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# Scientific Sensemaking: A Critical Resource for Science Learning in School

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## Conceptualizing Integration & Transfer

Science consists of both a body of knowledge and a process by which the knowledge is produced. Historically, these two aspects were often assessed separately (i.e., test items on knowledge and test items on skills) and taught relatively separately (e.g., with an introduction section on skills or via isolated projects or labs). The last decade has been marked by a substantial shift to an integrated view of both how science should be taught and how science learning should be assessed. Now, consensus reports (e.g., NRC, 2007, 2011) assert that scientific processes (renamed practices) should be used to learn science content (e.g., by designing, conducting, and interpreting experiments, or by arguing from existing sources). Further, new science standards (e.g., NGSS) strongly claim that science practices must be demonstrated in use with scientific content and that scientific content must be demonstrated through use with scientific practices.

While the central point about the importance of practice and content integration is well supported by existing data (for a summary, see NRC 2011), embedded within these new conceptions of teaching and learning science are some open cognitive foundations questions that bear further investigation. These questions have important implications for both assessment and instruction. The first open question is the about the generativity and transferability of practices across content. If students learn sciences practices in one science content area (e.g., in biology), are they able to apply those science practices in another domain (e.g., chemistry)? Expert scientists have some transferability of their skills (Schunn & Anderson, 1998), but will students also show such transferability? If so, they will be better positioned to learn new content having mastered practices in a prior science content area. However, if practices are very tightly bound to science content given how they are taught and learned, students may struggle with using these practices in new content areas.

The second but related open question has to do with the coherence of practices. If science consists of independent practices, is it meaningful to report an overall mastery level of science practices? However, if science practices work together in overall cycles of inquiry, then students who master some practices will be better positioned to master other practices, and there will be meaningful overall mastery level of science practices which can be taught and assessed.

Taking on both of these open questions, here I present recent tests of the general hypothesis that there is a general overall mastery level of core scientific practices that drives

learning in new science content areas. If supported, instruction should be organized around developing these core practices early in instruction (to accelerate later learning). Also, support for this approach suggests that computational agents could be developed to systematically acquire science content through experimentation and reading using scientific sensemaking skills as a foundation.

Conceptualizing this general mastery level as scientific sensemaking, and efficiently measuring it using scenarios that invoke shared, intuitive understandings of the natural world, I will describe recently obtained evidence that 1) students tend to vary along coherently along this overall sensemaking dimension; 2) overall sensemaking levels are a strong predictor of science learning; and 5) this overall sensemaking dimension can improve with effective science instruction.

## Conceptualizing Scientific Sensemaking

Approaching learning of science-related content as a sensemaking activity means recognizing that science is not a series of facts, but rather an ongoing and iterative employment of a set of practices that used in the pursuit of an increasingly rich understanding of natural and physical phenomena. These practices include asking good questions, seeking mechanistic explanations for natural and physical phenomena, engaging in argumentation about scientific ideas, interpreting data tables, designing investigations, and understanding the changing nature of science (Apedoe & Ford, 2009; Lehrer, Schauble, & Petrosino, 2001). Each of these practices play an important and complementary role in science learning. In selecting practices for inclusion within the scientific sensemaking construct, several criteria needed to be met: 1) an existing research-base for its role in predicting science achievement; 2) uniqueness in its contribution to learning; and 3) the flexibility to be improved through targeted instruction.

## Measuring Scientific Sensemaking

To cleanly measure scientific sensemaking, it is important consider several critical issues. First, the measure had to be about some scientific content: one cannot engage in scientific sensemaking void of content—science has some logic to its processes, but most of the logic is context specific about which assumptions or inferences are merited. Consider the class Control-of-Variables strategy (Zimmerman, 2007). This strategy can only be applied when it is clear what variables are possible to vary (and plausibly causal), which involves thinking about content.

A second consideration is that the assessment be effort-worthy. Engaging in scientific sensemaking requires effort, and there is often little incentive for students to put forth effort to perform on an assessment. If students are not putting effort into the assessment, then the scores obtained from the assessment are an underestimate of the abilities students have. In order to motivate students to put forth effort, the content we selected for the assessment scenarios were so-called “charismatic mega-fauna” (i.e., Dolphins, Monkeys, & Eagles), in which a general interest in the topic motivates some basic level of effort (Bathgate, et al. 2013).

A third consideration is assessment length. Items that are cognitively demanding of students and require them to make sense of scientific information, take relatively longer amounts of time than items simply requiring content recall.

### Empirical Tests of Scientific Sensemaking

After consideration of design considerations listed above, a new measure was created, and its psychometric properties were verified. Then, the validity of scientific sensemaking as a predictor of future content learning was tested in a large-scale study of students learning diverse science content across middle school and early high school grades in diverse curricula (included more hands-on and more text-book-based). Finally, changes in scientific sensemaking were examined in relation to levels of student engagement in classroom learning, to show that is malleable, rather than a fix construct like IQ.

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