abrams, and Kull (1998) emphasized the general beliefs of the implicit approach as reported in Khishfe & Abd-El-Khalick's (2002) study. In their study, they assessed the understanding of the NOS held by 11^{th} and 12^{th} grade students involved in a year-long environmental science class. Students were practicing science in conjunction with scientists through inquiry-based activities. The results showed that students' gains on the aspects of the NOS were not significant. The researchers validated the claims of many studies undertaken in the past 30 years that students would not be able to develop a satisfactory view of the NOS simply by doing science or being involved in inquiry-based projects.

The Explicit Approach

The effectiveness of the explicit approach was examined by Kenyon and Chiappetta (2003) who assessed the views of some aspects of the NOS on freshmen college science majors using a pre- and post-test control/experimental group research design. These aspects included the tentative and empirical NOS, the functions of and relationship between theories and laws, the distinctions between observation and inference (imaginative and creative), and the argument over the existence of one universal scientific method. Seventy-four students participated: 50 students constituted the experimental group and 24 students served as the control group. Views of the NOS questionnaire C (VNOS-C; Lederman; Schwartz; Abd-El-Khalick & Bell, 2001) was administered to both groups. In addition, the experimental group was required to answer an essay question related to the epistemology of science. Students were asked to answer the essay question prior to taking the post-test as a means to avoid any influence that may have come from the VNOS-C test. Students also had to write a few paragraphs to answer the prompt: "Explain the nature of science."

In order to help students develop adequate understanding of the NOS, a one-credit course, "Succeeding in Science", was designed. The course provided in-class explicit instruction about aspects of the NOS, and promoted inquiry-based activities. Out-of-class assignments and activities were also given to students to enrich their experience with the target aspects of the NOS. Classes were held once a week in 50-min blocks for six weeks.

The study revealed that students representing the experimental group outperformed those representing the control group. An examination of the covariance in the results suggests that student views of the NOS were significantly higher (p<.001) after being exposed to explicit instruction and inquiry-based activities than those who were not. The study concluded that the explicit approach and inquiry-based activities were more appropriate to teach students about aspects of the NOS than the implicit approach.

It is apparent from the aforementioned studies that researchers in science education widely support a greater use of an explicit approach to increase student understanding of the NOS (Abd-El-Khalick, 2002). Bell (2001) and Abd-El-Khalick (2002) believe that technology is a powerful tool that could be used to teach teachers and students about the application of the NOS. Bell (2001) argues, however, that the integration of technology to instruct students about aspects of the NOS should be done in conjunction with the explicit approach. It was simulation that Abd-El-Khalick (2002) referred to as one of the powerful technological tools that could be integrated in science instruction as a way to enhance students' understanding of the NOS.

BGwILE (Biology Guided Inquiry Learning Environment) is a technology–supported curriculum that aims to help students investigate real life problems in biology and ecology (Tabak; Smith; Sandoval & Reiser, 1996). *Struggle for Survival* is a type of computer-based learning environment that is part of the BGuILE, Galapagos Finches Software. *Struggle for Survival* is a unit in evolution designed for use by middle and high school students that teaches students about how species interact, the process of natural selection, and the relationship of form and function in a species.

Struggle for Survival includes many activities that correspond implicitly with the inferential and tentative NOS. For example, in one of the activities, students have to provide hypotheses as they investigate the data set of the program in their attempt to answer two driving questions: "Why are many of the finches dying?" and "Why are some of the finches surviving?" This activity corresponds to the inferential NOS. Students have to realize that science is based on both observation and inference. This activity challenges students to employ their senses and the extensions of these senses (observation) to gather data incorporated in the program that may help them answer these questions, and then interpret these observations (inferences). Another activity encourages students to share their already formed hypotheses about the driving questions with their classmates through email discussion. They are then required to re-investigate the data to gather the information necessary to distinguish between alternative hypotheses and find one which is best supported by the data. This activity corresponds to the tentative NOS. In their quest to complete this task, students should find that the data support only one hypothesis. Other hypotheses that are not supported by the data are refuted. This signifies that scientific knowledge, in this case, hypotheses, are subject to change.

Problem of the Study

Research has repeatedly revealed that students usually do not develop understanding of aspects of the NOS as a result of their engagement in school science (Aikenhead, 1973; Larochelle & Desautels, 1991; Lederman, 1992; Matthews, 1994; Khishfe & Abd-El-Khalick, 2002). This finding is mainly due to the prevailing assumption that by "doing" science or by getting involved in hands-on activities, students will develop or enhance their conceptions of the NOS. As previously mentioned, this type of approach is referred to as the implicit approach (Khishfe & Abd-El-Khalick, 2002).

To improve students' conceptions of the NOS, researchers have suggested providing students with opportunities to do science by involving them in science projects, extra-curricular activities, and/or working alongside actual scientists (Bell; Blair; Crawford & Lederman, 2003). Incorporating instruction specifically geared toward aspects of the NOS within the context of these projects or extracurricular activities will most likely lead to the development of a better understanding of the various aspects of the NOS. This explicit approach in teaching the NOS is favored by many science educators (e.g. Khishfe & Abd-El-Khalick, 2002; Abd-El-Khalick & Lederman, 2000 & Lederman, 1992).

Purpose of the Study

The purpose of this study was to examine the effect of an explicit versus implicit instructional approach during a technology-based curriculum on college students' understanding of the NOS within an introductory biology course. The technology utilized in the study was *Struggle for Survival*, simulation software that uses data based upon the finch population on the Galapagos Island Daphne Major, located in the Pacific Ocean. The effectiveness of the implicit versus explicit instructional approaches on students' understanding of the NOS was measured in terms of individual views of the inferential and tentative aspects of the NOS.

The following research questions directed this study:

1. What range of views of the inferential and tentative NOS do students enrolled in an introductory college biology course hold?
2. What is the effectiveness of an explicit versus an implicit teaching approach on increasing students' understanding of the target aspects of the NOS during a technology-based laboratory project?
3. Do students' views change as a result of the explicit, inquiry-based approach?

Terminology

Nature of Science (NOS): The phrase 'nature of science' (NOS) refers to the "epistemology of science, science as a way of knowing and beliefs of scientific knowledge and its development" (Lederman, 1992, p. 331).

The Historical Approach: The advocates of the historical approach (e.g., Aikenhead, 1979; Tamir, 1972; Klopfer & Cooley, 1963; Crumb, 1965) argue that integrating elements derived from the history of science in science instruction may lead to better understanding of the NOS among students and teachers.

The Implicit Approach: The implicit approach advocates the use of hands-on inquiry-based activities and science process skills instructions (Lawson, 1982; Rowe, 1974; Gabel, Rubba & Franz, 1977; Haukoos & Penick, 1985). This approach suggests that students will come to develop an informed understanding of the NOS merely by "doing" science (Lederman, 1992; Abd-El-Khalick & Lederman, 2000).

The Explicit Approach: The explicit approach argues that students develop informed understanding of the NOS through explicit instruction primarily aimed at different aspects of the NOS (Lederman, 1992; Abd-El-Khalick, & Lederman, 2000).

Limitations

The study was restricted by the following limitations:

1. This study targeted only students enrolled in Biological Principles II at a southeastern university in the United States.
2. The study targeted only two aspects of the NOS (inferential and tentative).
3. The relevance of the study's final results and findings to general populations was limited by the assumption that this sample was parallel to any other population.

Methodology

Research Design

An experimental design was used to evaluate students' understanding of the target aspects of the NOS. The data assessment included a pre-test and post-test control/experimental group research design.

Subjects

The Biological Principles II is a compulsory course in the Department of Biological Sciences for undergraduate Biology majors in a southeastern university in the U.S. Students from other science disciplines, pre-medicine, and non-science disciplines can enroll in this course to fulfill their science requirements. The sample of the study was comprised of 240 students, with 62.2% freshmen, 25.4% sophomores, 6.3% juniors, and 6.1% seniors.

The control group, which is referred to as the implicit group, consisted of 97 students, 64 female and 33 male. The experimental or the explicit group, which is referred to as the explicit group, consisted of 143 students, 92 female and 51 male. The participants' ages ranged from 19 to 23 years.

Instruments

An open-ended questionnaire and semi-structured individual interviews (Lederman & O'Malley, 1990; Lederman; Abd-El-Khalick; & Schwartz, 2002) were adopted to examine students' views of the inferential and tentative aspects of the NOS. In terms of the questionnaire, selected questions from the Views of Nature of Science C & D (VNOS-C & -D) instruments (Appendix 1) were used to examine the effectiveness of explicit instruction, as compared to an implicit instructional approach, during a technology-based laboratory project on increasing students' understanding of the tentative and inferential aspects of the NOS. Themes reflecting the aspects used in the current study were modified from VNOS-C items 6 and 9 (for tentative NOS) and VNOS-D items 4a, 4b, 5a, and 5b (for inferential NOS) (Lederman; Schwartz; Abd-El-Khalick & Bell, 2001). Two pilot studies were undertaken in the summer and fall of 2003 to test the validity of the instrument.

The first pilot study in summer 2002 had a sample of 14 students and adapted the VNOS-C questionnaire. The findings of this study revealed that though students showed some gain between pre and post intervention in some of the NOS aspects, the time allocated for the explicit instruction of so many of the NOS aspects was too limited (20 minutes per aspect). As such, students' gains may have been attributed to their level of experience prior to the study, since most have conducted some scientific experimentation and investigation, rather than to the intervention. Due to the small sample size and duration of the course, no implications were culled from this study.

The pilot study in fall 2003 included a sample size of approximately 330 students and incorporated a pretest and posttest control/experimental group research design. A sub-sample of 116 students was analyzed. Unlike the first pilot study, this pilot study revealed several issues that needed to be addressed prior to the present study. First, the time allocated for delivering the explicit lesson plan of the four target aspects of NOS was too short (20 minutes per aspect). Second, time on task—teaching assistants (TAs) spending equal amount of time delivering each aspect—varied from one TA to another. Third, the delivery of the explicit discussion of the NOS by the TAs did not include rich examples of scientific knowledge, nor did instruction include significant student-student and TA-student interaction. Fourth, the necessity of conducting semi-structured interviews became evident

The individual semi-structured interviews were employed to any possible bias which could have resulted from using a single instrument. It was hoped that the interviews would first, establish the validity of the questionnaire by making sure that students' responses corresponded to the researcher's interpretations of the target aspects of NOS and, second, produce thorough profiles of students' views on the target aspects of the NOS (Akerson; Abd-El-Khalick & Lederman, 2000).

The Intervention

Nine graduate teaching assistants (TAs) delivered the intervention (Appendix 2) to the explicit group and implicit group. They were all regular TAs for the 17 lab sections of the Biological Principles II course. All TAs had little or no prior knowledge about the NOS or philosophy of science.

To overcome the variations amongst the TAs' prior teaching experience and background in NOS or philosophy of science, and to ensure for consistency, the researcher outlined a lesson plan as well as the post-activity discussion questions for both the TAs of the implicit and explicit groups. Students worked on the *Struggle for Survival* program for two weeks. Each of the 17 sections met for three hours per week. The inferential NOS was delivered to each section in the first week for 20 minutes after students had half-way completed an activity on the program that had implicit connection to the inferential NOS. Students then continued with the activity. This way, students had time to reflect on the explicit discussion of the target aspect of the NOS. The tentative NOS aspect was delivered to the students in the second week for 20 minutes and followed exactly the same format. The researcher also observed the delivery of the lesson plans to ensure that the TAs followed the outlines.

The intervention for the explicit group was to adhere to the following criteria:

(1) The teaching of the target aspects of the NOS includes the provision of opportunities for students to analyze the finch activities from different perspectives, such as the NOS framework, and to draw an association between their activities and the work of others, such as scientists. This will be accomplished through discussions associated with the finch activities.

(2) The instruction of the target aspects of the NOS is embedded in specific science content (the theory of evolution and the Galapagos finches), which will provoke the students to reflect upon their personal understanding and views of the NOS as they relate to the activities.

(3) Students engage in inquiry-based activities in conjunction with discussion about various aspects of the NOS, which will encourage students to reflect on their experiences within a conceptual framework to clarify certain aspects of the NOS.

In contrast, the intervention for the implicit group (Appendix 3) revolved around the same aspects of the scientific knowledge but without specifically referring to the target aspects of the NOS.

Procedures

The 17 introductory biology course sections were randomly assigned to two groups; an implicit group and an explicit group. Nine graduates TAs delivered the intervention to the students. To control for the TAs' views of the NOS, as well as their teaching experiences, VNOS-C (Appendix 4) and interviews were administered to the TAs prior to intervention delivery. The researcher coded and assessed the TAs' views of the NOS and, as a result, assigned them purposefully to their respective group (implicit or explicit). To control for time on task, the researcher also tutored those TAs who were assigned to teach the implicit group using a lesson plan that is implicitly geared toward the target aspects of the NOS. Both groups utilized the technology software *Struggle for Survival*.

To establish the reliability of the pre-and post-test scoring and to minimize the author's bias, two research assistants were trained to score and code the pre- and post-test for both the implicit and explicit groups. The two evaluators were selected based on their prior experience in the NOS or philosophy of science in that they held moderate understanding of the NOS, and their interest in the study. Prior to the commencement of coding the assessments, the author spent four one-hour sessions training TAs about the nature of study, the NOS, and the scoring rubric for the VNOS-C. The author used tests from two previous pilot studies to train the evaluators on how to interpret and code the VNOS questionnaire. Using the Cronbach, an interceder agreement coefficient was 0.86.

The evaluators graded about two-thirds of the VNOS-C & D questionnaires. Each VNOS questionnaire took about ten minutes to grade. The author graded the remaining questionnaires and served as an expert grader when the evaluators were not confident in their grading of a particular response.

Data Analysis

Quantitative and qualitative methods were used to analyze the data. Quantitative analysis was limited to testing for a potential statistical significance between the intervention and the two groups. This was used as a preliminary tool to obtain a quick, preliminary analysis of typical cases and to create a map of outliers as a means to facilitate further in-depth investigation.

Quantitative Analysis

The data were entered in SPSS software. They were then analyzed using Chi-square test for independence, a method that determined whether the two categorical variables were associated or not associated. The students' understanding of the NOS (informed, naïve, uncategorized), as measured by pre- and post-tests, served as the dependent variable. The 95% confidence level ($p<.05$) was used as the criterion level for determining statistical significance.

Qualitative Analysis

Qualitative research was the primary method used to analyze the data. This is due in part to the type of instrument used in collecting the data but, more importantly, due to the major role qualitative research plays in investigating the relationships and patterns between variables and subjects where little is known beforehand. Students' views regarding the target aspects of the NOS were coded using one of the three possible levels (informed, naïve, uncategorized). This categorization scheme is similar to that found throughout the literature (e.g. Khishfe & Abd-El-Khalick, 2002; Akerson et al., 2000; Abd-El-Khalick & Lederman, 2000).

Findings

The quantitative results of the study are presented first, followed by the qualitative analyses. Students' responses are categorized by a letter and a number to facilitate the data analysis process. The letters "IM" and "E" denote students in the implicit and explicit groups, respectively. The responses of students in the implicit group are each assigned a number from 1 to 97. The responses of students in the explicit group are each assigned a number from 1 to 143. The interviews are denoted by the letter "I" and are each assigned a number from 1 to 11.

Results

Research Question One (RQ1): What range of views of the inferential and tentative NOS do students enrolled in an introductory college course hold?

RQ1: Quantitative Results

Analysis of students' pre-intervention NOS views as provided by the VNOS questionnaires revealed that there was no statistically significant difference between implicit and explicit groups in both targeted aspects of the NOS (Tables 1a & b). An analysis using *Chi-squared test for independence* yielded (P = 0.18) and (P = 0.34) for the pre-questionnaire of inferential and tentative NOS, respectively. 'Naïve' or 'not categorized' views regarding the inferential NOS were given by 183 out of 240 students across both the implicit and explicit groups; and for the tentative NOS, 176 students across groups. Only 18 (19%) students in the implicit group and 39 (27%) students in the explicit group had informed views regarding the inferential NOS (Table 1a). Moreover, 27 (28%) students in the implicit group and 43 (30%) in the explicit group manifested naïve views concerning the same target aspect of the NOS (Table 1a). The number of students holding an informed view regarding the tentative NOS was 28 (29%) for the implicit group and 36 (25%) for the explicit group (Table 1b). Naïve views in reference to the tentative NOS were given by 24 (24%) students in the implicit group and by 48 (34%) students in the explicit group.

Table 1a: The inferential NOS (Pre-questionnaire)

Group	Category			
	Informed	**Naive**	**Not Categorized**	**Total**
Implicit	18	27	52	
Expected Value	23.038	28.292	45.671	97
(%)	18.56	27.84	53.61	
Explicit	39	43	61	
Expected Value	33.963	41.708	67.329	143
(%)	27.27	30.07	42.66	
Total	57	70	113	240

Statistics	DF	Value	Prob
Chi-square	2	3.42	0.18

Table 1b: The Tentative NOS (Pre-questionnaire)

Group	Category			
	Informed	**Naive**	**Not Categorized**	**Total**
Implicit	28	24	45	
Expected Value	25.867	29.1	42.033	97
(%)	28.87	24.74	46.39	
Explicit	36	48	59	
Expected Value	38.133	42.9	61.967	143
(%)	25.17	33.57	41.26	
Total	64	72	104	240

Statistics	DF	Value	Prob
Chi-square	2	2.1468	0.34

RQ1: Qualitative Results:

Students' Pre-intervention Views of the NOS.

The inferential nature of scientific knowledge. Of the 240 students, 183 articulated either naïve (N=70) or not categorized (N=113) views of the inferential NOS across the implicit and explicit groups. Students did not seem to understand the distinction between observation and inference.

In regard to item 5a and b (Form D), students thought that weather people were certain of their predictions of weather patterns. Three major trends were apparent in students' answers to this particular question. First, students seemed to think weather people are certain about weather patterns due to the use of technology. For example, one student articulated, "I think that they are pretty sure about their weather patterns… due to the technology today. They can see the patterns and see them unfolding to be able to predict and are very often correct (more correct than not)" (IM12, pre-questionnaire). Second, some students attributed the certainty of weather peoples' prediction of weather patterns to their education and knowledge. As one student explained "[Weather persons are certain] because they have gone to school and are educated in that specific area" (E52, pre-questionnaire). Third, students believed that knowledge of previous weather patterns enabled weather people to be sure of weather patterns. As one student noted:

I think they are fairly certain about the weather patterns…. because they have done the research about what types of patterns are preceded by. They can compare the present situation with similar situations in the past. They are usually educated enough to make logical and usually accurate assumptions and predictions (IM30, pre-questionnaire).

Some students explained that weather persons were not accurate in their predictions of weather patterns, which may indicate some informed understanding of the inferential NOS. For example, one student noted, “No, they look certain so they can keep viewers believing and watching them” (E136, pre-questionnaire). However, during further probing in the interview, the student articulated a naïve understanding of the distinction between observation and inference when asked, “Why do you think weather persons are not accurate in their prediction of weather patterns?” The student responded:

I would say that… after a while, if you are wrong over a certain amount of times, you begin to lose confidence in yourself. They have to do their job, so they have to make predictions—that’s what they are, basically just predictions (I10).

This response demonstrates a naïve view because the response lacks explicit mention of the role of observation and inferences in developing scientific knowledge.

Students’ views about the way dinosaurs looked, targeted in items 4a and b (Form D) also indicated lack of understanding of the inferential NOS. Most students believed that scientists rely on fossils to conclude the existence of dinosaurs, which shows that students have an informed view of the role of observation in the development of scientific knowledge. However, prior to the intervention, the majority of students across both groups suggested that scientists were certain about how dinosaurs looked, which indicates a naïve view of inference. As one student reasoned:

I believe dinosaurs do exist because of the fossils found when scientists have been out digging the ground. I don’t know if they knew exactly what those fossils were but if they said they were dinosaurs hell I believed them… They are pretty certain because with all of the pictures and sculptures that have been made, it seems to me like they have a pretty good idea (E71, pre-questionnaire).

A total of only fifty seven out of 240 students articulated an informed understanding of the difference between observation and inference. Those views are probably attributed to students’ previous learning and knowledge. Students’ informed views in regard to items 5a and b (Form D) indicate that weather people are not certain about weather patterns, as demonstrated in the following student response.

Yes to a certain degree… because with nature nothing is always 100% positive. The weather can change in an instant, but usually the computer models do a good job of telling weather persons what will happen with the weather" (IM85, pre-questionnaire).

In regard to scientists’ certainty of dinosaurs’ physical appearance (items 4a and b, Form D), all informed answers indicated that students held adequate understanding of the distinction between what is observed (fossils) and what is inferred (physical appearance). As one student pointed out:

Scientists rely on fossil evidence to prove that a group of species—dinosaurs—existed…Scientists only know what they can infer from fossil evidences. Just because they know the bone structure does not mean the proposed means of covering those bones—i.e., skin, hair—is accurate(E38, pre-questionnaire).

The tentative nature of scientific knowledge. Seventy-two of 240 students across the implicit and explicit groups responded that scientific knowledge is absolute. Item 6a and b (Form C) target a common misconception that theories can change but laws cannot. One student revealed this misconception in the response, “Theories aren’t certain so they do change. Laws such as gravity do not change” (E54, pre-questionnaire). Several other students expressed that scientific knowledge does not change. They cited another common misconception that theories and laws do not change primarily because they have a large body of evidence that supports them. For example, a student wrote, “Scientific knowledge will not change because theories and laws have undergone years of scientific testing, and have been called such theories and laws because the results of these tests have been consistent” (IM32, pre-questionnaire). Another student wrote, “I believe that scientific knowledge does not change. The reason they are called theories and laws are because there is factual proof that they are right. They were tested many times” (IM37, pre-questionnaire). Many students demonstrated that laws were superior to theories. One such student asserted, “Theories can become laws but laws don’t just decrease to theories” (I6).

In regard to item 9, which discusses the dinosaur mass-extinction controversy (Form C), many of the students stated naïve views of tentative NOS as they believed that only one hypothesis or scientist could be correct. One student responded, “The first one is possible because a meteorite could have hit the earth” (IM17, pre-questionnaire)

Only 28 students from the implicit group and 36 from the explicit group articulated informed views of the tentative NOS. One such informed student wrote,

Yes… because new discoveries are made everyday and scientific knowledge is always changing because science, as always, is a process. We can never know everything for certain because there is always something deeper to know or something else to experiment with (E79, pre-questionnaire).

Research Question Two (RQ2):

What is the effectiveness of an explicit versus an implicit teaching approach on increasing students’ understanding of the target aspects of the NOS during a technology-based laboratory project?

RQ2: Quantitative Results:

Analysis of the VNOS post-questionnaire showed that there was a statistical significance between implicit and explicit groups for both target aspects of the NOS, yielding ($p < 0.02$) and ($p < 0.002$) for both inferential and tentative NOS, respectively (Table 2a & b).

Table 2a: The inferential NOS (Post-questionnaire)

Group	Category			Total
	Informed	Naïve	Not Categorized	
Implicit Expected Value (%)	26 31.929 26.80	24 16.167 24.74	47 48.904 48.45	97
Explicit Expected Value (%)	57 47.071 37.06	16 23.833 11.19	74 72.096 51.75	143
Total	83	40	121	240

Statistics	DF	Value	Prob
Chi-square	2	8.3424	0.0154

Table 2b: The Tentative NOS (Post-questionnaire)

Group	Category			Total
	Informed	Naïve	Not Categorized	
Implicit Expected Value (%)	22 31.121 22.68	33 22.633 34.02	42 43.246 43.30	97
Explicit Expected Value (%)	55 45.879 38.46	23 33.367 16.08	65 63.754 45.45	143
Total	77	56	107	240

Statistics	DF	Value	Prob
Chi-square	2	12.5156	0.001

The number of students with informed views regarding the inferential NOS increased from 39 (27%) to 57 (37%), whereas the number of naïve views of the same target decreased from 43 (30%) to 16 (11%) in the explicit group (Table 2a). The number of students who articulated informed views regarding the tentative NOS in the explicit group increased from 36 (25%) to 55 (37%) and the naïve views decreased from 48 (34%) to 23 (16%) (Table 2b).

Research Question Three (RQ3): Do students' views of the target aspects of NOS change as a result of the explicit, inquiry-based approach?

RQ3: Qualitative Results

Students' Post-intervention Views of the NOS. Post-intervention NOS views of students in the explicit group were statistically significant in both the inferential and tentative NOS.

The inferential nature of scientific knowledge. In contrast to the pre-intervention, the results of post-intervention showed statistically significant differences between the implicit and explicit groups in regard to the inferential NOS (Table 2a). The number of students in the explicit group who reported informed views increased from 27% to 37%, while the students giving naïve responses decreased from 30% to only 11%. Interestingly, the number of informed views among students in the implicit group also underwent a slight change, increasing from 19% to 27%. To items 5a & b (post-questionnaire) student IM21 responded, "They are not certain when predicting weather patterns. They are to a certain degree based on knowledge and previous experiences. They are educated predictions with support but not 100%." When further probed during the interview with the question, "What type of information do weather people use to predict weather patterns?" this student articulated a more informed view regarding the distinction between observation and inference:

Research from the past, like past experiences, things that have happened over time (observations). Seeing this weather pattern happened and this is what happened when it rained. Things like that are used to predict things that happened over and over again. They're just patterns, overall patterns that they can use to predict what will happen (inference), like what the weather will be for tomorrow (I1).

A noteworthy finding in the explicit groups' post-intervention views regarding inferential NOS was students' ability to provide a richer, more pointed, informed response, as compared to pre-questionnaire responses, on the questionnaire items concerning dinosaurs, but not on questionnaire items concerning weather patterns.

As an example of a richer response to the questionnaire items about dinosaurs, one student noted: "Fossils have been found… [scientists are] quite certain. Using computers and the fossils that have been found scientist are able to construct life-like models of the animals" (E16, post-questionnaire).

In response to the questionnaire items about weather patterns, some students' views explicitly articulated "scientists use observation" to describe what weather persons' predictions are based on. An example includes the student response:

Weather predictions are made strictly by observing patterns of previous weather meteorological events; no one can [be certain of weather predictions] because we can only make predictions based on the probability of weather patterns, [which is] based on our previous observations of meteorological tendencies (E98, post-questionnaire).

The tentative nature of scientific knowledge. Compared to pre-intervention data analysis, the post-intervention results indicate a statistical significance between the implicit and explicit groups (Table 2b). For the tentative NOS, the number of informed responses in the explicit group rose from 25% to 38%, whereas the number of informed responses in the implicit group decreased from 29% to 23%. Similarly, the number of naïve views in the explicit group decreased from 34% to 16%, and in the implicit group increased from 25% to 34%.

Most students demonstrated more informed views of the tentative NOS after the intervention, as compared to their views prior to the intervention. These students responded that both theories and laws are subject to change as new information and technologies emerge, as evidenced in the following response:

Theories and laws are constantly changing because we are constantly studying and learning new things. With more knowledge we can clarify and better understand our theories and laws. We bother to learn theories and laws in an ongoing attempt to understand the world we live in (E22, post-questionnaire).

Furthermore, in response to item 9 (Form C), students demonstrated an informed view of the tentative NOS. Students believed that a scientist's individual interpretations and perspectives were considered when an inference (possible causes of dinosaurs' extinction) must be drawn in the absence of direct observation (a complete skeleton of a dinosaur). As one student wrote, "It is about interpretation! The scientists infer some data as true and some as false, and as a result, they interpret differently the data and ideas that are accepted and rejected" (E11, post-intervention).

The "uncategorized" student responses. The majority of pre- and post-questionnaire responses from both groups fell within the "uncategorized" group. This was not a surprising result, since there is great variability in the sample's science education background, and also because of limitations of the VNOS instrument used in the study.

"Uncategorized" views are those responses in which a student articulates informed views in one item and naïve views in another item for the same aspect of the NOS. As a reminder, items 4a and b and 5a and b from VNOS-D (Form D) were used to assess students' understanding of the inferential NOS, and items 6 and 9 from VNOS-C (Form C), the tentative NOS. As an example of "uncategorized" view, one student responded to item 4a and b, "No, they base their judgment on past weather patterns and how the weather acted then. They just look at how the weather was when the conditions were the same in the past and use their best judgment" (E106, pre-questionnaire). This response was somewhat informed because the student distinguished between what was observed (past weather conditions) and what was inferred (judgment) as well as elucidated the uncertainty of predicting weather patterns. However, the student failed to recognize the inferential nature of scientific knowledge (observation and inference) in item 5a and b. The same student replied, "They have found fossils of the dead dinosaurs in the ground. They are fairly certain but it really is only a theory and can change at anytime. I know they now think that velociraptors had feathers so it must be a constantly changing theory. A second student responded to items 5a and b, "They know from the dinosaurs' remains, fossils. I think they are at least 80% certain from the way their fossils were arranged" (IM81, post-questionnaire). Again, in this first response the student was able to differentiate between observations (fossils) and inferences ("80% certain" of dinosaurs' appearance). However, this student failed to recognize the inferential nature of scientific knowledge when answering item 4a and b: "No, weather persons are not certain, because their instruments predict the weather and it is never 100% sure. An example would be when the weather channels say it is going to rain and it does not."

One student wrote, "Technology and techniques improve. It helps us understand the world around us; for instance, why we don't float off the planet" (IM66, post-questionnaire). This student indicated that only with the advancement in technology and techniques does scientific knowledge change. Although the student held an informed view about the tentative NOS, the student was not able to say how. Advancement in technology is not enough for scientific knowledge to change. Scientific knowledge could also change as a result of discovering new knowledge (laws or theories) or reinterpretation of existing knowledge. The student also failed to give examples supporting the answer. Another student wrote, "Scientific knowledge is always changing. Research is continuous. It brings up new concepts/ideas. It tells us why things happen as they do. Example: evolution" (E114, pre-questionnaire). Again, the student did not elaborate why scientific knowledge changes

Research Question Three (RQ3): Do students' views of the target aspects of NOS change as a result of the explicit, inquiry-based approach?

RQ3: Semi-structured Interviews

This section highlights the student interviews, starting with students from the implicit group whose views did not change from pre- and post-intervention followed by students from the explicit group whose views also did not change. Next, the responses of students whose views did change from pre and post questionnaire, starting with the control group and followed by the explicit group, are analyzed.

Implicit group, naïve to naïve. Students of the implicit group whose views did not change revealed very repetitive patterns. In their response to items concerning the inferential NOS, students explained that just because weather persons went to college, they were capable of accurately predicting weather patterns. As an example, a student wrote, "I think they are pretty certain. They have been studying weather for a while and can predict it pretty accurate" (I4, post-questionnaire). These students failed to understand that weather persons use weather patterns or previous events as observations tools to infer the weather conditions for a particular day. Though they indicated that weather persons depend on previous events in their attempt to predict the weather patters, they failed to make a connection between weather patterns (what was being observed) and how the weather will be in the future (what was being inferred).

With reference to items targeting the tentative nature of scientific knowledge, students disclosed a common misconception that laws hold a higher status than theories and are considered proven facts, and as a result laws are not subject to change but theories are. One student said, “I don’t think they will move a law back to a theory. To me, a law has been proven. But theories haven’t been proven yet. It could change in the future” (I6, post-questionnaire). In addition, students were not able to understand how two scientists could interpret the same set of data differently (item 9, Form C). One student said, “I just don’t see how one can say it was a volcano that erupted and here he says a meteorite killed them” (I4, pre-questionnaire).

Explicit group, naïve to naïve. The responses of the students in the explicit group whose views did not change from pre- to post-questionnaires also revealed interesting trends in student conceptions of the NOS. Some were similar to those of the implicit group. Even though the former were exposed to intervention, their views for the most part remained the same. Regarding the inferential NOS, two of the three students selected for the interviews reported naïve views. They believed that weather persons base their prediction of weather on previous events (observation) and therefore are rarely wrong. One student stated, “Weather persons are pretty certain because I watch the news and 99% of the time they are right. Because I have not seen them make many mistakes” (I10, pre-questionnaire).

In the case of the dinosaur scenario, this group of students believed that scientists were fairly certain about the existence of dinosaurs because of fossils. However, on further probing during the interviews, these students did not appear to understand the difference between the way scientists describe the appearance of dinosaurs (inference) and fossilized bones on which such descriptions are based. For example, one student claimed that scientists collect enough fossils that they can put together a good example of how dinosaurs looked. The researcher asked the student, “How certain are scientists about the classification—skin texture and color of dinosaurs, for example?” The reply was, “Scientists are very certain about the texture of their skins and sizes as well as the classification of dinosaurs because they found skeleton models deep down in the earth or just found different fossils” (I10, post-questionnaire).

Implicit group, naïve to informed. Students in the implicit group whose views changed from naïve to informed revealed slightly different conception patterns from those of the previous two groups. Analysis of the post-test questionnaire and interviews showed that this group understood the distinction between observations and inferences. They seemed to comprehend the role of inference in developing scientific constructs. Those views didn’t exist in the pre-test questionnaire. For example, on the topic of weather persons predicting the weather patterns, this group of students typically responded that weather persons based their predictions on knowledge, current and previous evidence, and experiences (observation), to predict weather patterns (inference).

They are not certain when predicting weather patterns. They are certain to a degree based on knowledge and previous experiences. Their educated predictions support but are not 100% certain. You can never be 100% certain, that’s why they are called predictions (I1, post-questionnaire).

Explicit group, naïve to informed. The post-intervention views of the explicit group showed more informed understanding of the target aspects of the NOS than the other groups. Students in this group were able to adequately understand and appreciate the role of observation and inference to develop scientific constructs in the context of weather predictions. In addition, they were able to realize that theories and laws are not absolute. This group of students used more sophisticated and scientific terms and phrases explicitly, such as “observations”, “predictions”, “collecting data”, and “generating hypotheses”, than the previous group.

In response to the question, “How certain are weather persons in predicting the weather?” students were able to recognize the role of observations in the development of scientific constructs. One student noted:

I don’t think you can ever be truly certain about predicting the weather, because it is something that in no way can be controlled. By studying and observing the weather over time, you are able to see patterns in the weather and are able to predict how the weather is going to be based on these patterns (I8, post-intervention).

In addition, students in this group provided rich examples of how uncertain weather persons could be of their prediction, thus reemphasizing the role of observations and inferences in the development of scientific constructs. For instance, one student articulated, “Weather persons have an idea about the weather patterns, but they don’t know the scenario of the weather at any given time. They can see the weather patterns for the condition of a tornado but don’t know for sure if a tornado will occur” (I7, post-intervention).

In response to the questionnaire item about dinosaurs, the students expressed a similar informed understanding of the inferential NOS. They noted that scientists use evidence such as fossils and radiocarbon dating to infer dinosaurs’ existence and their physical appearance. They also noted that scientists are not certain about dinosaurs’ physical appearance and that all scientists can do is to deduce the appearance of dinosaurs from the evidence they have gathered together, in an effort to construct a probable model. For example, one student responded:

Scientists are very uncertain of how dinosaurs looked. Some believe that dinosaurs had scaly skin just like reptiles today. However, many scientists believe that some dinosaurs have feather-like structures. At best, all theories are educated guesses based on observations (I9, post-intervention).

Post-intervention views of the same students regarding the tentative nature of scientific knowledge are more informed than those of the previous group. Students were able to articulate that scientific knowledge (theories and laws) are subject to change and validated their responses with rich examples. One student in particular showed more informed views than the other two: "Scientific knowledge is always subject to change because, in the world of science, nothing is proved, it is only supported. History attests to this with such ideas as Lamarkism and the belief that the world is flat" (I9, post-intervention). Students also demonstrated informed views regarding the mass-extinction dinosaur controversy. They pointed out that both explanations were possible because scientists interpret data differently. "Yes [both explanations are possible] because it shows how much mystery is involved in interpreting what one calls the data. It's the same thing as when two people see the same event and have two different stories about what happened" (I7, post-intervention).

Interestingly, this group of students attributed the change of view between pre- and post-intervention responses to the Galapagos Finch laboratory activity. In regard to the inferential NOS, one student said:

I guess the finch thing [changed my view] … especially when we had to look at the weather pattern to see what caused some finches to die…It said that the scientists had no idea what was going on then, and that influenced me to believe more that they really did not know 100% what was going on (I7, post-intervention).

Another student confirmed, "We discussed it [the finch activity]. It probably had a greater effect in general—just being able to think" (I8,post-intervention). On the subject of the tentative NOS, students also attributed the change in views to the finch activity, as one student wrote "the lab in general and the finch activity where we had time after the activity to discuss different people's opinions. It was also more interactive, attention-grabbing and user-friendly" (I9, post-intervention).

Discussion, Conclusions, and Recommendations

Discussion

What distinguishes this study from previous ones is that the findings here provide evidence that teaching the NOS can be achieved through short intensive discussion and does not necessarily require separate and independent courses similar to those developed by Abd-El-Khalick & Lederman (2000) and Kenyon & Chiappetta (2003). This is not to say that universities and colleges should not develop separate and independent courses to teach students about the NOS; however, universities and colleges may no longer need to allocate an entire course or semester to teach the NOS. Thus, a major finding of this study provides an immediate solution for universities and colleges which often cite time limitations as the reason for not incorporating the teaching of the NOS into their curriculum.

The present results were influenced by four factors, all of which are well-documented in relevant literature (e.g. Khishfe & Abd-El-Khalick, 2002; Abd-El-Khalick & Lederman, 2000; Lederman, 1992). The first was the duration of the intervention. Though the two targets aspects of the NOS were taught to the explicit group for only 40 minutes, or 20 minutes each, positive results were attained.

The second factor was the TAs' educational background. The TAs came from different NOS and teaching experience backgrounds. The researcher attempted to control this variable by developing a lesson plan for each group. However, the TA may have used his/her prior teaching and NOS experience during the delivery of the lesson plan. This definitely could have affected students' responses to the questionnaire: students with a more experienced TA may have demonstrated a better understanding of the targeted aspects of the NOS due to possibly enhanced instruction.

The third factor is the use of technology. Based on the assumption that the technology used (*Struggle for Survival)* is not a biased program, it may have negatively or positively influenced students' views of aspects of the NOS. Students who had a positive attitude toward technology may have thought of it as an effective learning tool and may have used technology to develop various scientific inquiries and process skills. At the same time, students who had a negative attitude toward using technology may have found it hard to develop scientific inquiry and process skills, and ultimately not been able to understand how aspects of the NOS and such skills are interrelated.

The final factor is that more students demonstrated an informed view of the inferential NOS in their responses to and discussions on the dinosaurs questionnaire item 5a and b (Form-D) than on the weather prediction questionnaire item 4a and b (Form-D). This supports the conclusion that changes in students' views of the NOS depend on the content and context in which aspects of the NOS are taught. This factor is consistent with what Khishfe & Abd-El-Khalick (2002) reported.

Conclusions

The results of the pre-questionnaire for both the explicit and implicit groups demonstrate that a majority of the students held naïve views of the two target NOS aspects. These results are consistent with those from previous studies that evaluated college students' views of the NOS (e.g. Kenyon & Chiappetta, 2003; Scharmann, 1990) and those that evaluated elementary and secondary students' views of the NOS (e.g. Bady, 1979; Meichtry, 1992; Tamir & Zohar, 1991; Lederman, 1986a, 1986b; Khishfe & Abd-El-Khalick, 2002). These results demonstrate that a tremendous effort is still needed in order to accomplish the goal of the current science education reform regarding the improvement of students' views of the NOS.

In addition, the results further support and confirm the claim that effective teaching of the NOS is achieved when its instruction is "contextualized and woven into inquiry activities and teaching about science content and process skills" (Khishfe & Abd-El-Khalick, 2002, p. 573). The *Struggle for Survival* finch activities emphasized content as well as science process skills for implicit and explicit groups. The quantitative and qualitative results of the study indicate that the implicit group students' views regarding the target aspects of the NOS did not improve. However, when explicit instruction of the target aspects of the NOS was embedded within these activities, the outcome was more promising. This finding is consistent with Khishfee & Abd-El-Khalick (2002) and Akerson; Abd-El-Khalick & Lederman (2000).

Finally, the results suggest that explicit instruction is a more effective method for developing college students' views of the NOS than the implicit approach. There was a statistically significant difference between students' post-questionnaire views and pre-questionnaire views in the explicit group for the target aspects of the NOS. Pre- and post-questionnaire views of students in the implicit group, however, did not reflect a statistical difference. This finding is consistent with that reported by Moss; Abrams & Kull (1998) who carried out an implicit approach that used only inquiry-based activities to teach secondary students about aspects of the NOS.

Students' Findings group were not surprising. The implicit approach stipulates that students will develop an understanding of the NOS just by being involved in inquiry-based activities and learning about science process skills. Thus the findings from the implicit group have undermined the central contentions of the implicit approach.

Recommendations

This study outlines the following implications and venues in regards to future research. First, the results of the present study suggest that teaching aspects of the NOS could be achieved through short intensive discussion when embedded within a framework of content-related inquiry activity. This study emphasized only two aspects of the NOS, however the implication for science educators and science teachers (in K-12 and colleges) is that additional aspects of the NOS could be taught using a similar approach in order to evaluate effectiveness. Furthermore, the findings of the study offer a research venue for science educators to do more research to evaluate whether short intensive discussions that are repeated for multiple time periods are more effective than separate and independent courses when more aspects of the NOS are incorporated within a content-related inquiry-activity over a semester-long course. The findings of the study should also encourage science teachers in middle and secondary schools to use science inquiry-based activities more effectively. Teacher-facilitated discussion, even as short as 10 minutes**,** may be used for productive lecturing about some aspects of the NOS. However, science teachers should be reminded that teaching aspects of the NOS is most effective when it is embedded within an inquiry-based activity. Most importantly, science teachers must know when and how to effectively contextualize aspects of the NOS into such activities.

Second, the findings were limited only to students who were enrolled in an introductory biology course. Views of the NOS of this student population are not representative of any other population. Therefore, more studies that use explicit instruction of NOS with different populations are desired to establish the validity of the present results. Third, more research is needed to assess the effectiveness of teaching aspects of the NOS when it is contextualized into a conceptual change approach, which itself is well-supported by the literature (e.g. Akerson et al., 2000; Khishfe & Abd-EL-Khalick, 2002) as an effective approach to facilitate change in views of the NOS.

Finally, the interview results of this study indicate that some students attributed changes in their views of the target aspects of the NOS to the *Struggle for Survival* program. Therefore, further investigation of how technology may help students to technology's potential to help students enhance their views of the NOS is needed.

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APPENDICES

Appendix 1: Selected Items for both VNOS-C and D

VNOS-D (Inferential NOS)

4. (a) How do scientists know that dinosaurs really existed?

(b) How certain are scientists about the way dinosaurs looked?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

(a) Do you think weather persons are certain (sure) about the weather patterns?

(b) Why or why not?

VNOS-C (Tentative NOS)

(6). 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.

(9). It is believed that about 65 million years ago 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?

Appendix 2: Explicit Lesson Plan

Objectives:

- Students will be able to understand the tentative and inferential aspects of the nature of science.
- Students will be able to relate the Galapagos Finch activities to aspects of the nature of science.
- Students will be exposed to the explicit approach of teaching the nature of science.

Procedures:

- The TA introduces the primary objective of the finch activities: “It is your job to determine what happened to the finch population by forming hypotheses and using relevant data to support these hypotheses.”
- Students do Activity #1 (formulate hypotheses based on the four given explanations).

(1) Observation and Inferences

- Examples: The TA introduces the following two examples to demonstrate that inferences can be made about an incident even if no witness is present.
  - *Forensic scientists gather evidence of a crime seen after the crime has been committed.*
  - *A dry spot is found after a rainy day, how? A car must have been parked in that spot.*
- The TA then hands students a chart. The chart includes the following columns: selected hypotheses, supporting observation, non-supporting observation, and interpretation (inference).
- The TA then tells the students that what they have been doing is gathering evidence to either support or refute their scientific claims (hypothesis). Then students are asked: “ What is the evidence they have collected based upon?”
- The TA should scaffold students to say the evidence is based on observation. Then the TA asks the students what particular senses they used to observe the data, for example, the sense of sight (the TA awaits students’ responses).
- Then the TA poses the following question: “What happens after a scientist observes evidence of something?” The TA scaffolds students to say they would interpret the evidence.
- The TA now asks students to differentiate between observations and inferences.
  - *Science is based on both observations and inferences. Observations are gathered through human senses or extensions of those senses. For example, students should be reminded that they are*

observing what happened to the finch population over the years and thus they are gathering evidence to formulate their hypotheses. Inferences are interpretations of those observations. Again, students are reminded that they should formulate their hypotheses based on their inferences of gathered observations.

- The TA asks the students to search for examples from the activity that demonstrate the inferential aspect of NOS.

(2) The Tentative Nature of Scientific Knowledge

- Have students look in their chart again and ask them if any non-supportive evidence of the hypotheses is found. If such evidence is available, ask them what will happen to such a hypothesis(s). The TA should scaffold students to say that such a hypothesis should be discarded, (ask them why). If such evidence is unavailable, ask what will happen to such a hypothesis, (the hypothesis must undergo further investigation).
- The TA now poses the following questions: "Does scientific knowledge change, or is it absolute? For example, once a theory such as evolution or plate tectonics has been developed, is it subject to change? Explain why or why not? Give examples if possible."
- The TA then asks "The history of science is full with examples of scientific theories that have been discarded or greatly changed. The life spans of theories vary greatly, but theories seem to change at one point or another. And there is no reason to believe that the scientific theories we have today will not change in the future. Why do we bother learn about these theories? Why do we invest time and energy to grasp these theories?"
- The TA awaits students' responses.

o *Yes. Theories and laws are tentative and subject to change with new observations and with the reinterpretations of existing observations. Scientists are never completely sure of anything because negative evidence will call a theory or law into question, and possibly cause a modification. For example, while the theory of plate tectonics is widely accepted, it never completely ruled out the two previous dominant theories (continental drift and sea-floor spreading) that explained dynamics of the earth.*

Appendix 3: Implicit Lesson Plan

First Finch 20-minute Discussion

Instructor should help students brainstorm for possible hypotheses. Pick out two or three and write them on the board. Try not to choose the mainstream hypotheses (especially beak size). .

Questions:

What makes a good hypothesis?

What does it mean to be testable?

Why should you think of multiple hypotheses?

Second Discussion (20-minutes)

Brainstorm with the students about your earlier hypotheses and about the data they might need to support or disprove those hypotheses. Focus on graphing. Pick a

hypothesis and draw the ideal graph to support or disprove it. This will help the students acquire the data they need.

Questions:

What data would you need to support or disprove these hypotheses?

Do you have the data you would need in the finches dataset?

What would your graph need to look like?

Appendix 4: Views of nature of science questionnaire, Form C (VNOS-C)

VNOS-Form 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?
3. 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.

4. 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.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
6. 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 that 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?

7. 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?

8. 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 of 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 answers?

9. 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 practiced.

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

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during investigations?

- If yes, then at which stages of the investigations 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.

Adapted from (Lederman et al., 2002)