WHAT WORKS - AN ESSAY FROM THE COMMUNITY

IMPLICATIONS OF LEARNING RESEARCH FOR TEACHING SCIENCE TO NON-SCIENCE MAJORS

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Research findings about how people learn should influence how science is taught, yet science instruction is rarely informed by the science of learning. The "cognitive revolution," which began about forty years ago, signaled a major shift in the study of how people learn and has since developed into a rich science of learning. Whether teaching majors or non-majors, many helpful principles have emerged that, if implemented correctly, could increase student learning in the science classroom.

Note: This essay has been distilled by PKAL from the larger paper by Etkina and Mestre:

http://www.sencer.net/resources/pdfs/Backgrounders/ImplicationsofLearningResearchforTeachingScience.pdf

Insights about the Learner from the Science of Learning

Constructivism and the Role of Prior Knowledge

Cognitive research has shown that learners construct knowledge and that the knowledge they already possess affects their ability to learn new knowledge. If new knowledge conflicts with prior knowledge, then new knowledge will not make sense to the learner.

This has implications for instruction. Because knowledge previously constructed by the learner will affect how she or he interprets what the instructor is attempting to teach, the instructor must evaluate whether students possess sufficient prior knowledge and whether this knowledge conflicts with what will be taught. To ignore learners' prior knowledge will most likely mean that the message intended by the teacher will not be the message understood by the students.

Instructional strategies that help students construct knowledge for themselves work better than strategies that keep learners passive. Approaches where students are discussing science, doing science, teaching each other science, and offering problem-solving strategies for evaluation by their peers facilitate construction of science knowledge. This is not to say that lecturing should be abolished. Research suggests that students can reap significant benefits from lectures, after they have been primed to learn from them— for example, by previous activity-based preparation.

The Nature of Expertise: Organization and Application of Knowledge

A salient finding of cognitive research is that experts' knowledge is highly organized in a hierarchical manner, with the top levels containing major principles and concepts of the domain, and the middle to lower levels containing ancillary concepts, related facts, equations, and other details. This organizing framework has several advantages. It allows experts to access knowledge quickly and with little cognitive effort; it "automates" the retrieval process, thus freeing experts to focus on analyzing and solving problems; and it makes it easier to learn more about an area of expertise because new knowledge is integrated into an existing structure with appropriate links that facilitate recall and retrieval.

Experts also approach problem solving differently from novices. For example, when approaching a problem in physics, experts focus on major principles they might apply, think about why a principle could be applied to the problem, and come up with a procedure for applying the principle. In contrast, novices jump immediately to the quantitative aspects of the solution and the equations they might use to arrive at an answer.

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The implication for teaching is that the tacit (or "automated") knowledge experts use to solve problems should be made explicit during instruction. Students should then practice applying (this now explicit) knowledge when solving problems. It is also helpful for students to engage in the same metacognitive activity that experts use (e.g., monitoring their problem-solving efforts and regulating their use of strategies). Simply telling students how major ideas apply to problems will not help them construct that knowledge; they need to actively engage in thinking about how major concepts apply to a set of problems so that this process becomes internalized and familiar.

Transfer of Learning

Transfer of learning is the ability to apply knowledge and procedures learned in one context to other contexts. A common assumption is that knowledge learned in school will transfer to situations and problems encountered outside of school. Yet research has shown that transfer of relevant knowledge from one situation to another is rare. Only after receiving hints about the similarity of situations are students able to transfer knowledge.

Cognitive research suggests that several factors affect transfer. To begin with, initial learning is necessary. Though this seems obvious, many failures to transfer knowledge result from inadequate opportunities to learn in the first place. Whereas rote learning tends not to facilitate transfer, learning with understanding does. Trying to learn too many topics quickly inhibits transfer because the learner may simply memorize isolated facts without organizing the material in a meaningful way and linking it to related knowledge.

Presenting new knowledge in multiple contexts is also important for transfer to occur. If knowledge is too tightly bound to the context in which it was learned, students will have difficulty transferring that knowledge to even superficially different contexts. Transfer is enhanced, then, when the learner abstracts the deep principles underlying new knowledge, and abstraction is facilitated by experiencing concepts and principles in multiple contexts.

Prior knowledge and experience also affect later transfer. The effect can be negative when previously learned concepts must be changed to accommodate new settings. This is frequently referred to as the "implementation dip."

Metacognition: Reflecting on Learning

Engaging in metacognitive activities can improve acquisition and transfer of knowledge. Metacognitive strategies are methods learners use to become more aware of themselves as learners and include the ability to monitor one's understanding, plan ahead, gauge success, and correct errors. By learning to employ these strategies, students become self-monitoring learners.

Reflecting on the types of problem-solving strategies used in the past is another type of metacognition that relates to a student's deeper understanding of concepts – it is thoughtful behavior geared toward selection and application. This type of meta-level understanding plays a critical role in students' ability to sustain their own learning and problem-solving skills once the teacher and other supports are no longer present.

Science instructors can promote metacognitive behaviors by engaging students in active and collaborative learning. However, when this type of instruction is viewed by students as deviant from the norm (i.e., lecturing), they may simply tolerate the course instead of becoming truly engaged. To avoid this reaction, instructors need to explain why their teaching methods are superior to learning-by-telling. Students will buy into the approach over time after seeing evidence that they are learning more than they would through lecture alone.

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Assessment in the Service of Learning

If students are to successfully construct and reflect on their knowledge, instructors need to design assessment strategies that evaluate and encourage this type of learning. Formative assessment (to help guide instruction and learning) and summative assessment (to evaluate student performance) send messages to students about what the instructor considers important while also providing feedback to the instructor about whether his or her methods are working.

Research has shown that learning gains from systematic attention to formative assessment followed by feedback are larger than for any other kind of educational intervention, and feedback is most powerful when it is descriptive and criterion-based. However, the same researchers also report that such practices are underdeveloped in most classrooms.

Examples of formative assessment include student self-assessment (using rubrics provided by the instructor); workshops during class (in which students work in groups on a set of questions, submit their answers electronically, and discuss their responses); and journal writing, in which students reflect on their learning. A less time-consuming alternative to journal writing is the weekly report – a structured journal written by students each week.

Examples of summative assessment include strategy writing, in which students are asked to write strategies for solving problems that discuss principles, justification, and procedures; and problem posing, in which students are asked to pose problems as a means of testing their conceptual understanding and ability to apply knowledge across contexts.

Instructional Principles Supported by the Science of Learning

Encourage Construction of Science Knowledge. Efforts made by a student to decode and make sense of new information cannot be substituted by even the most excellent presentation given by a teacher. Students must be allowed to construct new knowledge for themselves, and, because construction of knowledge is a social enterprise, students learn more when they work collaboratively.

Instructors should also keep in mind that how students construct new knowledge depends on prior experience. Teachers can use questioning and pre-tests to become aware of students' prior knowledge, and then design instruction to incorporate students' ideas through discussions of common phenomena, practical applications, and experimentations.

When teaching non-science majors, it is especially important to have students consider preconceptions they and others bring to class. Students will quickly see the diversity of views, not all of which can be scientifically correct. This will lead naturally to discussions about the science involved.

Encourage Hypothetico-Deductive Reasoning. Scientific explanations not only explain findings from experiments but also predict new phenomena. Students can use similar reasoning to test their ideas. Instead of simply telling students the explanation for a phenomenon, teachers can ask students to predict what will happen and then have students test their hypotheses. Students who have opportunities to engage in hypothetico-deductive reasoning acquire new concepts more quickly.

Provide Opportunities for Students to "Do Science." Whenever possible, students should engage in processes similar to those used by scientists to construct knowledge. This includes observing natural phenomena or laboratory events, classifying, recording, identifying patterns, testing hypotheses, and applying hypotheses to solve problems. To help students learn the process of doing science, instructors should create classroom environments that actively engage students through cooperative group learning, problem-based learning, Socratic dialogue, and inquiry-based lab exercises.

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Provide Opportunities for Students to Apply Knowledge in Multiple Contexts. Students need to learn to apply major concepts in multiple contexts in order to make knowledge "fluid." Providing practice exercises across a variety of contexts and situations will help students abstract the deep principles underlying new knowledge, which will then promote transfer. These types of assignments tend to work best in the later stages of a course. Instructors might consider a capstone project in which students apply what they have learned about the process of doing science to a topic completely outside of the course material.

Encourage Qualitative Reasoning Based on Concepts. When instructors make their tacit knowledge explicit, students learn to recognize and apply it. One way to make tacit knowledge explicit is to have students construct qualitative arguments using the science that is being learned. By constructing qualitative arguments and evaluating each others' arguments, students can begin to appreciate the role of conceptual knowledge in doing science. Mathematics is just one language used in science; qualitative forms of reasoning using verbal, pictorial, and graphical representations are equally useful.

Help Students Organize Knowledge According to a Hierarchy. To help students develop a highly organized mental framework, instructors can ask students to list major concepts needed to solve a particular problem and use hierarchical charts during instruction to show students where to place newly acquired knowledge in a knowledge system. Concept maps can also be used for both formative and summative assessment of learning.

Teach Metacognitive Strategies. Teaching students to become self-reflective about their own learning will help them acquire new knowledge more efficiently. Self-reflection includes learning to ask questions such as "What am I missing or what do I need to know to make progress with this problem" "In what ways is this problem similar to others I've encountered?" "Why did the instructor give this particular problem to us?"

Instructors can facilitate this type of reflection by asking students to write post-problem-solving summaries that address these kinds of questions. Teachers can also encourage students to reflect on construction of knowledge by asking "What did you learn today" and "How did you learn it?" Encouraging students to ask questions also promotes metacognition.

Use Formative Assessment Frequently. Formative assessment helps students realize what they do not understand and helps teachers tailor instructional strategies appropriately. Examples of formative assessment include asking students to devise hypotheses, reason qualitatively, design problems, and evaluate the work of their peers. Student self-assessment using scoring rubrics provided by the teacher is the most productive type of formative assessment.

Know How to Motivate Students. Motivation is especially important when teaching science to non-majors. Perhaps the best way to motivate non-science majors is to develop courses around timely topics about which students have some prior knowledge and opinions. Instructors can ignite interest by connecting what students are learning in the classroom to their everyday experiences.

Research also shows that students have higher achievement and greater satisfaction in classrooms where teachers are perceived to endorse independent thinking and to desire deep understanding of concepts. Instructors should therefore encourage questions, focus on explanations of phenomena, promote collaborative learning, and avoid grading on a curve. The autonomy felt by a student who can function like an investigative scientist is a great motivator. ■