DOI: 10.2436/20.2003.02.171 http://scq.iec.cat/scq/index.html

ISSN 2013-1755, SCQ-IEC Educació Química EduQ número 23 (2017), p. 24-31

Evidence-based approaches to curriculum reform and assessment

Enfocaments basats en evidències per a la reforma i l'avaluació curriculars

Melanie M. Cooper / Michigan State University. Department of Chemistry (USA)

abstract

Most of transformation efforts in STEM are focused on incorporating pedagogical techniques, rather than redesigning the curriculum and assessments. Assessments that emphasize scientific practices are more likely to elicit evidence about what students know and can do than assessments based on content fragments. Here I discuss a new general chemistry curriculum, «Chemistry, life, the universe and everything», which illustrates an approach to reform that focuses on core ideas, scientific practices and cross-cutting concepts, and is supported by assessments that elicit evidence of student use of their knowledge.

keywords

Curriculum transformation, assessment, chemistry education research, instructional technology, scientific practices.

resum

La majoria dels esforços de transformació en STEM se centren a incorporar tècniques pedagògiques, en lloc de redissenyar el currículum i les avaluacions. Les avaluacions que posen l'èmfasi en les pràctiques científiques tenen més probabilitats d'obtenir proves sobre allò que els estudiants saben i poden fer que les avaluacions basades en fragments de contingut. En aquest article, examino un nou currículum de química general, «Química, vida, l'univers i tot», que il·lustra una aproximació a la reforma centrada en les idees bàsiques, les pràctiques científiques i els conceptes transversals, i que se sosté en avaluacions que aporten evidències sobre el fet que l'estudiant utilitza el seu coneixement.

paraules clau

Transformació curricular, avaluació, investigació en educació química, tecnologia instructiva, pràctiques científiques.

Most instructors have at some point lamented the fact that students do not learn what they are taught. While it is tempting to place the blame for this on students who are disengaged, or who do not work hard enough, or simply are not «good enough», there is a significant literature base suggesting that we can do more to improve classroom performance than cast aspersions on our students. For example, pedagogies that allow (require) student active engagement have been shown to improve student success as measured by course grades and persistence, particularly for students from the lower half of the class distributions (Freeman *et al.*, 2014). These approaches may involve interactive pedagogies as diverse as whole class activities, use of clickers, group quizzes, or moving information delivery out of the classroom to the web and using class time for engagement activities (*i.e.* flipping the classroom). There is also a considerable body of research on affective issues, such as identity (Potvin & Hazari, 2013), mindset (Yeager *et al.*, 2016), student expectations (Grove & Bretz, 2007) and values (Miyake *et al.*, 2010), that have shed considerable light on how we can help students learn. However, while all these approaches have great value, far less attention has been paid to what it is that students are actually learning and what they can do with that knowledge. That is, less attention has been paid to the design of the curriculum and the concomitant assessment of student learning. In this paper, I will attempt to make the case that if we do not pay close attention to the curriculum and how it is assessed, then it may well be that these other approaches are wasted.

Students who succeed in traditional programs often have significant conceptual difficulties

In this section, I will review several of our earlier studies that provide evidence that some student difficulties are a consequence of the structure of the curriculum. All of the studies in this section were performed with students who were, by most common measures, very successful. Students in these interview studies were mainly A and B students, and the larger scale studies involved cohorts of students who scored on average over the 75th percentile on the ACS general chemistry examination (*ACS Exams*, 2014). As we will see, despite their success in the course, these students had some highly problematic ideas about core chemistry concepts. We believe that these ideas are a consequence of the course structure.

The examples I discuss here all center around the core idea of structure-property relationships. That is, the idea that the macroscopic properties of a substance are determined by (and can be predicted by) its molecular level structure. The difficulties cited here move beyond the notion of *misconceptions* and are (we believe) a consequence of the structure of the curriculum. For example, we studied how students use simple structures to predict properties, in particular, how molecular-level structures can be used to predict the relative melting points and boiling points of a set of compounds (Cooper, Corley & Underwood, 2013). During an interview, students were asked to draw structures and explain how they used them to predict properties. While students were typically able to correctly identify which compound (of a pair) had the highest boiling point, we found that they did not use the reasoning that they had been taught. For example, we had thought that they might use the three-dimensional structure of a molecule to discern its net dipole and deduce the strength of intermolecular forces that must be disrupted to separate several such molecules (*i.e.* to boil or melt the substance). Instead, most students used shortcuts or rules of thumb that typically did not involve chemical principles. For example, many students use some version of «more means more» (Hammer, 1996). That is, a student might say the heavier molecule had the highest boiling point, or the compound with more hydrogens (which could produce more hydrogen bonds), or the compound with more oxygens. It was also striking that many students, even those in organic chemistry, had trouble drawing appropriate structures, and many had trouble providing correct models of phase changes. In general, each student had an idiosyncratic collection of ideas that they wove into answers to questions that were dependent on the prompt, and were often contradictory. It became clear that the task we were asking of the students was too complex, and that we should «reboot» to simpler tasks to identify specific difficulties that might impede the larger task.

In order to examine areas of especial difficulty for students seeking to relate molecular structure to properties, we isolated particular tasks and ideas from the sequence of ideas that students should string together to predict properties from molecular-level structure. We began with studies that investigated how students draw Lewis structures, since those are the first structural representations that students meet that allow inferences to be made about properties (Cooper *et al.*, 2010). It became clear that many students had great difficulty with this task, that many students «did not understand the purpose» of learning to draw such structures. Using the implicit information from Lewis structures instrument (IILSI) (Cooper, Underwood & Hilley, 2012), we were able to track the information that students believe that they can predict from structural representations. It became clear that, even after four semesters of chemistry, many students still do not understand that structures can be used to predict properties (Underwood, Reyes-Gastelum & Cooper, 2015). In fact, the «only» reason to draw such structures would be to enable the prediction of chemical and physical properties. Clearly, if students do not understand the purpose of what they are learning, they are unlikely to be able to recall and use that information at a later date.

Determining which intermolecular forces exist between molecules of a particular structure represents another required competency on the path from structure to properties prediction. We found (Cooper, Williams & Underwood, 2015) that students asked to write about a particular IMF were able to provide textbook definitions but, when asked to depict a type of IMF using Lewis structures of three molecules, they commonly drew the intermolecular forces as «within» a given molecule rather than «between» molecules (fig. 1). In fact, only one out of ninety-eight students provided coherent representations of hydrogen bonding, dipole-dipole interactions and London dispersion forces, that placed intermolecular forces between molecules (rather than within molecules).

As a reminder, these students had succeeded by all the measures that we had asked of them, they were taught in a classroom that provided active engagement opportunities and yet they had profound misunderstandings about the nature of matter and its interactions.

Designing a more effective learning environment

It is our contention that the nature of the curriculum and the concomitant assessments have contributed to the problematic findings noted above. Students are unable to construct structure property relationships because they have not learned to do so, and in fact have not learned that this is an important (core) idea in chemistry. We believe that the current approach to introductory chemistry does not align with either theories of learning, or evidence about how people learn, and makes it difficult for students to construct a robust foundation of knowledge on which to build.

We know that experts in a domain have knowledge that is linked and contextualized (National Research Council, 1999). That is, experts' knowledge is organized into connected frameworks that allow it to be retrieved and used in new situations. On the other hand, novices' knowledge is typically not useful, except for the situation in which the knowledge was initially learned, and it is not meaningfully connected or contextualized. The question then is how can we help students construct more expert-like frameworks of knowledge, rather than the fragmentary and disconnected ideas that do not allow transfer to new situations. One approach that is being increasingly adopted is to use the vision provided in the framework for K-12 science education (referred to as «the Framework» here) (*A framework for K-12 science education*…, 2012), which is a synthesis of our current understanding of how people learn science and how we might redesign educational experiences to align with current evidence. This approach specifies «core ideas» that underlie each disciplinary area, crosscutting concepts that are common across the disciplines, and the scientific and engineering practices that put knowledge to use.

Core ideas are those overarching concepts that underlie a discipline. For example, in chemistry, the core ideas that we have used in our work are *structure-property relationships*, *bonding and interactions*, *energy* (macroscopic, molecular and quantum) and *change and stability* (Cooper & Klymkowsky, 2013; Cooper, Posey & Underwood, 2017). We believe that every important chemistry concept (at least in introductory general and organic chemistry courses) can be connected to these core ideas. For example, understanding phase changes requires one grasp how atom connectivity affects the arrange-

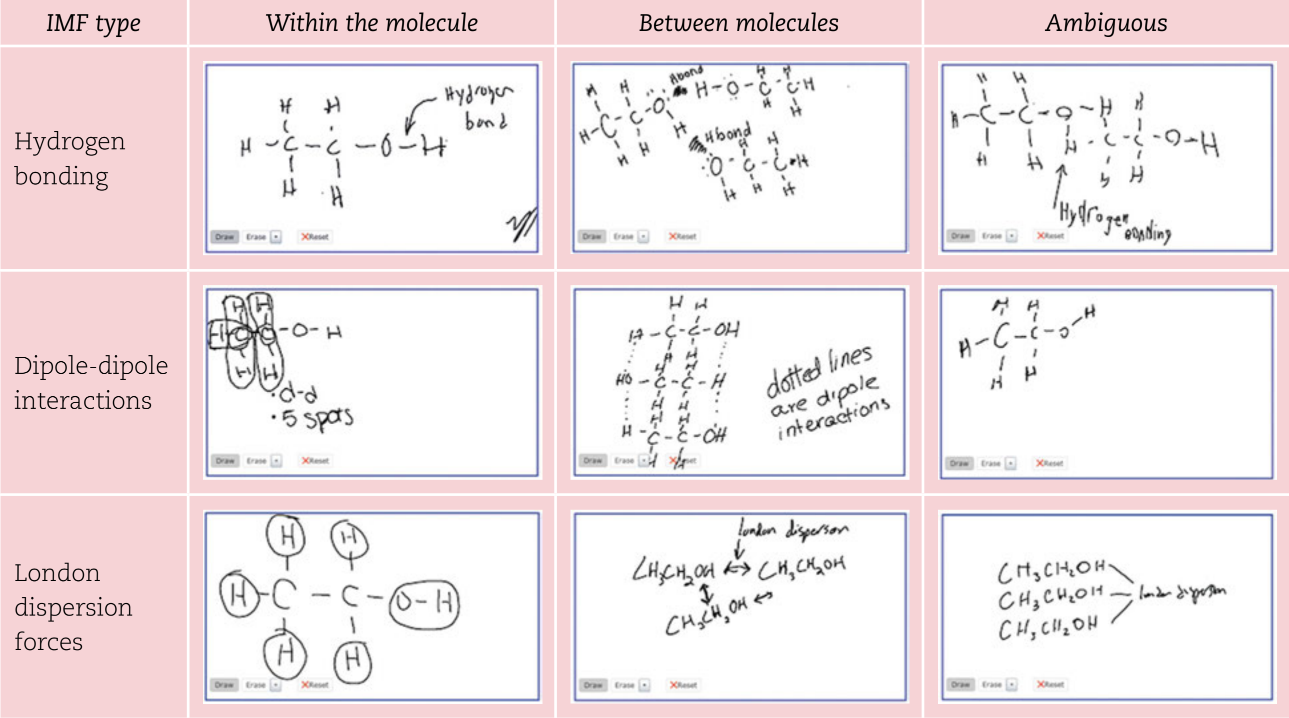


Figure 1. Examples of student drawings demonstrating understanding of selected types of intermolecular forces.

ment of electrons in a molecule (structure property relationships), which affects the interactions between particles (bonding and interactions), which affects the energy changes associated with either forming or breaking interactions (energy). In addition, whether a phase change occurs or not depends upon the energy transfer between a system and its surroundings (change and stability) (fig. 2). Connecting particular topics to core ideas allows students to construct a framework of ideas that are connected to each other (*i.e.* more expert-like), rather than ideas that are fragmentary and difficult to recall and use.

Knowledge of a concept is important, but even more important is how the student is able to use that knowledge. The practices (scientific and engineering practices), as defined in the Framework, are descriptions of what putting knowledge to use looks like. The practices are: asking questions; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; developing explanations; engaging in argument from evidence, and obtaining, evaluating and communicating information. These practices describe what it is that scientists (and engineers) do. By characterizing what it is that we are expecting students to do with their knowledge, it is possible to design assessments that are able to elicit evidence of engagement with one or more practices. Further, without assessing what students can do with their knowledge, it is impossible to know whether or not they have coherent and useful disciplinary knowledge. As we have seen, asking simply for a factoid (such as the definition of *hydrogen bonding*) may lead one to dramatically over-estimate student understanding.

The crosscutting concepts are those ideas that are common across the sciences and are intended to emphasize the connections among the scientific disciplines. Ideally, students we want to see science as a unified, rather than siloed, enterprise. Thus, concepts such as *cause* and *effect* (required for mechanistic understanding of a range of phenomena), and *energy* and *matter flows* are important across all domains of science.

Putting it together: «Chemistry, life, the universe and everything» (CLUE)

CLUE is a general chemistry curriculum designed to take advantage of our current understanding of teaching and learning chemistry (Cooper & Klymkowsky, 2013; Cooper & Klymkowsky, 2015). To foster integration of concepts into a more expert-like knowledge framework, CLUE anchors content to disciplinary core ideas and builds ideas in sophistication over time. Evidence of the development of a coherent knowledge framework is obtained by requiring students to engage in contextualized scientific practices. Students are asked to construct models with predictive and/or explanatory power, use data and evidence to fortify claims, and reason mathematically. The curriculum was developed as part of a unique interdisciplinary collaboration between a chemist (Cooper) and a biologist (Klymkowsky), which ensured that topics included were perceived important and relevant by an interested party outside the discipline. The new curriculum has a number of important features (fig. 3).

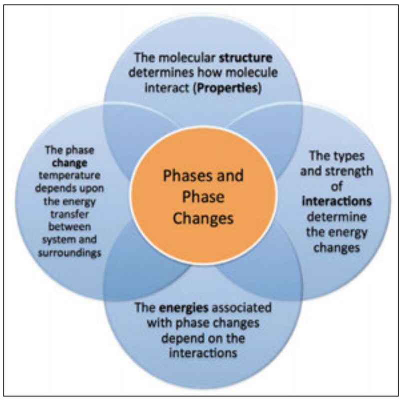


Figure 2. The relationships of the core ideas to a topic (phases and phase changes).

Designing assessment items

We believe that, while the design of the curriculum is important, the design of the concomitant assessments is of equal or greater importance. The assessment items used in a course send an implicit message to students about what is important. If the items ask for knowledge-based regurgitation (or algorithmic problem solving), then that is what students will focus on. Thus, assessments should reflect the goals of the course. It is all too common to see changes in pedagogy that are not reflected in the assessments by which students learn what is important.

In our work, we have used an approach that relies on the idea that assessments should have the potential to elicit evidence about what students know and can do (National Research Council, 2001). Assessments in CLUE are grounded in learning outcomes that combine concepts being studied with complementary scientific practices (Mislevy & Riconscente, 2011). For example, we might say: «Students will construct diagrams and use them to explain why different compounds have different boiling points», rather than: «Students will predict relative boiling points for a range of compounds». The former learning outcome requires that

1. Chemistry ideas are developed over time with increasing sophistication. Every important topic is explicitly linked to one or more core ideas.
2. Student constructed models, explanations and arguments are a central feature of the curriculum.
3. The curriculum materials, including text, student activities, formative and summative assessments, and instructor materials are all highly integrated.
4. The text is the narrative driver for the course: it discusses how and why the ideas we are developing are important. It does not contain «problem solving» activities or sample problems (since these are best administered in another medium).
5. The accompanying homework system, beSocratic, is a powerful web-based system that allows students to answer questions that require them to write and draw (construct models and explanations). Since the system is not limited to forced choice, drag and drop or other constraining interfaces, students can draw and write as they would normally without a steep learning curve (Bryfczynski, 2012; Bryfczynski, Pargas, Cooper & Klymkowsky, 2012).

Figure 3. The characteristics of the CLUE curriculum.

students produce evidence of their thought process in the form or diagrams and written explanations. By contrast, the latter outcome can be addressed by assessment items such as ranking tasks (rank these compounds in order of boiling point, see fig. 4). As discussed earlier, there is a great deal of evidence that students can answer ranking tasks without connecting their thinking to chemical principles. Instead they invent rules of thumb or use heuristics that rarely have a basis in science. By asking students to use their knowledge, we are able to elicit more convincing evidence about what it is that they know and can do. For example: we might develop a set of questions that provide needed scaffolding to help students understand what is required to answer the question.

The structure of a prompt is crucial to getting at what students understand and can do with their understanding. An unstructured prompt (*e.g.* explain why ethanol has a higher boiling point than carbon dioxide) is unlikely to elicit the kinds of reasoning we are seeking, and often results in surface level responses. If the prompt is too structured, it will often produce responses that over-estimate student understanding (in the same way that multiple choice questions often do). The prompt must be «just right»: it should signal to students that they should provide a reasoned answer, without providing that answer. In our work characterizing student understanding of acid-base reactions, a relatively unstructured prompt asking why a given reaction occurred returned largely surface-level descriptions of what was happening in the reaction. Modifying this prompt to first ask what was happening in the reaction and then subsequently ask why it happened elicited much more sophisticated responses (Cooper, Kouyoumdjian & Underwood, 2016).

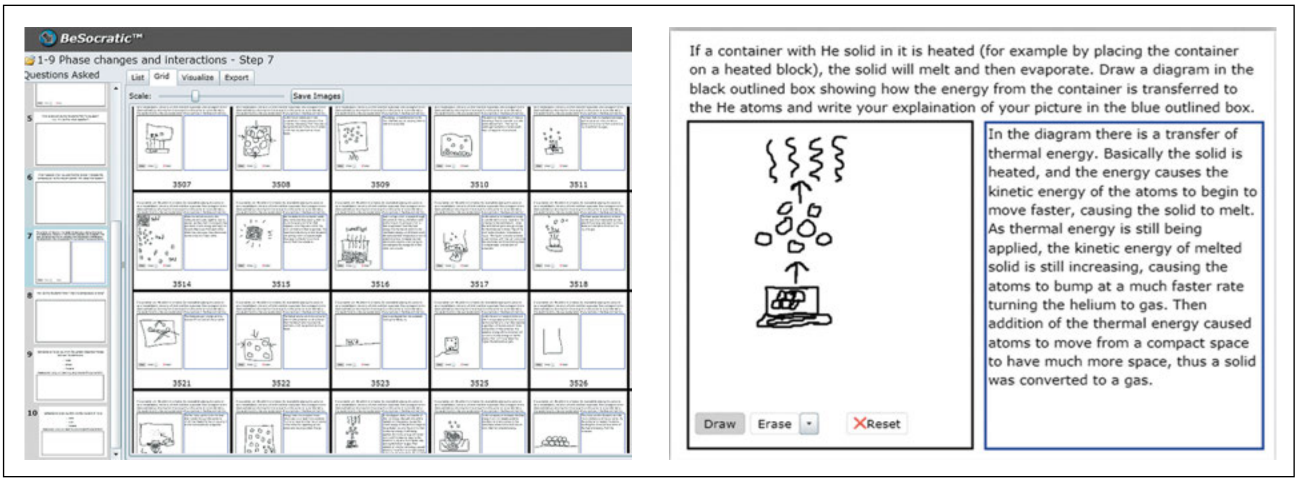
Students answer questions of this type on beSocratic, and receive feedback during the next class. In fact, these kinds of formative assessment items are often used to introduce the next class: students may discuss, critique and respond to the (anonymous) answers that can be called up from the beSocratic system. Student responses are shown on a grid, and individual responses can be shown by clicking on the appropriate response as shown in fig. 5.

Studies on the efficacy of CLUE

The CLUE curriculum has been taught in a number of settings over the past eight years ranging in size from small scale pilot classes of 50 students to an entire general chemistry program with 2 500 students per semester. It has been taught in large lecture halls and smaller scale-up type classes, in both a lecture and flipped formats. We have investigated student outcomes in a number of different ways. For example, we have carried out

Simple ranking task	*Scaffold task that requires students to link core ideas, and provide evidence of understanding*
Which has the highest boiling point? A) $CH_3CH_2CH_3$. B) CH_3OCH_3. C) CH_3CH_2OH. D) They all have the same boiling point.	*a*) Draw the Lewis structures of CO_2, CH_3CH_2OH. *b*) Draw three molecules of each substance and show where the strongest intermolecular forces are located. *c*) Which substance do you think has the highest boiling point? *d*) What factors affect the substances' boiling point? *e*) How do these factors affect the boiling point?

Figure 4. A comparison of a ranking task and a task designed to elicit reasoning.



If a container with He solid in it is heated (for example by placing the container on a heated block), the solid will melt and then evaporate. Draw a diagram in the black outlined box showing how the energy from the container is transferred to the He atoms and write your explaination of your picture in the blue outlined box.

In the diagram there is a transfer of thermal energy. Basically the solid is heated, and the energy causes the kinetic energy of the atoms to begin to move faster, causing the solid to melt. As thermal energy is still being applied, the kinetic energy of melted solid is still increasing, causing the atoms to bump at a much faster rate turning the helium to gas. Then addition of the thermal energy caused atoms to move from a compact space to have much more space, thus a solid was converted to a gas.

Figure 5. Examples of the grid and individual responses for the beSocratic system.

several quasi-experimental investigations in which we compared matched cohorts of students from traditional and CLUE curricula. For example, we were able to show that CLUE students are significantly better at drawing Lewis structures (with a large effect size r = 0.6) (Cooper, Underwood, Hilley & Klymkowsky, 2012). We were also able to show that CLUE students had a better understanding of what information can be predicted from Lewis structures (Underwood, Reyes-Gastelum & Cooper, 2016). Indeed, in a longitudinal study over the course of two years, we found that students from the CLUE curriculum consistently outperformed a matched cohort of their peers. For example, as shown in fig. 6, after general chemistry, over 75 % of CLUE students understood that chemical reactivity and physical properties can be predicted from a compounds' chemical structure, whereas students from a traditional general chemistry program never reached this level even after two years of chemistry instruction.

Studies on student understanding of intermolecular forces also showed that CLUE students were significantly more likely to identify intermolecular forces as being located between two (small) molecules, rather than within those molecules (Williams, Underwood, Klymkowsky & Cooper, 2015). Again, this improvement was maintained over two years, as shown in fig. 7. It is significant that once again students from the traditional general chemistry course do not seem to improve even after a second year of organic chemistry.

We have a number of other ongoing studies that also provide evidence of improved understanding and use of knowledge by students enrolled in the CLUE curriculum.

In summary, we believe that curriculum reforms such as the one discussed here are vital to improving student understanding of chemistry (and science). There is ample evidence that «active learning», while composed of useful pedagogical techniques, is not sufficient to allow students to develop deep and transferrable knowledge. Faculty must think careful about how their curricula are constructed, how the ideas and skills are connected, and what evidence is needed to support claims that students understand and can use course content.

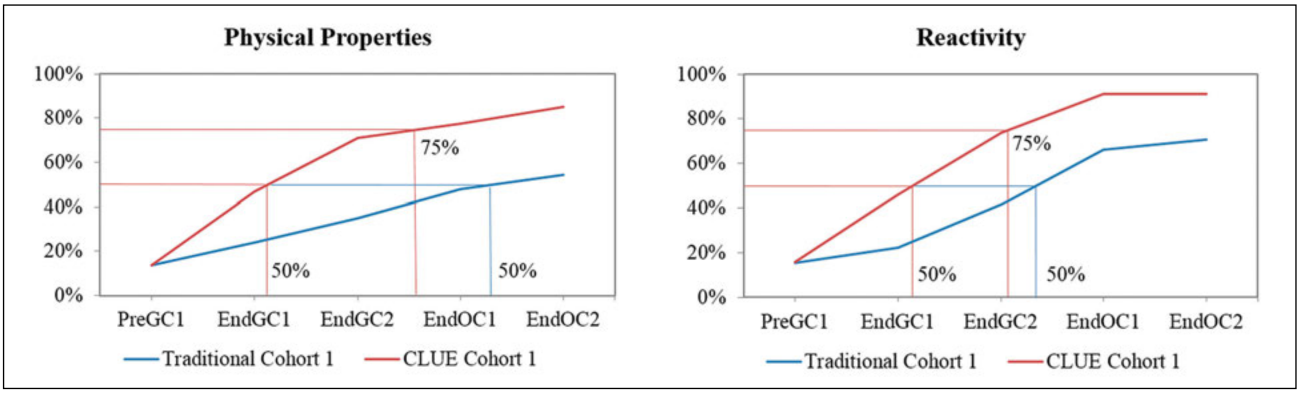


Figure 6. The percent of students who identify a relationship between structure and properties over the course of five time periods over two years of general and organic chemistry.

Finally, it is time to align what we teach with what we value as scientists.

Acknowledgements

I would like to acknowledge the extensive contributions of Mike Klymkowsky, Sonia Underwood, Sam Bryfczynski, Lynmarie Posey, Leah Williams and Hovig Kouyoumdjian to the work discussed here. I would also like to thank Ryan Stowe for helpful comments on the manuscript.

This work is supported by the National Science Foundation under DUE 0816692 (1359818), DUE 1043707 (1420005) and DUE 1122472 (1341987). Any opinions, findings, conclusions or recommendations expressed here are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

ACS Exams [on-line] (2014). Berthoud: ACS Division of Chemical Education Examinations Institute. <http://uwm.edu/acs-exams/> [Last accessed: June 30th 2017].

Bryfczynski, S. P. (2012). *beSocratic: An intelligent tutoring system for the recognition, evaluation, and analysis of free-form student input*. Doctoral dissertation. Clemson: Clemson University.

Bryfczynski, S.; Pargas, R. P.; Cooper, M.; Klymkowsky, M. (2012). «Analyzing and visualizing student work with beSocratic». In: *Proceedings of the 50th Annual Southeast Regional Conference* [on-line]. New York: ACM, p. 349-350. <http://dl.acm.org/citation.cfm?id=2184599> [Last accessed: June 30th 2017].

Cooper, M. M.; Corley, L. M.; Underwood, S. M. (2013). «An investigation of college chemistry students' understanding of structure-property relationships». *Journal of Research in Science Teaching* [on-line], vol. 50, No. 6, p. 699-721. <https://doi.org/10.1002/tea.21093> [Last accessed: June 30th 2017].

Cooper, M. M.; Grove, N.; Underwood, S. M.; Klymkowsky, M. W. (2010). «Lost in Lewis structures: an investigation of student difficulties in developing representational competence». *Journal of Chemical Education* [on-line], vol. 87, No. 8, p. 869-874. <https://doi.org/10.1021/ed900004y> [Last accessed: June 30th 2017].

Cooper, M. M.; Klymkowsky, M. W. (2013). «"Chemistry, life, the universe and everything": a new approach to general chemistry, and a model for curriculum reform». *Journal of Chemical Education* [on-line], vol. 90, No. 9, p. 1116-1122. <http://pubs.acs.org/doi/abs/10.1021/ed300456y> [Last accessed: June 30th 2017].

— (2015). *CLUE* [on-line]: *Chemistry, life, the universe & everything*. <http://clue.chemistry.msu.edu/> [Last accessed: July 18th 2017].

Cooper, M. M.; Kouyoumdjian, H.; Underwood, S. M. (2016). «Investigating students' reasoning about acid-base reactions». *Journal of Chemical Education* [on-line], vol. 93, No. 10, p. 1703-1712. <https://doi.org/10.1021/acs.jchemed.6b00417> [Last accessed: June 30th 2017].

Cooper, M. M.; Posey, L. A.; Underwood, S. M. (2017). «Core ideas and topics: building up or drilling down?». *Journal of Chemical Education* [on-line], vol. 94, No. 5, p. 541-548. <https://doi.org/10.1021/acs.jchemed.6b00900> [Last accessed: June 30th 2017].

Cooper, M. M.; Underwood, S. M.; Hilley, C. Z. (2012). «Development and validation of the implicit information from Lewis structures instrument (IILSI): do students connect structures with properties?». *Chemistry Education Research and Practice* [on-line], vol. 13, p. 195-200. <https://doi.org/10.1039/C2RP00010E> [Last accessed: June 30th 2017].

Cooper, M. M.; Underwood, S. M.; Hilley, C. Z.; Klymkowsky, M. W.

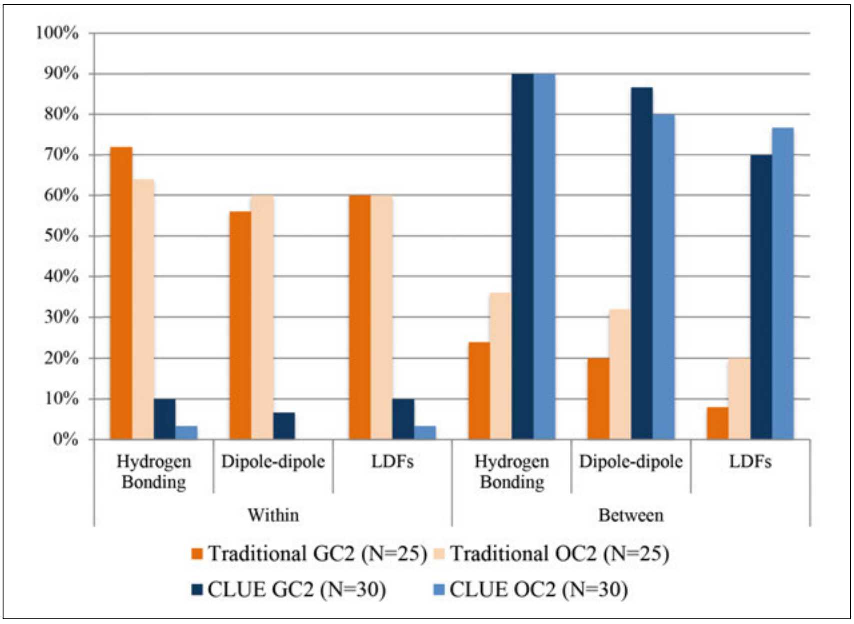


Figure 7. Comparison of IMFs drawing code frequencies for CLUE and control students at the end of general chemistry (GC2) and organic chemistry (OC2).

(2012). «Development and assessment of a molecular structure and properties learning progression». *Journal of Chemical Education* [on-line], vol. 89, No. 11, p. 1351-1357. <https://doi.org/10.1021/ed300083a> [Last accessed: June 30th 2017].

Cooper, M. M.; Williams, L. C.; Underwood, S. M. (2015). «Student understanding of intermolecular forces: a multimodal study». *Journal of Chemical Education* [on-line], vol. 92, No. 8, p. 1288-1298. <https://doi.org/10.1021/acs.jchemed.5b00169> [Last accessed: June 30th 2017].

A framework for K-12 science education: Practices, crosscutting concepts, and core ideas (2012). Washington: National Academies Press.

Freeman, S.; Eddy, S. L.; McDonough, M.; Smith, M. K.; Okoroafor, N.; Jordt, H.; Wenderoth, M. P. (2014). «Active learning increases student performance in science, engineering, and mathematics». *Proceedings of the National Academy of Sciences* [on-line], vol. 111, No. 23, p. 8410-8415. <https://doi.org/10.1073/pnas.1319030111> [Last accessed: June 30th 2017].

Grove, N.; Bretz, S. L. (2007). «CHEMX: an instrument to assess students' cognitive expectations for learning chemistry». *Journal of Chemical Education* [on-line], vol. 84, No. 9, p. 1524. <https://doi.org/10.1021/ed084p1524> [Last accessed: June 30th 2017].

Hammer, D. (1996). «Misconceptions or p-prims: how many alternative perspectives of cognitive structure influence instructional perceptions and intentions?». *The Journal of the Learning Sciences*, vol. 5, No. 2, p. 97-127.

Mislevy, R. J.; Riconscente, M. M. (2011). «Evidence-centered assessment design». In: Downing, S.; Haladyna, T. (ed.). *Handbook of test development*. Mahwah: Erlbaum.

Miyake, A.; Kost-Smith, L. E.; Finkelstein, N. D.; Pollock, S. J.; Cohen, G. L.; Ito, T. A. (2010). «Reducing the gender achievement gap in college science: a classroom study of values affirmation». *Science* [on-line], vol. 330, No. 6008, p. 1234-1237. <https://doi.org/10.1126/science.1195996> [Last accessed: June 30th 2017].

National Research Council (1999). *How people learn: Brain, mind, experience, and school*. Washington: National Academies Press.

— (2001). *Knowing what students know: The science and design of educational assessment*. Washington: National Academies Press.

Potvin, G.; Hazari, Z. (2013). «The development and measurement of identity across the physical sciences». In: *Proceedings of Physics Education Research Conference (Portland, OR, July 17-18, 2013)* [on-line]. Maryland: American Association of Physics Teachers, p. 281-284. <https://www.compadre.org/per/items/detail.cfm?ID=13182> [Last accessed: June 30th 2017].

Underwood, S. M.; Reyes-Gastelum, D.; Cooper, M. M. (2015). «Answering the questions of whether and when student learning occurs: using discrete-time survival analysis to investigate how college chemistry students' understanding of structure-property relationships evolves». *Science Education* [on-line], vol. 99, No. 6, p. 1055-1072. <https://doi.org/10.1002/sce.21183> [Last accessed: June 30th 2017].

— (2016). «When do students recognize relationships between molecular structure and properties? A longitudinal comparison of the impact of traditional and transformed curricula». *Chemical Education Research and Practice*, vol. 17, No. 2, p. 365-380. <https://doi.org/10.1039/C5RP00217F> [Last accessed: June 30th 2017].

Williams, L. C.; Underwood, S. M.; Klymkowsky, M. W.; Cooper, M. M. (2015). «Are noncovalent interactions an Achilles heel in chemistry education? A comparison of instructional approaches». *Journal of Chemical Education* [on-line], vol. 92, No. 12, p. 1979-1987. <https://doi.org/10.1021/acs.jchemed.5b00619> [Last accessed: June 30th 2017].

Yeager, D. S.; Walton, G. M.; Brady, S. T.; Akcinar, E. N.; Paunesku, D.; Keane, L.; Dweck, C. S. (2016). «Teaching a lay theory before college narrows achievement gaps at scale». *Proceedings of the National Academy of Sciences* [on-line], vol. 113, No. 24, p. E3341-E3348. <https://doi.org/10.1073/pnas.1524360113> [Last accessed: June 30th 2017].

Melanie M. Cooper
Is the Lappan-Phillips professor of science education and professor of chemistry at Michigan State University. Her research has focused on improving teaching and learning in large enrollment general and organic chemistry courses at the college level, and she is a proponent of evidence-based curriculum reform and assessment. She earned her BS, MS and PhD in chemistry from the University of Manchester, England.
E-mail: *mmc@chemistry.msu.edu*.