LETTERS

edited by Jennifer Sills

Teaching and Learning Strategies That Work

FOR MORE THAN FOUR DECADES, WE HAVE TAUGHT CHEMISTRY. AS WE STRUGGLED TO BECOME better teachers, we developed (and borrowed) a number of effective strategies. Learning and teaching are a double flame—each feeds the other. We begin with some suggestions for instructors.

Foster the mentor-apprentice bond you have with your students. Once established, this relationship helps students learn in two ways: First, the student admires the mentor and wants to attain the mentor's level of understanding. Second, the mentor can help the learner navigate boring or tough stages on the way to mastery.

Teach students how to learn. Students may not realize that learning progresses through stages, with memorization being only an early one (*1*). Bloom and colleagues identified levels of learning, now labeled as remembering, understanding, applying, analyzing, evaluating, and creating (*2*, *3*). Making students aware of different kinds of learning can transform them from rote memorizers into independent, self-directed learners (*4*). We have also found that when students learn about metacognition (thinking about your own thinking) (*5*) they change their attitudes about learning and begin to implement effective study strategies.

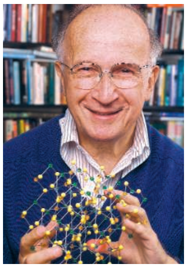
Grade on a combination of dominant absolute performance (examinations and quizzes) and minor "curved" components (such as labs). A clearly defined contract is best, in which performance at a certain level ensures a grade, with adjustments only to increase the grade. With this system, students are empowered—the outcome of their course grade is dependent on their work alone rather than their work relative to the work of others. For this to be effective, you will need to construct exams for which the level of mastery of the material is accurately reflected by the grade (*6*).

Do as many demonstrations as possible. Demonstrations are somewhere between magic and science (*7*), and they cross the bridge from entertainment to learning. Ideally, they also incorporate content and thus enhance learning.

We disagree about "cheat sheets"—allowing each student to bring to a test one page on which he or she can write anything. On one hand, the sheet serves as a learning tool; in composing it, the student organizes what he or she has learned. On the other hand, students may spend time looking for information to copy onto the sheet instead of working to understand concepts.

More generally, let these ideas shape your teaching: (i) Empathy. Students will respond when they know that you genuinely care about them. (ii) Active learning. Student participation will facilitate learning. (iii) Judicious interplay of groups and individuals. Learning is a solitary activity, yet it can be enhanced by group work. (iv) Empowerment. Encourage students to feel that they are responsible for their own learning successes.

Saundra Y. McGuire



Roald Hoffmann

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We have found that students can improve their learning through the following strategies:

Take notes by hand, even if the class notes are provided. As soon as possible, condense and extend the notes, paraphrasing them into your own words. Taking notes is active engagement, which is imperative for learning (*8*). The process of paraphrasing notes helps transfer information from short-term to long-term memory (*9*, *10*).

If you miss a class, get notes from a fellow student instead of downloading them from a Web page. Discussing class notes facilitates learning, both for the student who asks questions about the notes, and for the student who engages in teaching by answering the questions.

To maximize learning from homework problems, first study the text and lecture information relevant to the problems. Next, work through the problems without looking at an example or the solutions in a solutions manual. Finally, compare your approach—not just your answer—to the text's. (Instructors should always provide ways to work through each problem, not just the answers.) Focusing on methods, rather than final answers, helps you develop agile, flexible thinking.

To make the most of group learning, the alone-together-alone sequence is crucial. First try to do the homework problems or prepare for the exam alone. Then, access the collective wisdom of a group, watchful for the pitfalls of group dynamics. Finally, return to solving the problem set or facing the exam on your own. Social constructivist learning theorists have shown that meaningful learning results from study groups with two crucial features: discussion and problem-solving activities (*11*). Tips for forming effective groups are available (*12*).

Individually and in groups, make up practice tests when preparing for examinations. This exercise involves the selection and organization of all the material and fosters discussion of what material is important enough to be on the test. This is the only way to get into the teacher's mind.

Finally, we provide a suggestion for both teachers and students:

Recognize that students have different learning styles. Learning style can refer to a person's preferred modality [visual, auditory, verbal, or kinesthetic (*13*)], Myers-Briggs personality type (*14*), or other learner characteristics. People do disagree about these (*15*), but we think they are useful. Students should work to understand their individual learning preferences in order to become more efficient learners. Teachers need to recognize that there are different ways to learn and try to accommodate a variety of learning styles in their classes. Instructors should resist the temptation to teach only as they were taught or in a manner that suits their own learning style.

Our suggestions are not prescriptive; we just want to share with you some of the strategies we

Published by AAAS

have improvised and developed over the years to facilitate learning for, rather than to deliver instruction to, the students we have taught. We hope that you will find them useful tools in your teaching and in your students' learning (*16*).

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16. We thank B. Coppola, P. Kroll, S. McGuire, and J. Wandersee for helpful suggestions.

Science-Savvy Physicians

IN THEIR EDITORIAL ("SCIENCE FOR FUTURE physicians," 5 June, p. 1241), S. Long and R. Alpern mention the release of a major report on medical education arguing for increased emphasis on basic scientific competence. However, they fail to note the report's relevance to the broader arena of biomedical science and innovation. Beyond the obvious need for clinicians to understand the scientific underpinnings of disease mechanisms when treating patients, a sound scientific education is critical to training physicians who translate research findings to a clinical setting.

A key factor fueling these new recommendations is the desire for more students to enroll in physician-scientist (M.D./Ph.D.) programs in the United States. A commonly held belief is that these physician-scientists will use both their clinical and scientific training to facilitate the translation of discoveries to the clinic. More often, physician-scientists either become pure clinicians or focus all of their energies on basic sciences, thus playing the same role as Ph.D.-trained biomedical scientists (*1*).

Whether due to time constraints or intent, physician-scientist programs have generally failed to fulfill this dual role and have focused excessively on basic research. This creates unnecessary redundancy and also discourages and even deceives medical students interested in more applied research. While I support the findings of this report, maximal value from the recommendations can only be derived by training and allowing physicians with a sound scientific foundation to play a more downstream and enabling role in facilitating the delivery of innovation to the clinic.

Recently, several medical schools in the United States and internationally, including the University of Toronto, have recognized this trend. In response, they are revamping traditional clinical investigator programs and creating interdisciplinary team-based training programs in their place. The new programs bring together residents or M.D./Ph.D. students, biomedical engineers and scientists, and entrepreneurs to systematically generate innovations for surgery, imaging, and regenerative medicine, and then take them to the clinic.

Physicians with a strong basic scientific foundation can play a facilitating role in reconciling the science behind the prototypes, assays, or discoveries with the disease mechanisms underlying the clinical needs. This role is particularly important for global health applications, where tailored user-driven development and delivery is often more challenging than the actual discovery itself. Physicians need not actually be the ones discovering—leave that to the scientists. The recent development of several Ph.D. programs that include "rotations" in the clinic further relieves the need for inefficient M.D./Ph.D. training programs to train basic scientists with clinical understanding.

By optimizing the contribution of physicians through collaboration with scientists and engineers, such interdisciplinary programs can help to defuse the myth of medical innovation and practice as being an "art"—a myth that contributes to the perception among physicians that basic scientific competency is unimportant. What we need are not more physician-scientists, but physician-innovators and physician-facilitators.

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A Step Toward Unification

CONTRARY TO THE VIEW OF BIODIVERSITY INFORMATICS (BI) depicted in the News of the Week story "Biodiversity databases spread, prompting unification call" (C. Thomas, 26 June, p. 1632), substantial progress has been made in the past few years, particularly since the advent of the Global Biodiversity Information Facility (GBIF) in 2001. GBIF is not a project, as depicted in the News story, but a multi-country agreement to establish an international organization, modeled on other international treaties. An initial 17 countries (mandated through their Science Ministries) negotiated the establishment of GBIF as a commonly owned and commonly funded mechanism to meet their common BI challenges. The Memorandum of Understanding that each country signs commits them to contributing financially and to supporting free and universal sharing of their data. As such, GBIF has a sustainable funding model to support an international secretariat and implementation of an agreed work program as well as the mandate to build the infrastructure needed to make biodiversity data freely accessible to all through the Internet.

Through various community-owned initiatives and partnerships, GBIF has overcome many of the BI challenges highlighted in the News of the Week story as still problematic, including the development of global standards, data-sharing protocols, best practices in areas such as digitization and data cleansing, and increasingly, in developing metadata standards and registries, ontologies, and spatial analysis applications. GBIF is admittedly still a work in progress, yet it provides the international foundation through which solutions to these complex problems can be developed. In terms of collaboration and interoperability, GBIF has a growing membership of 51 countries and 42 international organizations (most of whom were represented at the e-Biosphere conference) and already provides access to over 180 million primary biodiversity records in more than 7600 data sets from more than 265 institutions around the world. This is undoubtedly a unification success story, albeit with much still to be done.

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

TECHNICAL COMMENT ABSTRACTS

Comment on "Energy Uptake and Allocation During Ontogeny"

Anastassia M. Makarieva, Victor G. Gorshkov, Bai-Lian Li

We demonstrate that the model of energy allocation during ontogeny of Hou *et al*. (Reports, 31 October 2008, p. 736) fails to account for the observed elevation of metabolic rate in growing organisms compared with similarly sized adults of different species. The basic model assumptions of the three-quarter power scaling for resting metabolism and constancy of the mass-specific maintenance metabolism need to be reassessed.

Full text at www.sciencemag.org/cgi/content/full/325/5945/1206-a

Comment on "Energy Uptake and Allocation During Ontogeny"

Tânia Sousa, Gonçalo M. Marques, Tiago Domingos

Hou *et al*. (Reports, 31 October 2008, p. 736) presented a model for energy uptake and allocation over an organism's growth and development. However, their model does not account for allocation to reproduction (essential to adults) and growth without assimilation (essential to embryos) and is therefore only applicable to organisms growing with abundant food in the juvenile stage.

Full text at www.sciencemag.org/cgi/content/full/325/5945/1206-b

Response to Comments on "Energy Uptake and Allocation During Ontogeny"

Wenyun Zuo, Melanie E. Moses, Chen Hou, William H. Woodruff, Geoffrey B. West, James H. Brown

Our extended ontogenetic growth model is a theoretical model based on conservation of energy and general biological mechanisms underlying ontogenetic growth. We do not believe that the comments of Makarieva *et al*. and Sousa *et al*. expose substantive problems with our model. Nevertheless, they raise interesting, still unresolved questions and point to philosophical differences about the role of theory and of simple, general models as opposed to complicated, specific models.

Full text at www.sciencemag.org/cgi/content/full/325/5945/1206-c