

It Is Time To Say What We Mean

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ABSTRACT: While there is now general acceptance that active learning and inquiry are desirable, there is much less agreement on what these terms actually mean—and perhaps surprisingly to some, quite contradictory evidence about their efficacy. Similarly, while we might agree that critical thinking is an important outcome, even experts cannot agree what critical thinking is. In this editorial, I argue that it is now time to be more specific about what we mean when we talk about effective pedagogical approaches and the desired outcomes. One approach is to adopt the scientific practices from the *Framework for Science Education*, which are well described, and by their very nature require that students construct and use their knowledge. If we know what we are looking for, it is easier to recognize and assess it when we see it.

KEYWORDS: *General Public, Elementary/Middle School Science, High School/Introductory Chemistry, First Year Undergraduate/General, Second Year Undergraduate, Upper Division Undergraduate, Chemistry Education Research*

Chemistry education has come quite a long way in the past 20 years. It is now routine to see and hear educators discussing “inquiry” activities, encouraging “active learning”, and advocating ways to promote “critical thinking”. Indeed, it is now generally acknowledged that these are all important aspects and outcomes of teaching and learning. This acceptance is a positive step along the way to evidence-based teaching and learning, yet unfortunately, things are not quite so simple. All of these terms can have multiple meanings, and depending on who is talking, some of these meanings can be quite different. While these terms are often used as shorthand, if we do not have well-defined meanings for them, it is hard to both identify instances and also to assess outcomes. I suggest that it is time to abandon these terms, and start to use better characterizations of what we actually mean.

The terms “inquiry” and “active learning” refer to pedagogies based on constructivism, that is, knowledge is constructed in the mind of the learner. The idea that students must build their own understanding by constructing and connecting ideas for themselves is the dominant, but not universally accepted, model of learning.¹ While some students do this naturally (e.g., Ph.D.-level chemists are likely to actively engage with chemistry materials presented to them, even in the context of a passive lecture environment), most students do not. It is believed that providing students with learning environments in which they are encouraged to construct ideas and connections leads to improved learning.

However, when we talk about “active learning”, it becomes clear that the term has a wide range of meanings (besides the fact that, presumably, if students learn, they are doing something active). While the title of the recent meta-analysis by Freeman et al.,² “Active learning increases student performance in science, engineering, and mathematics”, seems unequivocal, a careful reading reveals that the authors make no attempt to define exactly what they mean by active learning, nor do they go into detail about what “student performance” is. Instead they say:²

The active learning interventions varied widely in intensity and implementation, and included approaches as diverse as occasional group problem-solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs.

It seems highly unlikely that a few in-class worksheets, or any use of clickers in the classroom, will have an effect similar to that of restructuring a course in a workshop environment or activities where students construct and use models to predict and explain phenomena. It is also likely that the ways these activities are implemented has an impact. Indeed, Andrews et al.³ studied a large sample of typical faculty, rather than science education researchers—who are more likely to publish papers on “active learning”—and found that adding active learning activities to a course was **not** in and of itself associated with greater learning gains (as measured by course grades). Their hypothesis was that traditional faculty did not actually understand the purpose of active pedagogies and therefore were unable to elicit the constructivist elements necessary for these techniques to work. It may also be that course grades do not measure the types of improvements that “active learning” may promote.

Similarly, “inquiry” is another approach to improving learning “that has been interpreted over time in many different ways throughout the science education community.”⁴ When we speak of inquiry learning, do we mean open inquiry, confirmation inquiry, structured inquiry, guided inquiry, or something else entirely? Does inquiry require a hands-on laboratory setting? Who knows! It is striking that the National Research Council (NRC) *Framework for K–12 Science Education*,⁴ a document that synthesizes what we know about learning in science and lays out a vision for how science education could be structured based on our current evidence and theories of learning, contains little mention of scientific inquiry—and no mention of active learning.

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The use of inquiry and active learning has been put forth as an effective way to improve students' "critical thinking" skills, which have been identified as crucial for personal and national success in the 21st century,⁵ but critical thinking and how it is achieved have been interpreted quite differently by different authors. As noted in the NRC report *Assessing 21st Century Skills*,⁶ some definitions "essentially encompasses all of problem solving, judgment, and cognition."⁶ Indeed, in the past it was thought that critical thinking skills were universal (domain independent); that is, they could be achieved without reference to any specific discipline and readily transferred to other domains. There is, however, "little evidence that critical thinking exists as a domain-general construct distinct from general cognitive ability."⁶ Instead, critical thinking might be construed as "a domain-specific construct that evolves as the person acquires domain-specific knowledge."⁶ For example, an expert physicist may not be able to transfer their skills to chemistry unless they also have a great deal of chemistry-specific knowledge, a problem that occurs frequently in interdisciplinary collaborations.⁷

All of this background leads me to suggest that it is time for us to stop using diffuse terms that are difficult to define and that can have multiple (idiosyncratic) meanings, and start being more explicit about what exactly we mean. It is difficult to measure improvement in a construct if we do not have a common definition of what it is. One way to frame such a conversation is by adopting the approach described in the NRC *Framework for Science Education*. The *Framework* describes eight scientific and engineering practices that can be considered as the disaggregated components of the things that scientists do. All of these practices are well articulated and describe what students should do with knowledge (besides remember and regurgitate it). On the basis of this practice-based definition, students must be able to "do" something specific. For example, the practice of "designing and carrying out an investigations" means just that. "Developing and using models" requires the student to not only construct a model (either mental, graphical, computational, or physical) but also be able to use it productively to predict or explain a specific observation or scenario. "Analyzing and interpreting data", "engaging in argumentation from evidence", and "evaluating information" can all be seen as distinct components of critical thinking. If we describe our desired outcomes using these practices, the result will be that we will shift to more engaged pedagogies with clearer outcomes that can actually be assessed. After all if we do not know what we mean by critical thinking or inquiry, it is hard (i.e., impossible) to determine whether students actually have acquired these skills. Indeed, there is already an increased interest in using the vision set out in the *Framework* to guide future reform efforts in higher education. For example, at the upcoming Biennial Conference on Chemical Education (BCCE), there are sessions such as "Putting the Framework Into Practice", and at Michigan State University, we are using this approach to support the transformation of the gateway STEM courses.⁸

On a final note, scientific practices do not exist in isolation from disciplinary ideas;⁹ they need to be presented in a relevant and engaging context throughout the chemistry curriculum and across disciplines. The end result is likely to be a deeper understanding of chemistry AND a better understanding of how to apply science practices more broadly. If we are explicit about our goals, it will be easier to measure whether we have accomplished them.

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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) *Constructivist Instruction: Success or Failure?*, 1 ed.; Tobias, S., Duffy, T. M., Eds.; Routledge: New York, 2009.
- (2) Freeman, S.; Eddy, S. L.; McDonough, M.; Smith, M. K.; Okoroafor, N.; Jordt, H.; Wenderoth, M. P. Active Learning Increases Student Performance in Science, Engineering, and Mathematics. *Proc. Natl. Acad. Sci. U. S. A.* **2014**, *111*, 8410–8415.
- (3) Andrews, T. M.; Leonard, M. J.; Colgrove, C. A.; Kalinowski, S. T. Active Learning Not Associated with Student Learning in a Random Sample of College Biology Courses. *CBE-Life Sci. Educ.* **2011**, *10* (4), 394–405.
- (4) National Research Council. *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, 2012.
- (5) National Research Council. *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*; National Academies Press: Washington, DC, 2012.
- (6) National Research Council. *Assessing 21st-Century Skills: Summary of a Workshop*; National Academies Press: Washington, DC, 2011.
- (7) Greenwood, V. Physicists at the Gate: Collaboration and Tribalism in Science. <http://undark.org/article/collaboration-and-tribalism-in-science/> (accessed Apr 2016).
- (8) Cooper, M. M.; Caballero, M. D.; Ebert-May, D.; Fata-Hartley, C. L.; Jardeleza, S. E.; Krajcik, J. S.; Laverty, J. T.; Matz, R. L.; Posey, L. A.; Underwood, S. M. Challenge Faculty to Transform STEM Learning. *Science* **2015**, *350* (6258), 281–282.
- (9) Holme, T.; Murphy, K. The ACS Exams Institute Undergraduate Chemistry Anchoring Concepts Content Map I: General Chemistry. *J. Chem. Educ.* **2012**, *89*, 721–723.