The promise offered by inquiry learning is tempered by the problems students typically experience when using this approach. Fortunately, integrating supportive cognitive tools with computer simulations may provide a solution.

Learning by Inquiry
Studies of young students’ knowledge and skills indicate that many students in large parts of the world are not optimally prepared for the requirements of society and the workplace (1). To meet this challenge, curricula should be designed to help students learn how to regulate their own learning, how to continue to gain new knowledge, and how to update their existing knowledge.

Inquiry learning is defined as “an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding” (2). This means that students adopt a scientific approach and make their own discoveries; they generate knowledge by activating and restructuring knowledge schemata (3). Inquiry learning environments also ask students to take initiative in the learning process and can be offered in a naturally collaborative setting with realistic material.

The idea of inquiry, or discovery, as a learning approach has a long history (4, 5). Now, technological developments such as computer simulations can implement more effective inquiry learning. Using simulations to model a phenomenon or process, students can perform experiments by changing variables (such as resistances in an electrical circuit) and then observe the effects of their changes (e.g., the current). In this way, students (re-)discover the properties of the underlying model (Ohm’s law).

The Inquiry Process
Inquiry learning mimics authentic inquiry. There are some exceptions, such as the origin of the research question, the number of (known) variables, and the presence of flaws in data (6). Because they are closely related, they share the following constitutive cognitive processes (7): orientation (identification of variables and relations); hypothesis generation (formulation of a statement or a set of hypotheses); hypothesis scratchpads (software tools to create hypotheses from predefined variables and relations); predefined hypotheses; experimentation hints (such as “vary one thing at a time” or “try extreme values”); process coordinators (which guide the students through the complete inquiry cycle); and planning tools. Overviews can be found in (7) and (15); examples of integrated inquiry systems are (8).

Supporting the Inquiry Process
Research in inquiry learning currently focuses on finding scaffolds or cognitive tools that help to alleviate these problems and produce effective and efficient learning situations. Computer environments can integrate these cognitive tools with the simulation. Examples of cognitive tools are assignments (exercises that set the simulation in the appropriate state); explanations and background information; monitoring tools (to help students keep track of their experiments); hypothesis scratchpads (software tools to create hypotheses); and process coordinators (which guide the students through the complete inquiry cycle) and planning tools. Overviews can be found in (7) and (15); examples of integrated inquiry systems are (8).
SimQuest applications (16), Co-Lab (17), GenScope (18), and Inquiry Island (19).

One example from a SimQuest application explores the physics of moments (see the figure on page 532) (20). Support is offered in the form of an assignment that asks students to explore the balance of the seesaw by changing variables. Another available aid is a hypothesis scratchpad that lets students build expressions from variables (e.g., force F1, distance a1, and moment M1) and relations (e.g., increases) to create testable hypotheses (e.g., if F1 increases, then M1 increases).

Most experimental evaluations of cognitive tools offer different configurations of learning environments to different experimental groups. Effects measured include the acquisition of conceptual knowledge, procedural knowledge, and/or inquiry skills. Often the learning process can be analyzed from log files that track the behavior of students in the learning environment and/or data from students who are requested to think aloud during learning. The most effective learning results are found with tools that structure the learning process, provide students with pre-defined hypotheses and background information, help students plan (e.g., by providing a sequence of assignments), or give hints for efficient experimentation (7, 15, 21). For example, students offered simulations and assignments performed better in tests of intuitive knowledge of the physics of oscillation (22). Also, biology students who received prompts on experimental strategies outperformed in tests those who received other prompts or no prompts at all (23).

The Road Ahead

Unguided inquiry is generally found to be an ineffective way of learning (24). Reviewing classical research in three areas of learning—problem-solving rules, conservation strategies, and programming concepts—Mayer (3) concluded that guided discovery learning is effective. These guided inquiry environments are starting to enter educational practice, especially for ages 14 and up, and large-scale evaluations are promising (18). Mostly physical science topics have been tested, but inquiry environments have been used in other areas. In psychology, for instance, simulations have modeled Pavlovian (classical) conditioning, where an organism learns to relate one event to another previously unrelated event (25, 26) (see the figure below).

A number of research issues still lie ahead.

First, the introduction of cognitive tools may lead to overly complex learning environments that hinder learning by requiring too much working memory capacity. Ways to reduce this extraneous cognitive load, such as by integrating effective in acquiring intuitive, deep, conceptual knowledge; direct instruction and practice can be used for more factual and procedural knowledge. Ultimately, we want students to gain a well-organized knowledge base that allows them to reason and solve problems in the workplace and in academic settings. Finding the right balance between inquiry learning and direct instruction, therefore, is a major challenge.

References and Notes

20. The full interactive example, including hypothesis scratchpad, is available online (www.simquest.nl).
26. The classical conditioning example is available online (http://tap.psy.utwente.nl/english/).
30. In part sponsored by Netherlands Organization for Scientific Research (NWO/PRO), the Information Society Technologies (IST) priority of the European Community (the Kaleidoscope Network of Excellence), and Stichting SURF.