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CHEMISTRY TEACHING FELLOWS' UNDERSTANDING OF THE NATURE OF SCIENTIFIC THEORIES AND LAWS

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Abstract. *The purpose of this study was to assess five chemistry teaching fellows' understanding of the characteristics and functions of scientific theories and laws, as well as the relationships between them before and after an intervention. The chemistry teaching fellows were participating in a University-School partnership project funded by the National Science Foundation in USA. Data were collected through pre-and post-test questionnaires and semi-structured interviews. Data were analyzed by coding the responses to identify recurring themes. Results show that before instruction most fellows held un-informed views on the characteristics of scientific theories and laws, their functions and relationships. However, after the intervention most participants developed better understanding of these concepts. Four types of relationships between scientific laws and theories emerged from participants' responses: discrete, intertwined, concentric, and cyclical. The findings have significant implications for teacher education, science teaching and learning, and training of graduate teaching assistants at the university level.*
Key words: *science, nature of science, theory, law, chemistry.*

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Introduction

Current science education reforms in the USA accentuate the development of scientific literacy among students through the understanding of science concepts, process skills and the nature of science (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). In response to these reforms, the National Science Foundation (NSF) has implemented a nationwide NSF GK-12 program aimed at developing scientific and mathematical literacy among K-12 students by involving graduate and advanced undergraduate students (Teaching Fellows) in mathematics and science classrooms to provide content and pedagogical support to K-12 teachers. The acronym GK-12 stands for Graduate Teaching Fellows in K-12 Education (NSF, 2000). The fellows also act as science and mathematics role models in the classrooms to foster a positive attitude towards scientific and mathematical fields among K-12 students. The NSF also anticipates that after serving in the GK-12 program these future scientists and mathematicians will continue to contribute towards the improvement of the nation's educational enterprise. In addition, future K-12 education environments will benefit from the contributions of these professionals, who will have classroom experience and an understanding of science and mathematics education. These future scientists are also expected to learn how to communicate scientific knowledge and the process of inquiry to diverse novice learners in K-12 educational settings. Thus, the NSF GK-12 program assumes that the teaching fellows have sound science content knowledge, investigative skills, understanding of the nature of science, and abilities to translate their knowledge and skills to a level that students and teachers can attain. Without such translational abilities, their knowledge and understanding of science would remain as tacit knowledge (Polanyi, 1962) and unavailable to K-12 students and teachers. Research also suggests that individuals who are engaged in promoting scientific literacy among K-12 students should have informed understanding of science content knowledge, and the nature of science (Pomeroy, 1993) and that science teachers do not teach what they do not know or understand (Mellado, 1997). As such, the teaching fellows who are the agents of scientific literacy in USA schools through the NSF GK-12 program are expected to have a good understanding of science and its characteristics if they are to contribute to the development of scientific literacy among the K-12 students and teachers they are serving across the US. Therefore, it is most likely that the teaching fellows serving in the GK-12 program will attempt to teach more about the aspects of the nature of science in schools after they, themselves, have developed a sound understanding of the concept. Although many science educators disagree with this assumption, some studies (Aquirre, Haggerty & Linder, 1990; Abd-El-Khalick, & Lederman, 1998) show that teachers attempt to teach the aspects of the nature of science after receiving instruction on the concept.

In view of the above, one NSF GK-12 project found it appropriate to explicitly provide instruction on the nature of scientific theories and laws to its five chemistry teaching fellows. The chemistry teaching fellows were training to be scientists and not high school teachers. The term *explicit instruction* does not refer to a lecture teaching strategy, but is meant to highlight the notion that the nature of science is a cognitive outcome that should be intentionally targeted, planned and taught in the same way science concepts and process skills are taught (Abd-El-Khalick & Lederman, 2000).

This study contributes to teaching and learning of science not only in the NSF GK-12 projects, but in similar outreach projects and to those who train graduate teaching assistants at the university level. It was also viewed that knowing how the chemistry teaching fellows had previously internalized an understanding of the nature of science through instruction in their previous experiences as scientists and students would be essential for the development of the curricula or instructional approaches designed to promote appropriate understanding of science among pre-service and in-service science teachers in a professional development environment.

Framework and Intervention

The intervention on the nature of scientific theories and laws was guided by a conceptual change framework (Posner, Strike, Hewson & Gertzog, 1982). The framework has four linear steps: pre-instruction assessment, sharing identified misconceptions with participants, providing instruction, and post-instruction assessment to determine changes (if any) in participants' understanding of the concepts. Likewise, pre and post-instruction assessments were conducted to assess the teaching fellows' understanding of the nature of scientific theories and laws. The intervention was provided by two science educators in nine one-hour instructional sessions dispersed over one semester. The instruction focused on the following: descriptions of scientific theories and laws; their characteristics; their functions; the relationship between them; and how they are developed. The intervention was conducted in two phases. First, the fellows were engaged in hands-on activities and demonstrations that were designed to explicate the characteristics and functions of scientific theories and laws. The activities were commensurate with those that the teaching fellows were expected to foster in K-12 classrooms. Each activity was followed by a structured discussion aimed at getting the fellows to reflect on the sort of new ideas they had learned, and how the new ideas differed from their initial views. Second, the teaching fellows were engaged in reading the text from the science education reform document Project 2061 (AAAS, 1993) in order to help them recognize contemporary explanations of science, theories, and laws. Each fellow responded to the same reflective questions that were provided to guide the discussion of the text.

Context

This study was conducted in the NSF-funded GK-12 project at a medium-sized University (21,000 students) in the Midwestern United States. The main goal of the project was to promote scientific and mathematical literacy in participating schools by sending university students to work with K-12 teachers and students. This is an eight-year long university-school partnership project involving the departments of Biological Sciences, Chemistry, and Mathematics and more than ten school districts within a one hour driving distance from the university. Since its inception in 2001, the project has trained and supported more than forty senior undergraduate and graduate teaching fellows from mathematics and science disciplines within the university. The teaching fellows act as role models for students and provide subject matter knowledge and instructional support to teachers. In addition to their involvement in the GK-12 program, most graduate teaching fellows are engaged in authentic research for their degree programs and professional development.

Methodology of Research

The sample comprised five chemistry teaching fellows (four females and one male). The average age of the group was 26 years. All five fellows were in a master of science in chemistry degree program. In addition to their work in the GK-12 project, the teaching fellows were engaged in authentic chemistry research for their graduate degree programs as well as professional development activities. The research backgrounds of the chemistry teaching fellows were primarily in Biological, Analytical and Organic Chemistry. Except for one fellow, who was a trained high school chemistry teacher, the fellows' only teaching experiences prior to starting in the GK-12 program were as teaching assistants in undergraduate chemistry courses.

Data were collected through a questionnaire and semi-structured interviews. The questionnaire comprised five open-ended questions designed to assess the fellows' understanding of characteristics and functions of scientific theories and laws, as well as the relationships between them. The same questionnaire was administered to participants both before and after intervention. The post-instruction semi-structured interviews were conducted with individual chemistry teaching fellows following the administration of the questionnaire. During the interviews the participants were provided with their respective responses to the questionnaires. They were also asked to provide some examples and rationale to support any changes they wanted to make to their responses. This interview procedure provided the participants with an opportunity to identify changes in their pre-and-post instruction responses, and elaborate on them.

Data were analyzed by coding the responses to identify recurring themes and descriptors (Strauss & Corbin, 1998). Then, the categories were generated and provided representative profiles of the group studied. To a large extent the questions in the data sources provided the frameworks into which responses were categorized and further analysis led to a differentiation of the categories.

Results of Research

Scientific theories: Before the intervention the chemistry teaching fellows had multiple meanings and functions for scientific theories. For example, three fellows viewed scientific theories as mere beliefs in science which an individual can choose to believe in or not. Two others viewed theories as fundamental tenets of science yet to be "proven correct." However, after the intervention, most fellows viewed scientific theories as explanations of natural phenomena.

> Ideal Gas laws can well be explained through kinetic theory of matter. Now, I understand that they are actually explanations of natural events…why certain things happen (Beth).

Initially, Beth viewed scientific theories as unproven facts, however, now Beth suggests that scientific theories can be used to elucidate scientific laws.

Scientific laws: Similarly, before the intervention most teaching fellows had uninformed understandings of scientific laws. For example Kelly said:

> I have always believed that scientific laws are facts that can't be changed anyhow. I don't know of a law that has changed. For example, the law of gravity is still the same today as it was a century ago (Kelly).

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Kelly's response suggests that she had developed this view over a long period of time and strongly believed in it. As such, she subscribed to the notion that scientific laws are the best available scientific facts, and do not change.

However, after instruction most teaching fellows viewed scientific laws as descriptions of the relationships between or among variables. They also said that laws can be expressed quantitatively. Most of them cited Gas laws, Newton's laws of motion, first and second laws of thermodynamics as examples.

> I have come to understand what scientific laws are and their functions. For example, ideal gas laws can be described in words and expressed as a formula. Look at Boyle's law…it is PV= constant…Charles law is V/T= constant. I can get the descriptions from these expressions (Jessica).

Similarly, most fellows' responses suggested that the descriptions and relationships of the variables in the laws would completely detect the nature and kind of theories to be used to explicate them.

After the intervention, there was also awareness among the fellows that scientific laws have different descriptions. However, there was no evidence in their responses that scientific laws are embedded in theoretical matrices, suggesting that the fellows did not understand that scientific laws are embedded in theoretical backgrounds.

Relationships between scientific theories and laws*:* Each teaching fellow provided multiple responses on the nature of the relationship between scientific laws and theories. However, the following four relationships emerged: *Discrete, Intertwined, Concentric, and Cyclical*.

The *discrete relationship* represents the fellows' responses that indicated that scientific theories are independent of the functions of the laws and vice versa. As such, each has its own functions and applications in science.

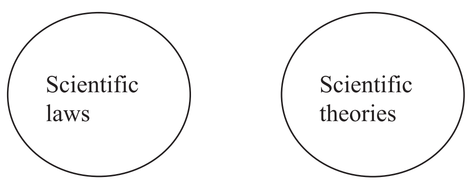

Figure 1. Discrete relationship of scientific laws and theories

The *intertwined* relationship represents responses that indicated an interdependent relationship between scientific theories and laws, with neither one of them assuming a dominant role. This relationship also suggests that any attempts to separate these two, as in the discrete relationship would seriously harm both.

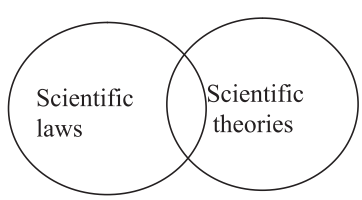

Figure 2. Intertwined representation of scientific laws and theories

The *intertwined* relationship also seems to indicate that the intersection between the two represents the currently-accepted knowledge about a natural phenomenon.

The *concentric* relationship represents fellows' responses for two sub-relationships between scientific laws and theories, one where theories are viewed as an integral part of scientific knowledge but they are a subset of scientific laws; and the other where scientific laws are viewed as subsets of scientific theories. Figures 3 and 4 below represent the two concentric relationship representations. In figure 3, theories are viewed as an integral part of scientific knowledge and they are a subset of scientific laws.

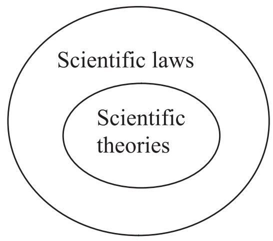

Figure 3. Representation of theories as subsets of laws

On the other hand, figure 4 shows that scientific laws were viewed as an integral part of the development of scientific knowledge but they are subsets of theories.

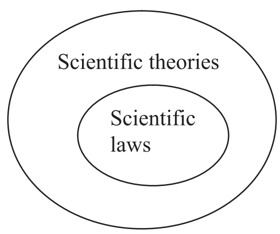

Figure 4. Representation of laws as subsets of theories

The *cyclical* relationship represents scientific laws and theories as separate entities, but one can become the other and such a process is incessant, repetitious, and never ending. This relationship suggests that the decisions on what is to be scientific laws are made after scientists decide to elevate or promote theories. This relationship also represents the view that after several tests, theories are promoted to become laws.

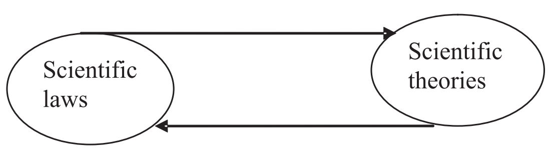

Figure 5. Cyclical relationship between scientific theories and laws

Furthermore, this category also indicates that the process of changing theories into laws and vice-versa is continuous, repetitious, and never ending.

Discussion

To a large extent the findings in this study are consistent with those reported in previous studies on the nature of science involving different groups of students (Brickhouse, 1990; Dagher, Brickhouse, Shipman, & Lens, 2004; Lederman, 1992; Ryder, Leach & Driver, 1999; Ryder & Leach, 1999; Lederman & O'Malley, 1990; Pomeroy, 1993; Abd-El-Khalick, & Boujaoude, 2003; Mumba, 2005). However, the major difference between the findings in this study and previous studies is the identification of the four distinct, previously-unreported relationships (Discrete, Intertwined, Concentric, and Cyclical) between scientific theories and

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laws that emerged from participants' responses. The nature of the relationship between scientific theories and laws is still debatable among science educators. They may be studied and analyzed as separate, but they can't function in isolation. As such, there is a significant interdependence between theories and laws and each may not function independent of the other. Such an interdependent relationship helps scientists provide descriptions, explanations and interpretations of natural phenomena.

Based on the findings in this study we suggest that science educators in the NSF GK-12 program or other outreach science education programs elsewhere should explicitly provide instruction on the nature of science to their participants before they start working in schools. Unless they do this, the promotion of scientific literacy through the NSF GK-12 program or other outreach programs will not be fully attained. These findings also have considerable implications for developing appropriate understanding of science among students at the university level. Because the chemistry teaching fellows in this study are similar to the teaching assistants for undergraduate courses in universities, we believe that the teaching assistants can improve their understanding of science, theories, and laws through instruction specific to the nature of science. Not only should the teaching assistants be trained on the nature of science, but also encouraged to explicitly teach about science, and its characteristics in undergraduate science courses. For example, chemistry is one branch of science that has many theories, laws, principles, and postulates. Sadly, most chemistry instructors and textbook authors simply describe them, and students memorize the descriptions. Students hardly learn about the nature of the chemical laws and theories and how they are developed. Thus, most chemistry students graduate from their programs without a good understanding of the nature of chemical theories and laws. In addition, they are not able to describe how chemical theories and laws are developed by chemists.

These results also reinforce our professional experience in chemistry teacher education that those involved in teaching can learn more about science and its characteristics by engaging in activities outside of traditional academic courses. Therefore, those who are involved in providing professional development to science teachers can effectively address the aspects of the nature of science in such contexts.

Future research should explore the extent to which these chemistry teaching fellows' understanding of the nature of science influences their instructional decisions and teaching practices in school classrooms where they work.

Conclusions

The purpose of this study was to assess five chemistry teaching fellows' understanding of the characteristics and functions of scientific theories and laws, as well as the relationships between them before and after an intervention. Most teaching fellows developed a more mature understanding of scientific theories and laws after the intervention in which four types of relationships between scientific laws and theories emerged: discrete, intertwine, concentric, and cyclical. Finally, the findings in this study also provide support to existing evidence that (a) in spite of their possession of sound science content knowledge, university science students have rather simplistic views of science (b) explicitly providing instruction regarding the nature of science is effective in promoting conceptually complex views of science among college science students.

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