New advances in cognitive psychology and learning science provide insights into how people construct knowledge, with important implications for how we learn from, and teach about, the Earth. Research on learning has demonstrated that effective instructional practices require students to construct their own knowledge bases (i.e. a shift in emphasis from teaching to learning), address diverse student learning styles, employ a variety of active-learning strategies, and encourage inquiry and discovery. These emerging principles provide a context for us to reflect collectively on what and how we teach in our mineralogy, petrology, and geochemistry courses. If we are to meet the challenges of the 21st century, our new instructional goal should be to develop students who are lifelong learners and who use the knowledge base, technical skills, and cognitive strategies that are used by “master” geoscientists. As a result, we will help sustain the long-term health and relevance of the mineralogy, petrology, and geochemistry community.

**Keywords:** human cognition, learning theory, learning goals, teaching strategies

Mineralogy, petrology, and geochemistry (MPG) have never been more important than they are today—as an integral part of the geoscience curriculum and in service to society. To sustain the exciting research currently being done in the MPG disciplines, to secure the long-term health and vitality of these disciplines, and to extend their influence in the broad public discourse, we need to effectively recruit and train the next generation of mineralogists, petrologists, and geochemists. We simply cannot afford to miss the opportunity to provide excellence in education in the MPG disciplines for all students in the geosciences and related fields. The training of the next generation of scientists may arguably be as important to the scientific enterprise as the direct results of our research.

Consequently, this is a good time for the MPG community to reflect on its goals and expectations for geoscience education. What should our students know and be able to do as a result of the courses they take? In light of the changing requirements of the workplace (both academic and industrial), what additional “orthogonal” skills are needed—for example, the ability to communicate complex ideas, verbally, in writing, and in visualizations; to apply quantitative reasoning; to integrate ideas across many disciplines and disparate lines of evidence; and to work in teams (NRC 1996; NSF 1996)? What critical-thinking and problem-solving strategies are exemplified by master geoscientists, and how can we best instill these characteristics in novice learners? How can we measurably demonstrate that our learning goals have been achieved in the classroom, laboratory, and field?

As noted in *Science for All Americans* (AAAS 1989), “Learning is not necessarily an outcome of teaching,” so it is also fair to critically ask what teaching methods and strategies are most effective in promoting student learning. Fortunately, new advances in research on learning from the fields of cognitive psychology and learning science (Bransford et al. 1999) provide a solid foundation on which we can design courses, develop instructional activities, and assess learning of mineralogy, petrology, and geochemistry to optimize student learning. In the past decade, the landscape of science education has changed dramatically to address the increased emphasis placed on learning. Among science educators there is a broad consensus on “what works”:

- Instruction that is increasingly “student-centered” and less “content-centered,” and that takes into account the diversity among students with respect to their experiences, expectations, and learning styles
- Learning environments that encourage “active” rather than “passive” learning and where a variety of instructional strategies are used to encourage inquiry, discovery, collaborative and cooperative learning, and critical thinking
- Instructors who assume the role of mentors, guides, and co-discoverers rather than simply purveyors of information
- Application of research on learning to the design, delivery, and assessment of courses, curricula, and instructional practices (e.g. NSF 1996; Mintzes and Leonard 2006)

As instructors, the application of these principles requires a major shift in emphasis from “what” we teach to “how” we teach. To help facilitate this transition, Table 1 provides a compilation of online collections of teaching activities, strategies, and related instructional resources that have been developed through a series of community-based workshops with support from the National Science Foundation (USA).

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TABLE 1
ONLINE RESOURCES FROM TEACH THE EARTH TO SUPPORT INSTRUCTION IN MINERALOGY, PETROLOGY, AND GEOCHEMISTRY

Teach the Earth: http://serc.carleton.edu

Collections of teaching activities and web-based supporting resources
- Teaching mineralogy: http://serc.carleton.edu/NAGTWorkshops/mineralogy/index.html
- Teaching petrology: http://serc.carleton.edu/NAGTWorkshops/petrology/index.html
- Teaching geochemistry: http://serc.carleton.edu/NAGTWorkshops/geochemistry/index.html

Finding analytical instruments to support teaching and learning
- Analytical instrument registry: http://serc.carleton.edu/NAGTWorkshops/petrology/instruments.html

Collections of teaching strategies with examples, instructions, and references
- The Starting Point collection: http://serc.carleton.edu/introgeo/index.html

Observing and assessing student learning
- Assessment tools, instruments, and more about research on learning: http://serc.carleton.edu/NAGTWorkshops/assessment/index.html

Teaching geoscience with visualizations
- Using images, animations, and models effectively: http://serc.carleton.edu/NAGTWorkshops/visualization/index.html

Using data in the classroom
- Collections of Earth data, tools, activities, examples, and pedagogic resources: http://serc.carleton.edu/usingdata/index.html

Teaching quantitative skills in the geosciences
- Techniques, activities, and resources: http://serc.carleton.edu/quantskills/index.html

An Earth system approach
- Designing an Earth system course, learning resources: http://serc.carleton.edu/introgeo/earthsystem/index.html

Integrating research and education
- Examples include use of EarthChem and the MSA Crystal Structure Database: http://serc.carleton.edu/research_education/index.html

Course design
- Tutorial for designing effective and innovative courses: http://serc.carleton.edu/NAGTWorkshops/coursedesign/index.html

In this collection of articles, we introduce many new advances in learning theory and give examples of how these can be applied to MPG courses. We do not presume to provide a detailed outline of topics and texts for MPG courses—Earth provides too many learning opportunities, and instructional settings are too diverse to attempt to prescribe a preferred curriculum. Rather, by exploring the intersection between our knowledge of Earth and research on learning, we hope to provide an intellectual framework that will help guide the development of future instructional practices. Implementation of better practices will allow us to recruit and train students who are happier in their studies and better prepared in their professional development and will help faculty teach in ways that are more effective, personally satisfying, and fun. The articles in this volume provide an introduction to different aspects of the scholarship of learning:

**Cathy Manduca** summarizes research on the impacts of our teaching methods on recruiting and retaining students, and shows how research on learning can be applied to the design and implementation of a full array of learning exercises. This article also identifies the need to engage into discipline-specific research on learning in mineralogy, petrology, and geochemistry.

**Dexter Perkins** asks us to carefully reflect on the essential content that we deliver in our classes and to place a higher emphasis on helping students develop the cognitive skills to help them become lifelong learners, including the ability to self-assess and reflect on their own learning.

**Karl Wirth** continues with the theme of lifelong learning and advocates a co-curriculum that allows students to take responsibility for their own learning. He provides examples of active-learning, collaborative-learning, and problem-based learning activities in mineralogy and petrology courses.

**Alan Boyle** provides a practical example of how we can achieve measurably better learning outcomes by aligning teaching and assessment methods with students’ learning-style preferences.

**Barb Dutrow** presents the latest research from cognitive psychology in the use of visualizations, and she demonstrates their effective use in both education and research presentations.

The articles in this issue focus on undergraduate education because a large segment of the MPG research community has teaching responsibilities at this level. But these principles are also applicable on a broader basis, including graduate and K–12 education and community outreach. And, although the curricular structure of teaching MPG will be different in detail from country to country and the demographics of students may also be different, the principles of how people learn are universal.

In the MPG disciplines, we have always had great content to work with, using Earth as the best-possible natural laboratory. We now have the opportunity to redirect our instructional efforts to train the next generation of scientists more effectively, bringing to bear the new advances in research on learning from cognitive psychology and the learning sciences. In the following articles, we hope you will find new and interesting insights into learning that will help make teaching and learning about Earth more rewarding for you and your students. **For further exploration, we have compiled a comprehensive bibliography and collection of online resources, which can be accessed at http://serc.carleton.edu/NAGTWorkshops/petrology/elements.html.**

**REFERENCES**


NSF (National Science Foundation) (1996) Shaping the Future New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology. NSF 96-139, 76 pp