[1]Ten Things We Know About Learning and Their Implications for Geoscience Education

Joel Michael[1,3] and Harold Modell[2,3]
[1]Rush Medical College, Chicago, IL
[2]National Resource for Computers in Life Science Education, Seattle, WA
[3]Physiology Educational Research Consortium, Seattle, WA

Learning and memory have been issues of central concern to psychology since the late 19th century. Over the past 40 years the development of cognitive science has greatly accelerated the pace of studies of these phenomena. More recently the learning sciences have extended such studies to the classroom.

One dominant school of thought about learning, one that is particularly prevalent in all discussions of science learning, is constructivism. There are two basic tenets of all forms of constructivism. (1) Knowledge can not be transmitted from one individual to another; rather, knowledge is built by the learner using internal cognitive processes acting on stimuli from the external environment. (2) The learner's process of building new knowledge starts with a foundation of everything that he or she already knows; the learner is never a blank slate (tabula rasa). Ten key ideas can be extracted from current attempts to understand learning. These are listed below and some of their educational implications are indicated.

Key Idea 1: All learning occurs on the foundation of already learned knowledge and skills.

Educational implications: There are several implications of this tenet about learning. First, it is essential to understand what students already know when they embark on any learning experience. Without an understanding of this input state of the students, it is impossible to set realistic goals for students and impossible to plan activities that will help them reach those goals.

Second, it is to understand that some of what the students bring to the classroom is flawed (incomplete or simply wrong). One goal for all teachers is presumably to help students correct existing mental models. Without knowing what misconceptions are prevalent, it is impossible to plan activities that will help students correct their mental models. Another goal must be to avoid inadvertently contributing to the students' building faulty mental models because of something that happens in your classroom.

Finally, since new knowledge will be learned in the context of old knowledge, it is important to understand the students' prior knowledge so that new material can be organized and presented in a way that can be most appropriately related to the old knowledge.

Key Idea 2: To the extent that the old knowledge is faulty, the learning of new knowledge will be compromised.

Educational Implications: Again, it is essential to understand that misconceptions exist, and to know what misconceptions students exhibit. That being said, it is important for you to understand that telling the learner that some piece of their knowledge is wrong, or simply attempting to provide them with, "give" them, the right knowledge, DOES NOT WORK.

Just as students come into the classroom with misconceptions, it is important to recognize that things that happen in the classroom may very well create new misconceptions or at least reinforce old ones, even though that is obviously not your intention. Teachers must be sensitive to the mechanisms that are known to contribute to misconception formation and seek to minimize their occurrence in the classroom. For example, while analogies can be powerful aids to learning, their misuse in the classroom can leads to serious misconceptions if the learner over-generalizes the analogy to situations in which it does not apply.

Key Idea 3: Declarative (what) and procedural (how) knowledge are different, and the processes of learning them are different.

Educational implications: It is important to understand the difference between declarative and procedural knowledge for several reasons. Decisions about the learning objectives for some content area in a course must reflect the type of knowledge being addressed. Learning resources must be made available to facilitate student mastery of both types of knowledge. In addition, assessments must be appropriate for the kinds of knowledge the students have been asked to learn. If students are expected to master both declarative and procedural knowledge, it is essential that assessment tools test for the mastery of both kinds of knowledge.

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[1]This material is adapted from Michael and Modell, *Active Learning in the Science Classroom* (under contract to Lawrence Erlbaum Associates, Publishers). **DO NOT CITE!**

Key Idea 4: Learning declarative knowledge involves building mental models or representations.

Educational implications: It is essential that the learner be given opportunities to build many different models of the knowledge being learned, perhaps differing in the modality that is activated (vision or audition) or the source of the information that is used. Aids to relating the new knowledge being learned to old knowledge are also helpful. It is also important that learners be required to think about their models in an overt, and explicit way. In some instances it may be helpful for the learner to use specific model-building skills such as concept mapping.

Key Idea 5: Practice with timely and appropriate feedback is required for all procedural psychomotor learning.

Educational implications: Practice and appropriate feedback are the keys to procedural learning. Thus, the learning environment must provide opportunities for students to solve problems or practice some sensory-motor skill and receive appropriate, timely feedback. This can be difficult to arrange. Students learning to solve problems need to have access to many problems. Learning to prepare a thin section of a mineral sample for microscopy may require many samples and adequate access to the needed equipment. Moreover, many of the educational experiences commonly incorporated into science courses may not help students reach the desired level of mastery. Textbook problems with their minimalist solutions at the end of the chapter or book may not provide enough feedback to help the learner. Similarly, watching an instructor solve a problem at the board is all too often a passive experience for students, one that contributes little to procedural learning. Watching the instructor carry out a task in the laboratory will not lead to the level of student proficiency desired.

Key Idea 6: Retention and the ability to utilize knowledge (meaningful learning) is facilitated by building associations (links) between old knowledge structures and the new knowledge being learned.

Educational implications: In order to assist students to link their new knowledge to their old knowledge, it is essential to understand what is in the students' existing knowledge base. Knowing this, one can assist students to overtly and explicitly build links or associations with that old knowledge. Furthermore, having insight into the students' old knowledge base helps put the new material into a context that students are likely to find most relevant and, thus, more easily related to their old knowledge.

Key Idea 7: The ability to construct multiple representations of new knowledge is an important component of meaningful learning.

Educational implications: All learning environments must provide the learner with opportunities to engage new material in a context that facilitates establishing relationships between the old and the new. Further, the learning environment must make obvious the relationships that exist between what the learner already knows and what he or she is attempting to learn.

Success at meaningful learning will be facilitated if the learner is given opportunities to create multiple representations of the new knowledge being acquired. One way to do this is to provide new information using multiple modalities (vision, audition, touch). Another useful tactic is to provide different examples of the phenomenon being learned, thus facilitating links to many different, already stored mental models.

Key Idea 8: Some knowledge and skills, when acquired, are context-specific while other knowledge and skills may be more readily transferred to a new domain.

Educational implications: If certain skills can be generalized, and if certain scientific models can be applied to many situations, it is imperative that students be taught these skills and models. This focus on generality must start with the initial learning and must be reinforced as each new opportunity for application is encountered.

Key Idea 9: Collaborative or cooperative effort can yield more individual learning than individual effort alone.

Educational implications: The learning environments that teachers create must provide opportunities for students to work with one another in ways that will result in learning for all students. Students learning together share their knowledge, explain their position, argue and debate and in this way build more robust mental models (representations). Group work can occur in the lecture hall, the student laboratory or the discussion section.

Key Idea 10: Articulating explanations, whether to peers, teachers, or one's self, facilitates learning.

Educational implications: The benefit to students of having to articulate their knowledge is one explanation for the benefits of collaborative/cooperative learning. In all settings in which students work together to learn or solve

a problem, one critical feature is the need for the learners to communicate with one another. Communication is essential if information is be shared and ideas exchanged. Arguing and debating issues, negotiating and reaching agreements in order to complete the assigned task all require that each individual be able to articulate to others what he or she believes, understands, and doesn't understand. When learners who are solving problems generate explanations of what they are doing, whether voiced or not, they seem to learn more. Clearly, then, it is essential to arrange learning environments in which students are encouraged to talk to students and to the instructor.

Where do we go from here? Incorporating these ideas about learning into our teaching

Constructivism has demonstrated great explanatory power about what happens in our classrooms. While it does not answer all of the questions about learning, and certainly does not provide a prescription for what we ought to do in the classroom, it offers solid evidence in support of many of things supporters of classroom reform are advocating. Incorporating what we have learned about learning into classroom practices will call for changing at least some of what you do, but if your goal is helping the learner to learn, the results of these changes will be gratifying.

References and a bibliography are available on request.