Linking Evidence and Learning Goals

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The NRC committee on "Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education" was commissioned by the National Science Foundation to assess the current state of evidence of effectiveness of STEM undergraduate education practices using a workshop format. In addition to a broad exploration of the evidence, the committee sought to connect educational researchers from different disciplinary fields and to provide foundational information for a parallel NSF-funded initiative by the Wisconsin Center for Education Research on "Mobilizing STEM Education for a Sustainable Future" (http://mobilizingstem.wceruw.org/) that aims to identify new strategies for organizing and implementing STEM undergraduate education practices.

The first NRC workshop was held on June 30, 2008 and focused on "Linking Evidence and Promising Practices in STEM Undergraduate Education." One of the challenges that emerged in the workshop was that of aligning learning goals and evidence. This paper summarizes the outcomes of the June 30th workshop in the context of evidence and learning goals. For additional information, four papers commissioned for the workshop are available on-line (http://www7.nationalacademies.org/bose/PP_Commissioned_Papers.html), as are the presentations of workshop speakers (http://www7.nationalacademies.org/bose/PP_Agenda_1_June30_2008.html). The NRC committee used the findings of the workshop to identify particularly promising practices for extended consideration and analysis in the second workshop held October 13-14, 2008.

What counts as evidence?

The legitimacy of a given form of evidence depends on the context of the question being asked. Evidence of student learning might be used to inform one's teaching, to generate a knowledge base, or convince colleagues to adopt new teaching practices. Evidence that is useful in working with a group of students may not be of sufficient rigor to contribute to a broader knowledge base. It was observed that conversations about evidence of learning are difficult to elicit among practitioners and there appears to be some resistance to bringing the social sciences into the discussion of evidence of learning in STEM undergraduate education. For many practitioners, the way into education research appears to be the application of methods and approaches used in their research on scientific questions rather than considering social science methodologies, which were not part of their professional training (Etkina et al., 2005). Both the scale and extent of research collaboration on undergraduate STEM learning needs to expand if a coherent body of evidence is to be established. With respect to modifying faculty teaching behavior, evidence supporting a teaching practice was seen as a necessary but not sufficient factor

(Henderson and Dancy, 2007; 2008). A possible exception being that physics faculty who used the Force Concepts Inventory have changed their behavior in response to evidence that their students were not mastering core concepts in introductory physics (Mestre 2005).

The importance of multiple modes of evidence in evaluating promising practices was stressed. There is a need for many kinds of evidence in contrast to a collection of instruments developed without coherence or intent. The evidence sought needs to be aligned with the desired learning goals. Types of evidence include:

- Mastery of broad content or concept/s (e.g., understanding ecosystems), being as specific as possible

- Skill development; these may be:
    - scientific skills (e.g. measurements, observations, etc.);
    - higher-order thinking skills (define these);
    - life-long learning skills (communication--writing, speaking, graphical presentations; quantification skills);
    - interpersonal skills (e.g. collaborative or cooperative work)

- Affective domain--motivations to learn, overcoming identified barriers to learning, addressing values and attitudes about science, other attitudinal changes

- Behavioral changes, as might be reflected in curricular or institutional goals, such as increasing STEM retention, preparing students to engage learning in larger contexts of a discipline, department or institution.

Learning goals and evidence

For learning goals to be effective in a classroom setting, they need to be explicitly stated with a specific student population being the focus. For purposes of defining and advancing the field of STEM undergraduate education research, more broadly writ learning goals linked to evidence types are need to build coherence and enable researchers to move forward in more concretely addressing questions. The following goals were identified by workshop participants as being important given STEM workforce demands and the rapid rate of knowledge and information growth in STEM fields:

- Master a few major principles/concepts well and in-depth (distinct from procedural knowledge)

- Retain what is learned over the long-term

- Build a mental framework that serves as a foundation for future learning

- Develop visualization competence including ability to critique, interpret, construct, and connect with physical systems

- Develop skills (analytic and critical judgement) needed to use scientific information to make informed decisions

- Understand the nature of science

- Find satisfaction in engaging in real-world issues that require knowledge of science

Different types of evidence would suffice as indicators of student accomplishment of examples of goals above. Evidence of visualization competence might include a student constructing a useful visualization or developing their own representational strategies and systems, such as a symbol system that a peer could use. Affective assessments could provide evidence indicating whether or not a student finds satisfaction in engaging in real-world issues that require knowledge of science.

The success of strategy writing (writing about a problem rather than immediately using equations) in helping students to master a major principle needed to solve a physics problems rather than relying on procedural knowledge can be assessed by asking students to categorize problems according to the major principle needed to solve the problem (Chi, Feltovich & Glasser, 1981; Hardiman, Dufresne & Mestre, 1989).

Evidence of mastery of concepts can also be demonstrated with concepts inventories. The thirty year history of the physics Force Concepts Inventory (FCI) is an exemplar of how a shared instrument moved both student learning and the field of physics education research forward (Hake, 1998). Concept inventories are now emerging in other fields. While valuable in moving research forward, there is more to understanding and enhancing student learning in STEM fields than addressing alternative conceptions uncovered in concepts inventories, underscoring the need for multiple modes of evidence in undergraduate learning in STEM fields.

<u>Gaps in evidence</u>

Gaps between learning goals and evidence are found across STEM disciplines. Longitudinal studies are largely missing from the current body of evidence for STEM undergraduate learning. Current assessment practices are very light on conceptual understanding and long-term retention, likely because factual and procedural knowledge are easier to evaluate than conceptual knowledge.

Even thoughtfully designed, well-established practices like the American Chemical Society's *Chemistry in Context* (Eubanks et al., 2009) can have clearly stated learning goals without supporting evidence or a comprehensive set of accompanying instruments to obtain the evidence. Among the promising practices discussed at the workshop, those that did have an evidence base were more likely to rely on a single type of evidence rather than multiple modes of evidence linked to specific learning goals.

Physics has a theoretical framework for physics education research that offers approaches to closing gaps in evidence (Redish, 2004). Given epistemological differences among STEM disciplines, establishing similar agendas in the other disciplines could prove helpful in more broadly addressing gaps in evidence.

<u>Linking evidence and promising practices</u>

Numerous promising practices to improve STEM undergraduate education were discussed at the workshop in terms of learning goals, assessments, and evidence of effectiveness in achieving learning goals. A representative, but not comprehensive, set of examples are presented here to illustrate the degree of linkage between learning goals and evidence (for a detailed analysis, refer to Jeffrey Froyd's white paper - http://www7.nationalacademies.org/bose/PP_Froyd_WhitePaper.html). While promising practices occur at all grain sizes, from activity to course to department to college, institution and professional society, most practices discussed at the workshop were at the level of a course. While the focus here is on the link to student learning, a practice is more likely to be "promising" if it is easily implemented and, therefore, more likely to be readily disseminated.

Institutional change: Evidence of successful institutional transformation is found in both the existence of new programs and student feedback. Comparative studies are difficult because of the multifactorial institution specific context. Detailed examples are provided in Jeanne Narum's white paper for the workshop (http://www7.nationalacademies.org/bose/PP_Narum_WhitePaper.html).

Using learning goals: A lack of comparison studies and learning goals that are not sufficiently specific have stalled assessment development. There is good evidence, however, from both a critical thinking assessment (http://www.wolcottlynch.com) and self-assessment developed at Alverno College (http://depts.alverno.edu/saal/selfassess.html) that explicitly stated learning goals can enhance aspects of student learning.

Small groups: A range of pedagogical strategies, including collaborative learning, peer-led, team based learning, arrange students in small groups. In terms of student learning, evidence is stronger for small groups than any other promising practice except active learning. Lines of evidence come not only from individual studies, but also from meta-analyses (Johnson, Johnson, & Smith, 1998;

Springer, Stanne, and Donovan, 1999) and multi-year studies (Crouch & Mazur 2001). Assessments include the Force Concepts Inventory.

Learning communities: Students participating in learning communities are enrolled in linked courses with a learning goal of students making connections between courses. Several quasi-experimental studies for engineering curricula have been summarized by Froyd and Ohland (2005). The National Resource Center for Learning Communities reported on assessment of learning communities and publishes the Journal of Learning Communities Research, but the evidence matching learning goals and evidence is at the moderate level, at best.

Scenario-based content organization: Curriculum is organized around a scenario intended to be of relevance to the students. Examples range from the *Chemistry in Context* curriculum discussed earlier to case studies to Process Oriented Guided Inquiry Learning (POGIL). Many scenario-based activities organize students in small groups, making it difficult to sort out whether improved student performance on assessments is attributable to the scenario approach or small group work. It is difficult compare approaches grouped under the scenario heading because they are structurally quite different.

Systematic formative assessment in a course: Providing ongoing feedback to students. Mechanisms include one minute papers at the end of class where students write about fuzzy parts of class that are addressed by the instructor during the next class. There is very limited evidence that systematic formative assessment enhances student performance for specific learning goals.

Classroom activities that actively engage students: Often referred to as pedagogies of engagement, active learning includes a range of activities where faulty members replace at least a portion of lecture with activities that invite student participation. Enhanced student learning has been shown with assessments including pre- and post-tests and homework (Knight & Wood 2005). Overall, evidence supporting active learning is strong.

Undergraduate research experiences: Assessments of student learning as a result of engaging in research with a faculty member rely on student reports or interviews with students. There is evidence that students who participate in research experiences are more likely to attend graduate school (Seymour et al., 2004). The current assessments do not address specifics about student learning.

Faculty-initiated interactions with students: Faculty members initiate connections with students by requiring outside of class meetings rather than waiting for students to visit during office hours if they choose. More general evidence exists that faculty-student interactions enhance learning and retention and the inference that faculty-initiated interactions is logical, there is not strong evidence that this supports student learning.

Other practices that show promise include discipline-based faculty development workshops, encouraging metacognition, and teaching the nature of science explicitly. Metacognition and explicitly teaching the nature of science are promising because of research in cognition. Faculty development workshops, often through professional societies, have the potential to change faculty teaching behavior. As the effect on student learning is one step further removed there are additional challenges to evaluating the effectiveness of the practice on achieving student learning goals.

While there is evidence supporting the efficacy of a number of STEM undergraduate promising practices in enhancing student learning, there is also considerable room for additional research, including development of a coherent set of assessment tools. Strong evidence is very important for the uptake of STEM education practices, but is not sufficient for broad dissemination.

References

Chi, M.T.H., Feltovich, P.J. & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. American Journal of Physics, 69(9), 970-977.

Etkina, E., Mestre, J., & O'Donnell, A. (2005). The impact of the cognitive revolution on science learning and teaching. In J.M Royer (Ed.) *The Cognitive Revolution in Educational Psychology* (pp. 119-164). Greenwich, CT: Information Age Publishing.

Froyd, J. E., & Ohland, M. (2005). Integrated engineering curricula. Journal of Engineering Education, 94(1), 147-164.

Hake, R. (1998). Interactive-engagement vs traditional methods: A six thousand student survey of mechanics test data for introductory physics courses, American Journal of Physics, 66, 64-74.

Hardiman, P.T., Dufresne, R. & Mestre, J.P. (1989). The relation between problem categorization and problem solving among experts and novices. Memory & Cognition, 17, 627-638.

Henderson, C., & Dancy, M. (2007). Barriers to the Use of Research-Based Instructional Strategies: The Influence of Both Individual and Situational Characteristics. Physical Review Special Topics: Physics Education Research, 3(2), 020102.

Henderson, C., & Dancy, M. (2008). Physics Faculty and Educational Researchers: Divergent Expectations as Barriers to the Diffusion of Innovations. American Journal of Physics (Physics Education Research Section), 71(1), 79-91.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). Cooperative learning returns to college: what evidence is there that it works? Change, 30(4),

26-35.
Knight, J. K., & Wood, W. B. (2005). Teaching more by lecturing less. Cell Biology Education, 4, 298-310.
Mestre, J.P. (2005). Facts and myths about pedagogies of engagement in science learning. Peer Review, 7(#2, Winter Issue), 24-27.
Redish, E.F. (2004). A Theoretical Framework for Physics Education Research: Modeling student thinking, Edward F. Redish, In E. F. Redish and M. Vicentini (Eds.) *Proceedings of the International School of Physics, "Enrico Fermi" Course CLVI*, Amsterdam: IOS Press.
Seymour, E., Hunter, A.-B., Laursen, S. L., & Diatonic, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Science Education, 88, 493-534.
Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. Review of Educational Research, 69(1), 21-51.