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Writing-to-Learn the Nature of Science in the Context of the Lewis Dot Structure Model

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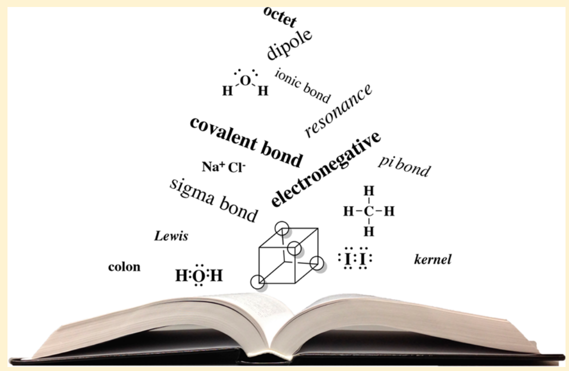
Ⓢ *Supporting Information*

ABSTRACT: Traditional methods for teaching the Lewis dot structure model emphasize rule-based learning and often neglect the purpose and function of the model. Thus, many students are unable to extend their understanding of molecular structures in new contexts. The assignment described here addresses this issue by asking students to read and write about the 1916 paper, in which Lewis proposed the original ideas that led to the dot structure model taught in modern general chemistry courses. This directed writing-to-learn approach is designed to promote conceptual learning of the Lewis dot structure model and to transform students' beliefs about the nature of science as they evaluate the early model presented by Lewis and compare it to the conventional model taught in lecture. Participating students responded to a pre–post survey, which indicated modest gains in their conceptions of the nature of science. The assignment is designed for college-level general chemistry students but may be modified for use in high school chemistry and is generally transportable to other fundamental topics in chemistry in which accessible literature is available as an appropriate source for directed reading and writing.



KEYWORDS: *First-Year Undergraduate/General, High School/Introductory Chemistry, Curriculum, Communication/Writing, Lewis Structures, History/Philosophy*

Lewis dot structures form the basis of the symbolic language that is used for communication among chemists. Students in introductory chemistry must learn to draw and interpret these structures fluently so that they can predict molecular structures, identify structure–property relationships, and draw reaction mechanisms. Drawing and interpreting Lewis structures provides the foundation for further learning in chemistry and other science courses.

Unfortunately, many students simply apply rule-based methods to drawing Lewis structures and do not learn to interpret their purpose and function.[1−4] Such students have difficulty with the complex interpretation involved in connecting structure to physical properties.[5−7] Reports advocating new and improved "step-by-step" approaches to drawing Lewis structures may support students in learning the mechanics of Lewis structure drawing,[8−16] but these approaches do not address the issue of interpretation. A version of writing-to-learn based on directed reading and writing responds to and builds on the constructivist model of learning advocated by Cooper (2010), who claims that a new approach is needed (ref 5, p 873):

> *It is crucial that we rethink how to best develop and reinforce these skills in a framework that allows students to learn in a meaningful way so that they can develop and appreciate the relationship between structure and function.*

The literature of writing-to-learn shows that asking students to explain, reflect on, and elaborate in writing the concepts they study in science classes fosters meaningful learning.[17−21]

This approach is guided by principles of science literacy, which affirm the value of literacy capacities that enable critical thinking and understanding of key science concepts.[22] One of the challenges of helping students develop science literacy is that many of today's texts are inaccessible to all except highly trained specialists.[23] In part this is a result of increasingly detailed scientific understanding,[24] but it is also a consequence of the lack of attention given to reader-expectation principles in most contemporary scientific writing.[25] This opaque quality poses a challenge for employing a directed reading and writing approach in science. Fortunately, texts written long ago are often more accessible.

Historical articles are one type of accessible text that can be appropriate for reading and writing assignments at the introductory level because their subject matter is more relevant to the content that introductory chemistry students learn. Unlike contemporary literature, older texts often directly describe the fundamental chemistry concepts that correspond to traditional general chemistry curriculum and as a consequence, they are much more likely to be appropriate for

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a reading and writing focused assignment at the introductory level. Such science texts give students a historical snapshot and illustrate the dynamic nature of science. Learning about the development of scientific models from the scientists who originally proposed them provides students with an example of how knowledge in chemistry grows and changes over time.

Older texts, because they enable students to view science through a historical lens, lend themselves to writing-based instruction on the nature of science. Nature of science (NOS) was identified by the NRC[26] as a key component of science literacy and is defined by Lederman[27] as:

> *The epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and development.*

Both implicit and explicit curricular approaches have been investigated for NOS.[28−31] Implicit NOS curriculum operates under the assumption that students gain an understanding of the nature of science indirectly when they actively participate in the process of science during activities such as guided-inquiry.[28] Conversely, explicit and reflective (ER) curriculum may use history or philosophy of science, is directed toward aspects of the NOS, and includes a reflective activity such as discussion or writing. Recent reports suggest that ER curriculum is more effective at changing students' conceptions of NOS[28,31] than implicit approaches. Furthermore, it has been proposed that ER will be both more effective and feasible when it is "embedded in subject matter".[31,32]

The assignment described here is aimed at changing students' conceptions of NOS using an ER approach, which employs directed reading and reflective writing to foster learning about NOS in the context of the Lewis structure model. The approach is based on principles of scientific literacy that understand reading and writing as interactive cognitive activities.[21,22] The accessible literature source of the activity is the 1916 article "The Atom and the Molecule" written by Gilbert Lewis.[33] This article is ideal for the purposes of this assignment because the theory and models that Lewis proposed to describe it were derived from empirically observed properties and Lewis used descriptive language that helps students to form an explicit link between structure and function as they read. The article is also ideal for demonstrating the changeable nature of science to students because Lewis builds a logical argument for his model by addressing the limitations in the theories of Helmholtz and others that were put forth prior to his efforts.

■ ASSIGNMENT DESCRIPTION

Lewis' 1916 paper is appropriate for this assignment because it is written in a descriptive fashion that is accessible to first-year college students and because it was written about a topic that is central to communication among chemists and is an important component of the general chemistry curriculum. For this assignment, students are tasked with reading a section of Lewis' article (Box 1) and writing a summary of how Lewis proposed to simplify the depiction of electron sharing and valence in covalent bonds. Students are tasked with comparing Lewis's proposed model to prior theory on molecular structure and bonding and to the model they learn in class.

Peer review of first drafts provides students with the opportunity to learn from one another's writing. A standard peer review process was employed where students are directed to write a first draft and, in keeping with principles of process writing,[34] receive peer response[35] to their drafts, revise in response to peer comments, and then submit a final version. In peer review, students were directed to provide constructive feedback and to evaluate their peers' writing in response to the three main objectives of the assignment by rating each on a scale from 1 to 7 (Table 1). We employed an electronic system of peer review in order to capture both drafts as well as all peer comments and ratings.[36] Student scores for draft 1 were based on peer ratings and draft 2 was evaluated by the instructor.

Box 1. Lewis Reading and Writing Prompt

In 1916, Gilbert Lewis wrote an article for the Journal of the American Chemical Society describing how he used dots to explain the sharing of electrons between atoms. On page 774, after introducing the topic and explaining the background behind his ideas, he starts a section called "Molecular Structure." Write a 350-500 word summary of how Lewis proposes to simplify the depiction of electron sharing and valence in covalent bonds. This summary should emphasize what's useful in Lewis's idea (based on your understanding of chemistry from lecture) as well as how Lewis's initial proposal helps you better understand bonding and structure.

Questions to Consider

(1) Can you use your understanding of Lewis structures nearly 100 years later, to summarize it more clearly and concisely than Lewis did?
(2) What are the most important points that Lewis proposed in the nine pages he published in 1916?
(3) How did Lewis improve on previous theories of molecular structure and bonding?
(4) How are the ideas that Lewis proposed in 1916 different from how we understand bonding and molecular structure today?

Table 1. Rubric for Student Peer-Review Rating

Rating	Description
Objective I. Complete Summary of Important Points Made by Lewis	
7	Includes all important points made by Lewis.
5	Includes most of the important points made by Lewis.
3	Several important points missing.
1	Most important points are missing.
Objective II. Describes How Lewis Improved on Previous Theories of Molecular Structure and Bonding	
7	Described all important pre-Lewis theories that were mentioned by Lewis in the 1916 paper and accurately identified how Lewis improved on them.
5	Discussed a few theories and how Lewis improved on them, but were not thorough.
3	Only discussed a few theories and/or did not really help the reader to understand how Lewis improved them.
1	Did not discuss pre-Lewis theories
Objective III. Compares Ideas Proposed by Lewis in 1916 to Those Presented in Lecture	
7	Effectively compared ideas that Lewis proposed in 1916 to ideas taught in lecture.
5	Compared Lewis ideas to lecture, but a few items were left our or not explained.
3	Made only a few weak comparisons.
1	Did not make comparison.

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Table 2. Comparison of Mean Expert Rating Scores between Drafts One and Two

Objectives	Expert Rating Mean Scores[a] (N = 58) Draft 1	Draft 2	t-Test Values	Effect Size
I. Summary of important themes	5.2155	5.6207	2.770[c]	0.364
II. Discussion of pre-Lewis theories	3.1983	4.2931	7.117[b]	0.765
III. Comparison to conventional theory	2.6379	3.5345	4.232[b]	0.444

[a]Scores could range from 1 to 7; see rubric in Table 1. [b]$p < 0.001$. [c]$p < 0.01$.

Table 3. Comparison of Student Responses to a Pre−Post Nature of Science Survey Using a Paired-Samples *t*-Test

Question: When Two Different Theories Arise To Explain the Same Phenomenon, What Should Scientists Do?				
Statements for Student Response	Pretest Mean[a]	Posttest Mean[a]	t-Test Values[a]	Effect Size
a. Scientists must accept both theories because the two theories may provide explanations from different perspectives; there is no right or wrong in science.	2.85 ± 1.201	3.47 ± 1.150	5.002[b]	0.640
b. Scientists should not accept any theory before distinguishing which is best through the scientific method because there is only one truth about phenomenon.	2.22 ± 0.811	2.58 ± 1.133	2.251[c]	0.297
c. Scientific theories may change in light of new evidence or new interpretation of existing evidence.	4.61 ± 0.831	4.69 ± 1.050	0.711	0.093
d. Scientists can abandon personal biases to make objective observations because they are well-trained professionals.	2.90 ± 0.986	2.95 ± 1.050	0.353	0.047
e. Scientists use their imaginations to develop scientific theories.	3.02 ± 1.280	3.47 ± 1.135	3.690[b]	0.481

[a]Students rated the statements a−e in response to a question about the emergence of scientific theories using a Likert scale: 1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree (N = 48). [b]$p < 0.001$. [c]$p < 0.05$.

■ STUDENT WRITING

The assignment was completed by 58 students, who voluntarily participated in a supplementary activity outside of regular general chemistry lecture. The summaries produced by participating students were evaluated by expert readers, who ranked the student writing using the peer review rubric (Table 1) to evaluate both drafts 1 and 2 (Table 2) on the three main objectives of the assignment. A description of the ranking process is provided in Supporting Information (Table S-1).

Expert evaluation revealed that the majority of students were able to provide a reasonable summary of the paper (objective I), which improved between drafts. However, the other two writing objectives proved more challenging for students. This is not surprising given that both objectives II and III are more demanding because students had to identify and contrast both pre-Lewis and conventional theories to the ideas that Lewis posed in the paper. Students performed most poorly on objective III, which required them to critically evaluate the ideas described by Lewis and compare them with their own knowledge of molecular structure and bonding. However, a substantial improvement on both objectives II and III was observed following peer review and revision, which is consistent with previous reports on peer review.[37,38]

Student Discussion of Pre-Lewis Theories

In response to objective II, students contrasted the ideas proposed by Lewis to previous theories of molecular structure and bonding. The theories they described most frequently were those that Lewis included in the manuscript rather than theories from class and they include the Helmholtz theory of valence, Baeyer's Strain theory, and electrochemical theories of Davy and Berzelius. For example:

> *Lewis explains that the current model [Helmholtz] of chemical reactions and electron transferring is not an acceptable model to account for binding in nonpolar molecules.*

Students scored higher on the comparison to historical theory (mean = 4.29) presumably because they were able draw on the reasoning that Lewis provided for building on or departing from these theories when he developed his model, whereas the comparison to conventional theory (mean = 3.54) required that they draw on their own knowledge, lecture notes, or text.

Student Comparison to Conventional Theory

In response to the writing prompt, which tasked students with identifying how the ideas that Lewis proposed in 1916 are different from how we understand bonding and molecular structure today, the majority of students responded in one of two ways. First, they compared the 1916 Lewis model to modern theories of molecular structure and bonding, and second, they compared specific notation introduced by Lewis to conventional dot notation used in class.

General chemistry topics are typically taught as a series of unconnected ideas and there is often little opportunity for students to form connections between the different models that describe molecular structure and bonding. Thus, it is common that students do not develop an understanding of the strengths, weaknesses and utility of each of the theories that are presented. The conventional theories of molecular structure and bonding that were most frequently used for comparison by students were molecular orbital theory, Valence Shell Electron Repulsion theory (VSEPR), and hybridization. While most students mentioned conventional theories, many did not discuss them in detail or compare them to the model proposed by Lewis, which resulted in a lower rating on objective III.

Lewis dot notation is typically not taught within a context of how or why; thus, students generally rely on memorization and often may not have the opportunity to critically evaluate aspects of the model.[1−4] The students' identification of differences in the Lewis notation indicates that they comprehended and built on the rules taught in class in order to identify differences in the 1916 notation. There were four main differences that students identified and discussed in their writing. First, Lewis used a colon to represent a covalent bond, whereas today we use a line. Second, Lewis uses the position of the colon to illustrate the polarity of the bond and today the polarity is implicitly defined by the elemental symbol of both atoms, which one must interpret or identify by using a vector arrow. Third, Lewis

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limited his examples to elements that will only bond to fulfill an octet and omitted hypervalent elements (main group metals). Lastly, Lewis used a series of colons between the two atomic symbols, but today we use multiple parallel lines between the atomic symbols to illustrate a multiple bond. In their writing students identified these differences, described what the notation represented, and compared the relative utility of old vs new. In response to the comparison question, one student stated that

> *One of the most significant changes is the representation of covalent bonds as lines between atoms instead of a simple shared pair of electrons [colon].*

■ STUDENT RESPONSE TO NATURE OF SCIENCE SURVEY

To measure student gains in understanding of the nature of science, students responded to an abbreviated pre-post survey to assess students' conceptions of NOS, which was adapted from a multiple choice version[39] of the VNOS (Views of the Nature of Science) questions originally developed by Lederman et al.[40] The survey items were selected based on aspects of NOS that were most aligned with the assignment, including (Table 3): (i) theory formation; (ii) the tentative nature of science; (iii) science is theory laden (subjective); and (iv) the empirical nature of science (scientists use their imagination).

In response to a question posed about the emergence of scientific theory, students indicated their agreement with a series of statements (Table 3). Statements "a" and "b" were designed to measure students' conceptions of theory formation and alternative explanations in science. Statement "a" indicates that alternative explanations are possible in science and agreement (i.e., a response of 5 or strongly agree) indicates an adequate (or sophisticated) conception of this aspect of NOS. Initially students were neutral (on average) in their agreement, but gained a more sophisticated conception after writing about Lewis, a result that was statistically significant with a medium effect size. Conversely, agreement with statement "b" indicates a naïve conception of this aspect of NOS, because it conveys the belief that science is absolute. Students disagreed on average both before and after the assignment, indicating a more sophisticated view of this aspect. However, their view became more neutral (less sophisticated) after the writing assignment, which was significant at the 0.005 level. A possible explanation may lie in students' belief in the myth of a single the scientific method, which is a common misconception reported in the NOS[41] and would not be addressed through this assignment. Statement "c" is aimed at revealing students conceptions of the tentative nature of science (i.e., scientific knowledge is robust, but changeable). It was anticipated that, through the comparison of old and new theories, students might be expected to learn that the process of science is dynamic. However, students held a sophisticated understanding of the tentative nature of science prior to reading and writing about Lewis' paper. Their conception of the changeable nature of science was unchanged (remained adequate) after the assignment, which suggests that the assignment at least reaffirmed this conception.

Statement "d" measures students' beliefs about the subjective nature of science: that scientists are influenced by cultural norms and their personal characteristics.[32] Disagreement with this statement indicates a sophisticated understanding. However, students were on average neutral about whether scientists could abandon personal bias, a view that did not change appreciably after the assignment.

Statement "e" is designed to measure students' views about the empirical nature of science, specifically the idea that scientists must use their imagination when developing theories. Agreement with this statement represents a sophisticated conception of this aspect of NOS. On average, students' response was neutral before the writing, though an increased number of students agreed with the statement after. In his paper, Lewis proposed a new model to communicate about molecular structure and bonding and students' increased agreement might be attributed to a perception by students that Lewis used his imagination when developing the model.

■ INSTRUCTOR TIPS

The assignment presented here could be adapted to make it more accessible for lower division or high school students. The original Lewis article is long and dense, and thus, we identified a shorter section for students to focus on. We suggest cutting the reading requirement further to 1−2 key pages from the original Lewis manuscript for high school or introductory students. The analysis of Lewis' ideas could be made less challenging by engaging students in a classroom discussion to brainstorm the differences between the notation proposed by Lewis and the notation learned in class. Likewise, the impact on students' NOS conceptions could be improved by an explicit discussion reflecting on specific aspects of the NOS.

The reading and writing prompt described here can be adapted for use with other accessible scientific literature sources. An ideal paper for use with this prompt is one that (1) is written descriptively and is understandable by students at the introductory level; and (2) focuses on a fundamental topic taught in introductory chemistry. Students should be directed to compare and contrast to theory from class, and the guiding questions should be specifically tailored to the source that is selected.

■ SUMMARY

Reading and writing can be used in combination as a strategy to facilitate conceptual learning of topics that are typically learned by rote. With the use of accessible articles, students can write summaries in which they explain key points. Electronic peer review of first drafts gives students the opportunity to learn from one another's writing. Because the electronic system preserves drafts, peer responses, and final revisions, it also enables instructors to see the learning gains of their students. Many articles that were written long ago may be appropriate for this type of assignment because they are often written more descriptively than conventional science articles, they are written about the fundamental topics that students learn in general chemistry, and they have the capacity to demonstrate the evolving nature of scientific theory through a historical lens.

■ ASSOCIATED CONTENT

Supporting Information

A detailed description of expert coding, Table S-1, and practitioner notes. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Maeyer, J.; Talanquer, V. The Role of Intuitive Heuristics in Students' Thinking: Ranking Chemical Substances. *Sci. Educ.* **2010**, *94*, 963−984.

(2) Stains, M.; Talanquer, V. Classification of Chemical Reactions: Stages of Expertise. *J. Res. Sci. Teach.* **2008**, *45* (7), 771−793.

(3) Taber, K. S. Building the Structural Concepts of Chemistry: Some Considerations from Educational Research. *Chem. Educ. Res. Pract.* **2001**, *2* (2), 123−158.

(4) Nicoll, G. J. A Qualitative Investigation of Undergraduate Chemistry Students' Macroscopic Interpretations of the Submicroscopic Structure of Molecules. *J. Chem. Educ.* **2003**, *80* (2), 205−213.

(5) Cooper, M. M.; Grove, N.; Underwood, S. M.; Klymkowsky, M. W. Lost in Lewis Structures: An Investigation of Student Difficulties in Developing Representational Competence. *J. Chem. Educ.* **2010**, *87* (8), 869−874.

(6) Cooper, M. M.; Underwood, S. M.; Hilley, C. Z. Development and Validation of the Implicit Information from Lewis Structures Instrument (IILSI): Do Students Connect Structures with Properties? *Chem. Educ. Res. Pract.* **2012**, *13* (3), 195−200.

(7) Bodner, G. M.; Shane, J. W. General Chemistry Students' Understanding of Structure-Function Relationships. *Chem. Educ.* **2006**, *11*, 1−8.

(8) Ahmad, W.; Omar, S. Drawing Lewis Structures: A Step-by-step Approach. *J. Chem. Educ.* **1992**, *69* (10), 791−792.

(9) Pardo, J. Q. Teaching a Model for Writing Lewis Structures. *J. Chem. Educ.* **1989**, *66* (6), 457−458.

(10) Clark, T. J. Another Procedure for Writing Lewis Structures. *J. Chem. Educ.* **1984**, *61* (2), 100.

(11) Zandler, M. E.; Talaty, E. R. The "6N+2 Rule" for Writing Lewis Octet Structures. *J. Chem. Educ.* **1984**, *61* (2), 124.

(12) Lever, A. B. P. Lewis Structures and the Octet Rule: An Automatic Procedure for Writing Canonical Forms. *J. Chem. Educ.* **1972**, *49* (12), 819.

(13) Ahmad, W.; Zakaria, M. B. Drawing Lewis Structures from Lewis Symbols: A Direct Electron-Pairing Approach. *J. Chem. Educ.* **2000**, *77* (3), 329−331.

(14) Logan, S. R. The Role of Lewis Structures in Teaching Covalent Bonding. *J. Chem. Educ.* **2001**, *78* (11), 1457−1458.

(15) Miburo, B. B. Simplified Lewis Structure Drawing for Nonscience Majors. *J. Chem. Educ.* **1998**, *75* (3), 317−319.

(16) Purser, G. H. Lewis Structures in General Chemistry: Agreement between Electron Density Calculations and Lewis Structures. *J. Chem. Educ.* **2001**, *78* (7), 981−983.

(17) Bangert-Drowns, R. L.; Hurley, M. M.; Wilkinson, B. The Effects of School-based Writing-to-learn Interventions on Academic Achievement: A Meta-analysis. *Rev. Educ. Res.* **2004**, *74* (1), 29−58.

(18) Connolly, P.; Vilardi, T. *Writingo Learn Mathematics and Science*; Teachers College Press: New York, NY, 1989.

(19) Prain, V. Learning from Writing in Secondary Science: Some Theoretical and Practical Implications. *Int. J. Sci. Educ.* **2006**, *28* (2), 179−201.

(20) Reynolds, J. L.; Thaiss, C.; Katkin, W.; Thompson, R. J. Writing-to-Learn in Undergraduate Science Education: A Community-Based, Conceptually Driven Approach. *CBE: Life Sci. Educ.* **2011**, *11*, 17−25.

(21) Keys, C. W. Revitalizing Instruction in Scientific Genres: Connecting Knowledge Production with Writing to Learn in Science. *Sci. Educ.* **1999**, *83* (2), 115−130.

(22) Yore, L. D.; Treagust, D. F. Current Realitites and Future Possibilities: Language and Science Literacy—Empowering Research and Informing Instruction. *Int. J. Sci. Educ.* **2006**, *28* (2), 291−314.

(23) Hayes, D. P. The Growing Inaccessibility of Science. *Nature* **1992**, *356*, 739−740.

(24) Marcovich, A.; Shinn, T. Regimes of Science Production and Diffusion: Towards a Traverse Organization of Knowledge. *Scientiae Studia* **2012**, *10.SPE*, 33−64.

(25) Gopen, G. D.; Swan, J. A. The Science of Scientific Writing. *Am. Sci.* **1990**, *78*, 550−558.

(26) National Research Council. *National Science Education Standards*; National Academy Press: Washington, DC, 1996.

(27) Lederman, N. G. Students' and Teachers' Conceptions about the Nature of Science: A Review of Th Research. *J. Res. Sci. Teach.* **1992**, *29* (4), 331−359.

(28) Khishfe, R.; Abd-El-Khalick, F. Influence of Explicit and Reflective versus Implicit Inquiry-Oriented Instruction on Sixth Graders' Views of Nature of Science. *J. Res. Sci. Teach.* **2002**, *39* (7), 551−578.

(29) Bell, R. L.; Blair, L. M.; Crawford, B. A.; Lederman, N. G. Just Do It? Impact of a Science Apprenticeship Program on High School Students' Understandings of the Nature of Science and Scientific inquiry. *J. Res. Sci. Teach.* **2003**, *40* (5), 487−509.

(30) Yacoubian, H. A.; BouJaoude, S. The Effect of Reflective Discussions Following Inquiry-Based Laboratory Activities on Students' Views of the Nature of Science. *J. Res. Sci. Teach.* **2010**, *47* (10), 1229−1252.

(31) Akerson, V. L.; Abd-El-Khalick, F.; Lederman, N. G. The Influence of a Reflective Activity Based Approach on Elementary Teachers' Conceptions of the Nature of Science. *J. Res. Sci. Educ.* **2000**, *37* (4), 295−317.

(32) Lederman, N. G. Nature of Science: Past, Present, and Future. In *Handbook of Research on Science Education*; Talbot-Smith, M. A., Bell, S. K., Appleton, K., Hauscin, D. L., Eds.; Routledge: New York, NY, 2013; p 869.

(33) Lewis, G. N. The Atom and the Molecule. *J. Am. Chem. Soc.* **1916**, *38* (4), 762−785.

(34) Emig, J. Writing as a Mode of Learning. *Coll. Compos. Commun.* **1977**, *28* (2), 122−128.

(35) Gere, A. R. *Writing Groups: History, Theory and Implications*; SIU Press: Carbondale, IL, 1987.

(36) Peerceptiv Home Page. http://www.peerceptiv.com (accessed May 2015).

(37) Cho, K.; Schunn, C. D.; Wilson, R. W. Validity and Reliability of Scaffolded Peer Assessment of Writing from Instructor and Student Perspectives. *J. Educ. Psych.* **2006**, *98* (4), 891.

(38) Nelson, M. M.; Schunn, C. D. The Nature of Feedback: How Different Types of Peer Feedback Affect Writing Performance. *Inst. Sci.* **2009**, *37* (4), 375−401.

(39) Aydeniz, M.; Baksa, K.; Skinner, J. Understanding of an Apprenticeship-Based Scientific Research Program on High School Students' Understanding of Scientific Inquiry. *J. Sci. Educ. Technol.* **2011**, *20* (4), 403−421.

(40) Lederman, N. G.; Abd-El-Khalick, F.; Bell, R. L.; Schwartz, R. S. Views of Nature of Science Questionnaire: Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science. *J. Res. Sci. Teach.* **2002**, *39* (6), 497−521.

(41) Abd-El-Khalick, F.; Lederman, N. G. Improving Science Teachers' Conceptions of the Nature of Science: A Critical Review of the Literature. *Int. J. Sci. Educ.* **2000**, *22* (7), 665−701.

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