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Editorial

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Modeling Instruction: A Learning Progression That Makes High School Chemistry More Coherent to Students

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ABSTRACT: Current chemistry education reforms have reestablished the process of science as a priority. Despite this progress, many students cannot comprehend the interrelatedness of the content. Modeling Instruction incorporates the components of inquiry with the added benefit of a logical sequence of conceptual development that provides a dynamic learning progression. The cohesiveness of the chemistry content along with using evidence to build understanding makes learning chemistry more intuitive for students.

KEYWORDS: *High School/Introductory Chemistry, Curriculum, Inquiry-Based/Discovery Learning, Analogies/Transfer*

■ BACKGROUND

Many have called for chemistry education reforms over recent decades.[1−5] These calls have led to research and initiatives involving new pedagogical approaches promoting inquiry instruction. Process-oriented, guided inquiry learning (POGIL),[6] peer-led team learning (PLTL),[7] and project based learning (PBL)[8] each focus on a constructivist approach that includes social interaction and peer support. The Next Generation Science Standards (NGSS)[9] (which stem from the National Research Council, or NRC, Framework for STEM Education)[10] and the advanced placement (AP) chemistry redesigned curriculum[11,12] have further defined the way that chemistry content is to be taught by defining key science practices that are "essentially the disaggregated components of inquiry".[13] The term "inquiry" can be interpreted many ways, so these tools provide clarification for developing lessons. They delineate a shift of focus from teaching students about *what we know about chemistry* to "*why we believe what we do*".[14] "Students are moved from mere uncritical belief to an informed understanding based on experience."[15] The content of the high school course has been largely defined and the process of science has been reestablished as a priority. Despite these pivotal changes, even when chemistry teachers integrate these advances into their practice, many students cannot comprehend the interrelatedness of the content. The tenets of Modeling Instruction align directly with the standards defined for high school chemistry content and science practices.[8,16] Furthermore, I assert that the conceptual model sequence and instructional materials designed for Modeling Instruction allow for the added value of a robust learning progression that develops cohesion between the concepts in the course.

■ LEARNING PROGRESSION OF CONCEPTUAL MODELS BUILDS A STRONG FOUNDATION FOR DEEP CONCEPTUAL UNDERSTANDING AND FUTURE LEARNING

To enhance my teaching practice, I enrolled in a 15-day Modeling Instruction workshop held during June and July of 2014.[17,18] I was already experienced in using inquiry methods in my classroom and using particulate-level representations. So, I had already embraced the idea of using science practices and having students develop models.[19] Having been taught in the traditional methods of education, I still feel I need to continue to hone my skills to support my students as they learn. I find that the Modeling Instruction approach depends heavily on collecting data and using that data as evidence to make claims. Of course, this requires a great deal of focus on scientific discourse. The training helped me to develop my skills, learn additional strategies, and gain confidence in those areas.

The part of Modeling Instruction that I had not fully comprehended before the training had to do with the unique organization of the content. In his article, "Applying Modeling Instruction to High School Chemistry To Improve Students' Conceptual Understanding",[20] Larry Dukerich discusses the disingenuous order of topics in most current chemistry texts.[21] Modeling Instruction focuses on developing the atomic model in a genuine progression just as the history of the atomic theory evolved. Just as scientists used prior knowledge to make further discoveries, students can build on prior knowledge and make connections. This paradigm aligns with constructivist theories of learning.[22] Each successive unit revisits previous content, allowing opportunities for students to make those connections several times throughout the course. It is important to allow time for complex concepts to mature within the minds of students, along with providing many opportunities for reflection and making connections. Scaffolding ideas from concepts a student understands to a concept that is a bit higher in complexity provides students with opportunities to make sense of the new ideas, allowing for a progression of learning.[23] Revisiting those ideas on a regular basis after even more concepts are learned allows for added depth of conceptual knowledge.[24]

As the units progress, students develop models to explain and predict the behavior of physical objects and chemical and physical processes using data, graphs, and other representations. The teacher facilitates learning as students use their observations and data as "evidence" to support their understanding of the chemistry content. Students must also be

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prepared to present this information and defend their conclusions based upon their cited evidence.[25] Prior to the training, I had some understanding that Modeling Instruction promoted learning progression, yet I had not fully appreciated the full value of this organization. My most powerful revelation was that this approach does not confine the content to distinct chapters. I was convinced of the overarching value of Modeling Instruction for chemistry when I understood that it affords the added intrinsic value of providing cohesion to the content, the lack of which has caused me much frustration throughout my career. I agree with de Vos, van Berkel, and Verdonk's statement "the meaning of a specific concept is determined largely by the way it is related to other concepts, either explicitly or implicitly."[26] And, furthermore, "relations between concepts are as important as the concepts themselves because they provide much of the context in which each concept acquires a specific meaning."[26]

■ ADDED TIME REQUIRED TO AVOID ALGORITHMIC LEARNING TO MAXIMIZE STUDENT GAINS IN UNDERLYING TRANSFERABLE PRINCIPLES PAYS OFF IN SAVED TIME

Students work through several units before electrons are added to their models. It is not until the end of the year that the other subatomic particles are considered. Likewise, the periodic table and electron configurations receive attention at the end of the course rather than the beginning. As a teacher new to the curriculum, I held a common concern about the time spent on the front end of the year covering topics that I had previously covered just briefly with much more focus and depth. Conservation of mass, Dalton's postulates, Avogadro's hypothesis, and developing a conceptual view of the relationships between the variables of pressure, temperature, and volume of gases are examples of areas that I devoted more time to than in previous years. Modeling Instruction avoids a heavy reliance on algorithms in these and other topics; we already know that the ability to calculate the correct answer using an algorithm does not guarantee that a student can explain or apply the related conceptual knowledge.[27] However, the upfront time spent laid a foundation of base conceptual knowledge, and I experienced the payoff midway through the year when students began to make connections between every previous unit to explain new ideas. New concepts began to require fewer prompts from me as students made connections more readily. Because students have been so actively engaged in scientific discourse and helping themselves and their classmates understand the underlying concepts in chemistry, they finish the course with skills to evaluate scientific models and data.

■ CONTINUING THE DISCUSSION TO BENEFIT TEACHERS AND STUDENTS

I was pleasantly surprised that along with the training in Modeling Instruction, I received a full binder and flash-drive containing instructional materials, including teacher notes, unit objective note pages for students that outline specific learning targets, videos, and links to online materials such as simulations, activities, worksheet assignments, reading assignments, and tests. The materials provided an outline and made implementation of the approach less intimidating. Having only worked through the materials with students for one year, I know that I will make changes for next year. I expect that I will be more effective as a teacher using it the second time around. In a recent conversation with American Modeling Teacher Association (AMTA) executive officer, Colleen Megowan-Romanowicz, she explained, "It takes a couple years of deliberate practice to build confidence and competence in a new method of a teaching." She mentioned, "Workshops help teachers learn how to practice deliberately, and when they get back to their classrooms they know what to pay attention to in order to continue with productive practice."[28] I am interested in evaluating how my students transition to AP Chemistry next year. I am hoping that they will use the skills gained from Modeling Instruction and be able to make connections between prior knowledge and new ideas. I hope that they will be able to use what they know to continue to build a deeper conceptual understanding of chemistry just as Erica Posthuma-Adams reports of her students in her *JCE* article, "How the Chemistry Modeling Curriculum Engages Students in Seven Science Practices Outlined by the College Board".[16] The research community can support by collaborating with Modeling Instructors to collect and analyze data on the value of this pedagogy. High school teachers will benefit from information on how to use and analyze good conceptual concept inventories. I look forward to exploring research data that might relate to anecdotal evidence observed in my classroom this past year.

In talking with Colleen Megowan-Romanowicz, she said:[28]

> *This year for the first time in 10 years or so we are collecting workshop data nationwide so we will have "fresh" data on teacher change that happens during the workshop. We should have, by the end of the summer, pre and post surveys for about 800 teachers—both concept inventory data and self-efficacy data. This is a start. It is much harder to get student data (due to rules involving research in human subjects) but we have developed an online concept inventory that allows us to collect anonymous data that might make it a little easier—we just have to have teachers who are willing to share their data. The biggest challenge we face now is to foot the bill for evaluating this data.*

She explained that they had been providing some small grants for publishable research on aspects of Modeling Instruction, but that they are looking for more funding before they can offer more of those.[28] Members of the AMTA have free use of the online concept inventory mentioned above.

I am excited about Modeling Instruction and I will continue to use the approach. I hope that the modeling community will collaborate further to revise and disseminate the currently provided instructional resources. Updated materials, including more thorough teacher notes that discuss common misconceptions of the content and provide more links to optional reading assignments and resources, would be helpful. More activities that intentionally focus on training students to collect data and analyze it as evidence for claims would be valuable for creating a classroom culture consistent with what NGSS advocates. Revised lab activities that provide more detailed procedural and safety information for the teacher are necessary. Publication of a textbook aligned with the instructional materials and Modeling Instruction would help teachers convince administrators and parents of the value in adopting Modeling Instruction in their districts. This would also encourage some teachers who are hesitant to adopt the curriculum because they feel it is important to teach students how to use a textbook in the general chemistry course before students continue to the next level. These improvements are not the sole responsibility of the AMTA. They may like to see

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many of these same improvements, but I also expect that the funding to make those updates will be difficult to obtain. Megowan-Romanowicz told me that many of the second-year Modeling workshops include opportunities for material revisions and creation of new resources, and that many modelers are doing this on their own.[28] Now that thousands of chemistry teachers have been trained, we need some of them to share these resources more readily to encourage continued conversation and reform. There are many avenues for teachers to share locally and globally. Teachers can communicate benefits and solicit ideas to overcome barriers and negative issues by engaging in conversations about the topic with members of the Chemical Education Xchange community (ChemEd X)[29] or the AMTA community.[25] They can also submit instructional resources and materials to *JCE* or ChemEd X.

Modeling Instruction aligns well with the reforms our community has advocated for. It was developed using ideas of constructivist theories and seems to allow for an intuitive development of conceptual understanding with the added value of providing cohesiveness that has been lacking since at latest the 1950s.[14] Furthermore, I am excited to see the development of Modeling Instruction to include biology and middle school science courses. To achieve the full benefits of the curriculum, I expect the K−12 community must buy in to the pedagogy. One of the biggest hurdles might be to insist that early educators focus only on macroscopic science phenomenon as they provide experience with scientific practices.[30] If we are to scaffold information to build on prior knowledge and expect students to construct new concepts based upon evidence in the chemistry course, it seems imperative to insist that the instructors of earlier science courses refrain from presenting students with ideas related to the particle nature of science content without evidence that will help them develop the most accurate conceptual models possible. One of the reasons that I have overheard teachers share for being unable to use Modeling Instruction in chemistry is that their school district insists that they cover more rigorous material that they can complete using that curriculum. I would argue that if the science education community were to use Modeling Instruction throughout K−12, we would be better prepared to reach a wider breadth of materials by the time students reach the typical chemistry course because one of the biggest obstacles many modelers experience is having to "unteach" misconceptions that students develop because they were "told" information that they have no evidence for so their minds have conceived their own explanations for the information.

The fact that many of us are working to modify our practice to meet new expectations has been established. However, I am disheartened by the number of teachers who are still resisting change. I have met experienced teachers who continue to use their districts' high test scores as evidence that they do not need to modify their teaching methods. As Megowan-Romanowicz suggests:[28]

> *Learning isn't stamp collecting—cognitive science has shown us that it's knowledge construction, and knowledge structures in use. If we can learn to teach with that in mind, test scores will take care of themselves.*

Even more concerning is the number of new teachers I meet who obviously have not been trained to teach with a focus on science practices. This makes me wonder how many teacher prep institutions have not yet begun modeling the science practices outlined above. It is imperative that the chemistry education community continues to champion a climate of change, including an expectation that all science teachers make curriculum decisions based on current research of best practices. Teachers "have a critical need to understand the value of inquiry, and an ability to conduct climate setting"[15] within their classroom, their school districts, and their teacher networks. As we reimagine the high school chemistry curriculum, Modeling Instruction may be an excellent avenue for promoting a paradigm shift that is long overdue.

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Notes

Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

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REFERENCES

(1) Krajcik, J. S.; Yager, R. E. High School Chemistry as Preparation for College. *J. Chem. Educ.* **1987**, *64* (5), 433.

(2) Deters, K. M. What Are We Teaching in High School Chemistry? *J. Chem. Educ.* **2006**, *83* (10), 1492−1498.

(3) Walford, E. T. High School Chemistry: Preparation for College or Preparation for Life. *J. Chem. Educ.* **1983**, *60* (12), 1053−1055.

(4) Cooper, M. M.; Klymkowsky, M. W. Chemistry, Life, the Universe, and Everything: A New Approach to General Chemistry and a Model for Curriculum Reform. *J. Chem. Educ.* **2013**, *90* (9), 1116−1122.

(5) Spencer, J. N. New Approaches to Chemistry Teaching. *J. Chem. Educ.* **2006**, *83* (4), 528−533.

(6) Moog, R. S.; Creegan, F. J.; Hanson, D. M.; Spencer, J. N.; Straumanis, A.; Bunce, D. M.; Wolfskill, T. POGIL: Process-Oriented Guided-Inquiry Learning. In *Chemists' Guide to Effective Teaching*; Pienta, N. J., Cooper, M. M., Greenbowe, T. J., Eds.; Prentice Hall: Upper Saddle River, NJ, 2009; Vol. *II*, pp 90−107.

(7) The Center for Peer-led Team Learning home page. https://sites.google.com/site/quickpltl/ (accessed Jul 2015).

(8) Buck Institute for Education home page. http://bie.org (accessed Jul 2015).

(9) Next Generation Science Standards home page. http://www.nextgenscience.org (accessed Jul 2015).

(10) Committee on Conceptual Framework for the New K−12 Science Education Standards, National Research Council. *A Framework for K−12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; The National Academies Press: Washington, DC, 2012.

(11) AP Chemistry Course and Exam Description. http://media.collegeboard.com/digitalServices/pdf/ap/ap-chemistry-course-and-exam-description.pdf (accessed Jul 2015).

(12) Kennedy, C. J. Integrating "Big Ideas" With a Traditional Topic Sequence in the AP Chemistry Course: First Steps. *J. Chem. Educ.* **2014**, *91* (9), 1280−1283.

(13) Cooper, M. M. Chemistry and the Next Generation Science Standards. *J. Chem. Educ.* **2013**, *90* (6), 679−680.

DOI: 10.1021/acs.jchemed.5b00544
J. Chem. Educ. 2015, 92, 1269−1272

(14) Spencer, J. N. General Chemistry Course Content. *J. Chem. Educ.* **1992**, *69* (3), 182.
(15) Wenning, C. J. Minimizing Resistance to Inquiry-Oriented Science Instruction: The Importance of Climate Setting. *J. Phys. Tchr. Educ. Online* **2005**, *3* (2), 10−15.
(16) Posthuma-Adams, E. How the Chemistry Modeling Curriculum Engages Students in Seven Science Practices Outlined by the College Board. *J. Chem. Educ.* **2014**, *91* (9), 1284−1290.
(17) Cullen, D. M. Modeling Curriculum Pedagogy (ChemEd X blog posted 7/3/2014). http://www.chemedx.org/blog/modeling-instruction-pedagogy (accessed Jul 2015).
(18) Cullen, D. M. Opportunities for Chemistry Modeling Training (ChemEd X blog posted 2/24/2015). http://www.chemedx.org/blog/opportunities-chemistry-modeling-training (accessed Jul 2015).
(19) Cullen, D. M. Model Engagement for Your Students. *J. Chem. Educ.* **2012**, *89* (5), 565−566.
(20) Dukerich, L. Applying Modeling Instruction to High School Chemistry To Improve Students' Conceptual Understanding. *J. Chem. Educ.* **2015**, *92* (8), DOI: 10.1021/ed500909w.
(21) Herron, D. *The Chemistry Classroom*; American Chemical Society: Washington, DC, 1997.
(22) Lowery-Bretz, S. *J. Chem. Educ.* Online Symposium: Piaget, Constructivism, and Beyond. *J. Chem. Educ.* **2001**, *78* (8), 1107. http://pubs.acs.org/doi/pdf/10.1021/ed078p1107.6 (accessed Jul 2015).
(23) Cooper, M. M.; Underwood, S. M.; Hilley, C. Z.; Klymkowsky, M. W. Development and Assessment of a Molecular Structure and Properties Learning Progression. *J. Chem. Educ.* **2012**, *89* (11), 1351−1357.
(24) Brown, P. C.; Roediger, H. L.; McDaniel, M. A. *Make It Stick: The Science of Successful Learning*; Belknap Press: Cambridge, MA, 2014.
(25) American Modeling Teachers Association home page. http://modelinginstruction.org (accessed Jul 2015). The American Modeling Teachers Association (AMTA) is an organization of teachers, by teachers, and for teachers who utilize Modeling Instruction in their teaching practice. Member dues support the goals and activities of the organization. Members and nonmembers have access to a wealth of resources at the AMTA Web site. Curricular materials and assessment instruments are available to members only.
(26) de Vos, W.; van Berkel, B.; Verdonk, A. A Coherent Conceptual Structure of the Chemistry Curriculum. *J. Chem. Educ.* **1994**, *71* (9), 743−746.
(27) Stamovlasis, D.; Tsaparlis, G.; Kamilatos, C.; Papaoikonomou, D.; Zarotiadou, E. Conceptual Understanding Versus Algorithmic Problem Solving: Further Evidence from a National Chemistry Examination. *Chem. Educ. Res. Pract.* **2005**, *6* (2), 104−118.
(28) Megowan-Romanowicz, C. American Modeling Teachers' Association, Sacramento, California. Personal communication, 2015.
(29) Chemical Education Xchange. http://www.chemedx.org (accessed Jul 2015).
(30) Bent, H. A. Let's Keep Chemistry out of Kindergarten. *J. Chem. Educ.* **1985**, *62* (12), 1071.

DOI: 10.1021/acs.jchemed.5b00544
J. Chem. Educ. 2015, 92, 1269−1272