Assessment and Education Research in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education

Connie Kubo Della-Piana, Evaluation and Organizational Consultant, Oak Ridge Associated Universities, Inc./Oak Ridge Institute for Science and Education (ORISE/ORAU) and Education and Human Resources, Division of Undergraduate Education (EHR/DUE), NSF, Ann Arbor, MI

Since the mid-1990s, higher education has been in the middle of two powerful pressures: 1) increasing interest in systematic investigations of student learning by discipline faculty and 2) rising demand for focus on and evidence of student learning by many constituents of higher education. Exemplary efforts and activities in the STEM disciplines that are addressing these pressures are described in the chapters in this section. One of the major strengths of the chapters is the willingness of the authors to describe the issues, challenges, and steps involved in the development and appropriate use of assessment tools and in the conduct of education research in STEM disciplines. Currently, a small but growing cadre of STEM faculty along with experts in cognitive science and education research and assessment are 1) engaging in systematic investigations of how students learn discipline-oriented knowledge, skills, and attitudes and 2) developing rigorous assessment and documentation of student learning. The efforts are ongoing and are being developed for accountability, improvement, and understanding purposes. They can be viewed as starting points for the difficult and challenging task of transforming higher education into educational environments that serve a diverse set of learners.

These scholars who represent a range of disciplines describe common efforts that link systematic investigation of student learning (i.e., research and assessment) with classroom practice (i.e., curriculum development and instruction). Their writings invite the reader to consider five questions.

1. What methods are available to examine, assess, and document student learning?
2. What do students know about a discipline?
3. How do students learn discipline-oriented knowledge, skills, and attitudes?
4. How can this knowledge be used to transform higher education settings and the ways students learn?
5. What is the impact (expected outcomes and unanticipated consequences) of the innovations on student learning?

The first chapter by Richardson describes numerous efforts in STEM disciplines to develop concept inventories to undercover students' misconceptions or common beliefs about important concepts and processes in the discipline of interest. In general, concept inventories are based on the Force Concept Inventory (FCI) in physics, its development, and use. Richardson singles out as exemplary, the research and development process underlying a concept inventory for thermal and transport science at the Colorado School of Mines. He describes five characteristics that make this research and development effort exemplary: 1) the work draws on a theory of cognition in which there is a distinction between students' understanding of causal processes in science (correct understanding) and "emergent" processes in science (misconception), 2) the work is being carried out by a team of experts in engineering, cognitive science, education research, and assessment, 3) building the concept inventory is based on a fundamental and pervasive misconception in thermal and transport science, 4) the concept inventory is based on observations of student performance and on applying a cognitive theory of student learning to the interpretation of student performance on selected tasks, and 5) reliability and validity studies are conducted. In addition to providing a set of characteristics of exemplary research and development of concept inventories, Richardson

describes and explains steps for construction of a concept inventory 1) determining the concepts, 2) studying and articulating the learning process, 3) constructing several multiple-choice questions for each of the concepts, 4) administering the beta version and analyzing the results, and 5) revising to improve readability, reliability, validity, and fairness. He concludes with a caution: "while concept inventories are powerful tools for assessing students' understanding of a narrow range of concepts, concept inventories alone cannot provide sufficient guidance for improving students' concept development—there must be intimate knowledge of students' thought processes gained through other methods such as interviews and observation."

The second chapter by Maki answers the two questions posed during the threaded discussions conducted before the CCLI conference: 1) "...You decide to develop new curriculum materials, or adapt and implement them in your institution—what evidence enables (or will enable) you to infer that it is working—and why?" 2) "...What characterizes an acceptable evaluation plan?" To answer the questions, he proposes a framework for understanding and addressing the challenges and issues facing STEM faculty as they develop or adapt educational innovations and evaluate if they are effective in increasing student learning. Maki poses a set of questions whose answers help guide the design of the evaluation and collection of data. What measures should be taken? What comparisons should be made? What is a suitable control group? What if a control group is not possible? How can sense be made of student differences? Maki describes typical scenarios and describes research and evaluation methods that are designed to assist in the development of an acceptable evaluation plan. Answers to Maki's set of questions assist the researcher and curriculum developer in designing an evaluation plan that addresses potential alternative hypotheses explaining the findings and in developing an evaluation plan that controls for extraneous or confounding variables, such as "student self-selection." The chapter alerts STEM faculty involved in course, curriculum, and laboratory improvement projects to threats to validity and the role of research and evaluation methods to limit or control those threats.

The final chapter by Heron et al. describes a framework that links discipline-based education research with curriculum development and instruction. Based on previous research and knowledge of the context and nature of the educational experience in the discipline, the discipline-based education researchers ask and answer two questions: 1) Is the standard presentation of a basic topic in the textbook or lecture adequate to develop a functional understanding? 2) If not, what gaps need to be filled? Using multiple methods to answer the questions, the researchers engage in an iterative process through which they discover and examine students' understanding of key concepts in physics through structured interviews about and observations of undergraduate students' problem-solving behavior and concept development. Based on the knowledge and understanding of how the students solve (partially solve or do not solve) the problems, the researchers-turned-curriculum-and-instructional-designers develop a set of tutorials that consist of worksheets and instruction (collaborative problem-solving) along with training for teaching assistants and faculty. Worksheets are used to assist students in 1) developing the reasoning processes to develop and apply important concepts and 2) assessing students' levels of concept development. Information about student performance is integrated into the ongoing research on student learning and into the revision of materials and instruction. Heron and associates present examples of ongoing research and development and pilot projects. Based on their research agenda and framework, they conclude that, "if students go through the reasoning involved in the development and application of important concepts, they can significantly deepen their understanding of ... very difficult material."

The authors describe ongoing efforts in undergraduate STEM education that integrate research and assessment into curriculum development and instruction. Each stresses the value of conducting systematic investigation of student learning as an integral part of developing assessment tools and curricula and contributing to a body of knowledge on how students learn STEM disciplines. Each invites the STEM community to engage in activities that focus on the systematic inquiry and development of student learning.