Comparing inquiry & traditional instruction: Understanding the nature of science in non-science majors

Subject/Problem: In many science classrooms in schools and colleges, students are taught to recite content rather than understand it. This has created a population of learners with only a superficial understanding of what they have learned. Schneps and Sadler (1988), for example, found that while college graduates knew the earth traveled around the sun in a year's time, a large majority did not know what caused the four seasons during the voyage. In another study, students could perfectly describe the hydrological cycle (water cycle) but did not know what would happen if water ended up in a plant system rather than stream/lake system (Lord 2006). The culprit to this dilemma isn't knowing the content with its facts and terms, but rather in understanding the content with its inferences, analyses and applications (Hanum and Briggs1992). Many educational researchers suggest that change in teaching style is overdue and have recommended a more constructivist approach to teaching (Good 1993, Yager 1991). Students need to understand that science isn't knowing terms and formula or following formatted lab experiments; science is developing new ideas and relationships and devising investigations to test the ideas. Many of these researchers have suggested inquiry teaching, also called scientific teaching, is the best way of achieving this (Handelsmen et al. 2004). Bell, Binns, and Smetana (2005) define inquiry teaching as a form of instruction in which students take an active role in learning and teachers emphasize questions, data analysis, and critical thinking. It's a form of constructivism that teaches concepts through discovery, and educators develop unique experiments where answers are unknown.

Design/Procedure: To see if inquiry instruction produced better results than direct instruction for students to learn and perform science of instruction and influence their understanding of the nature of science, the writers studied students taking an environmental biology course for non-science majors over a year and a half period of time. Typically, students who enroll in this course were of sophomore or junior standing. A preliminary questionnaire of all participant indicated they had taken very few college science courses and, for the most part, did not feel comfortable taking a science course in any discipline.

The non-majors class (environmental biology) consisted of two hours of class and two hours of lab each week and enrolled 35 - 40 students in each of the semesters. A three-fold experimental design of a control, experimental and placebo population was employed for this study. The study was conducted during the weekly laboratory component over three separate semesters. During the initial semester, the students in a traditional taught class were evaluated as the control group; the following semester students with inquiry instruction were evaluated as the experimental population, and during the third semester, students in the placebo group were taught using traditional teaching methods but received different introductory materials than had the control group. For the most part, this treatment consisted of historical information relevant to the respective experiment but designed to have no bearing on the experiment's outcome.

To assess the students initial understanding of the nature of science, each participant in the class was administered a pretest called the Views of the Nature of Science questionnaire designed by Lederman and O'Malley (1990). The exam is open ended and designed to gauge the participants' under-standing of how science is actually done. Lederman et al. (2002) acknowledge there are two compatible versions of the exam to measure pretest-post test reliability. In this study the tests were administrated under controlled conditions in the classroom by a third party to reduce any unwanted influence. There was also no set time limit for the completion of the test. In addition, the instrument was analyzed using a rubric developed by Lederman for scoring by a third-party to assure that unwarranted bias did not enter the analysis.

At the conclusion of the semester students from all populations were given the second version of the Views of the Nature of Science questionnaire. The same procedure that occurred in the pretest was followed for the administration and scoring of this exam. Results of the exams were compared between the three populations to assess which teaching strategy was most effective in conveying the nature of science.

Participant Groups:

Control Group: This group was instructed in a direct, teacher-centered manner (the placebo population was also taught with the same techniques) and laboratories were designed to give students the instructions they needed to follow in order to complete the experiment ("cookbook"). Little or no conceptual questions were asked during the period, and students received direct and definitive answers when questions arose.

The class structure was a blend of both indoor and outdoor challenges. For example, all students were required to test the health of a local stream; the control population received explicit instructions on how to evaluate this. Prior to the excursion, the instructor informed the class of some general scientific techniques used to access stream health, like measuring pH, turbidity, and oxygen content. Also, students received a pre-made chart, hat they were required to complete with their respective data by the following week.

Indoor laboratories were utilized when weather conditions no longer allowed for outdoor experiments. An example of an indoor investigation would be for students to perform an activity to discover the concentration of sodium chloride in which grass seeds ceased germination. For the control population, participants received explicit instructions on performing the experiment (Fig 3.); also, instructors precisely answered all student questions, that is, no conceptual questions were queried. Finally, each student received a data template that only required them to fill in tables and graphs.

Experimental Group: The experimental group abided by the same syllabus as the control and placebo groups, thus they experienced the same indoor and outdoor laboratories. In the laboratories, however, they did not receive explicit instructions on how to successfully complete the experiment. Instead they were given a specific challenge, and asked to develop their own experimental procedure to discover the solution. In the stream analysis described earlier, members of the experimental population were not directly informed on the techniques used to assess water quality. Instead, the instructor provided the students with a brief background on water quality, and gave a challenge to the students to assess its health. Next, students were shuttled to the field site and were be required to develop their own procedure to access the quality of the stream. They were asked to keep accurate data and develop their own charts and graphs to represent their findings.

The indoor laboratories were also the same for the experimental population; however, following inquiry guidelines, students did not receive explicit instructions. In the toxicity experiment, for example, teams were presented with the challenge to determine the concentration of sodium chloride that would result in zero grass seed germination. The students were given the freedom to choose any tools needed; an abundance of materials, many not useful, were provided in the room. Throughout the period, the instructor traveled around the room to guide students, that is, they did not give direct answers but provided a hint in the right direction. Students were required to record accurate data and devise their own graphical method for displaying their results (no templates were given).

Placebo Group: The placebo group followed the same protocol as the control population, but they also received a short placebo intervention. The placebo treatment consisted of extra background of each particular experiment. This extra information was designed to have no effect on the participants' nature of science levels. Instead it was provided to instill a feeling of special treatment to the students.

Analysis and Finding The results of the control population show no significant difference between pre-tests and post-test, ($P>.05$). Surprisingly, for many of the participants in the control group, the pre-test scores revealed a higher average in understanding of the nature of science than did the post-test (44% vs. 41%).

Results, however, show a significant difference ($P<.05$) between pre-test/post-test for the experimental population. On the experimental pre-test scores, participants showed an average of 43%, and on the post-test they scored an average of 47%. Therefore, unlike the control group members, the majority of the students performed better on the post-test in the experimental population

The placebo population demonstrates results similar to the control population; here there was no significant difference between the pre-test and post-test scores. Placebo pre-test scores an average of 40% and a post-test score average of 38%. These results coincide with the control population, which also performed worse average scores on the post-test.

TABLE 1: Results for the Scheffe and Tukey contrasts performed for the pre-test and post-test

Pre Test						95% Confidence Interval	
	(I) VAR	(J) VAR	Mean Diff.	Std. Error	Sig	lower	upper
Tukey	Con.	Exp.	.0153	.0196	.72	.0315	.0623
		Plac.	.0436	.0188	.06	.0011	.0885
	Exp.	Con.	-.015	.0196	.72	.0623	.0315
		Plac.	.0282	.0169	.22	.0121	.0686
	Plac.	Con.	-.043	.0188	.06	.0885	.0011
		Exp.	-.028	.0169	.22	.0686	.0121
Scheffe	Con.	Exp.	.0153	.0196	.74	.0336	.0643
		Plac.	.0436	.0188	.07	.0031	.0904
	Exp.	Con.	-.015	.0196	.74	.0643	.0336
		Plac.	.0282	.0169	.25	.0139	.0704
	Plac.	Con.	-.043	.0188	.07	.0904	.0031
		Exp.	-.028	.0169	.25	.0704	.0139

Post Test						95% Confidence Interval	
	(I) VAR	(J) VAR	Mean Diff	Std. Error	Sig	lower	upper
Tukey	Con.	Exp.	-.072	.0236	.01	-.129	-.016
		Plac.	.0103	.0225	.89	-.043	.063
	Exp.	Con.	.0728	.0236	.01	.016	.129
		Plac.	.0831	.0208	.00	.033	.132
	Plac.	Con.	-.010	.0225	.89	-.063	.043
		Exp.	-.083	.0208	.00	-.132	-.033
Scheffe	Con.	Exp.	-.072	.0236	.01	-.131	-.014
		Plac.	.0103	.0225	.90	-.045	.066
	Exp.	Con.	.0728	.0236	.01	.014	.131
		Plac.	.0831	.0208	.01	.031	.134
	Plac.	Con.	-.010	.0225	.90	-.066	.045
		Exp.	-.083	.0208	.00	-.134	-.031

Scheffe and Tukey statistical contrasting tests were performed on the pre-test and post-test for all three groups. The results of these instruments show no difference among the three populations for the pre-test. However, both the Tukey and the Scheffe test show the experimental group significantly differing from the control and placebo populations for the post-test (TABLE 1).

These results are consistent with other studies involving traditional and inquiry teaching techniques (Hannum 1992). Research performed by Anastasiow, Borich, and Leonhardt (1970) showed that students instructed in a traditional manner throughout the term didn't understand how science was done at the course conclusion.

Pre-test and post-test scores for the experimental population did show a significant difference (P<.05). With this data, it can be conclude that inquiry instruction is an effective teaching method for raising the understanding of the nature of science. Lederman et al. (2002) found that nature of science levels were increased when a thorough understanding of seven target nature of science aspects are achieved. These aspects are: 1) scientific knowledge is subject to change, 2) knowledge is empirically based, 3) it is theory laden and subjective, 4) it is the product of human imagination and creativity, 5) it involves the combination of observation and inferences, 6) laws and theories play an important role in developing new ideas, and 7) scientific ideas are validated by repetition and peer reviewing. Because the nature of science levels was increased in the experimental population, it can be concluded that inquiry instruction is an effective teaching strategy in conveying the seven target aspects. Through the development of their own laboratory procedures and the interpretation of their data, students were able to raise their understanding of the nature of science.

Pre-test and post-test nature of science scores for the placebo population showed no significant difference and was consistent with the control population. The results of this population strengthen the notion that inquiry teaching is more effective than traditional teaching, because students in the experimental population may have experienced a feeling of special treatment, which could have influence the final results. However, because no significant difference was found in the placebo group, the special treatment explanation for increased nature of science levels is annexed.

The Tukey and Scheffe test were performed on the pre-test and post-test for all the populations to pinpoint the difference among all three groups. These tests compared the means of every treatment to the means of every other treatment and identified where the difference between the two means was greater than the standard error would be expected to allow. For the pre-test, both test showed no difference between the control, experimental, and placebo groups. We can conclude that all three non-science major populations initially possessed similar nature of science levels. However, both the Tukey and the Scheffe tests showed significant differences in the post test for the experimental population when compared to the other groups. This data suggests that the experimental population was unique when compared to the control and placebo.

Contributions: This study supports the conclusion that inquiry instruction is an excellent method for conveying the nature of science to non-science majors. Not only does the data find a significant difference on the understanding of the nature of science in an inquiry-based instructed classroom, but that the Tukey and Scheffe contrasting instruments pinpoint the difference among all three populations to the post-test for the experimental population. Thus, we can confidently state that inquiry instruction conveyed the target nature of science aspects more effectively than traditional instruction. These results are similar with other studies comparing inquiry and traditional instruction. In several studies, inquiry instruction reigned superior over traditional techniques in raising course grades and attitudes (Travis 2004, Bell et al. 2005).

General Interest: This study would be of interest to contemporary college science educators who are contemplating introducing inquiry instruction to their teaching. The study forcefully supports the notion that traditional, teacher-centered, instruction does not create learners who understand how science is actually performed.

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