Time-Saving Resources -- Aligned with Cognitive Science
To Help Instructors Flip

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If students are given lecture notes that they can read with comprehension during homework, can faculty gain time during lecture for activities that build conceptual understanding? Could this lead to measurable gains in student achievement?

In our experience, under the right conditions, the answer has been: Yes and yes.

For several years, the authors have been working to develop materials that would make it easier for faculty to "flip" instruction in first-year chemistry -- without having to videotape lectures. We will discuss our experience and then suggest factors to consider whether you choose among existing resources to assist in flipping or create your own.

Tutorials

Our interest in flipping grew out of necessity. In 2006, engineering curricula nationwide began to move to a single semester of first-year chemistry. At Rowan University (NJ), Dr. Don Dahm was encouraged develop a course which covered all the topics normally covered in two semesters of general chemistry in a single semester course. After a semester in which 30% of lab time had to be utilized for lecture, Don and Eric Nelson began a collaboration aimed at transferring a part of lecture content to study time.

From research on reading comprehension, we learned that during *initial* study, students need reading materials with a different design than a comprehensive text. "Lecture notes with clickers" were recommended as a format for homework: systematic instruction with frequent questions that require students to think about what they have read.

After two years of writing, re-writing, and assigning "lecture/clicker" tutorials, Don's engineers scored at the 63rd percentile on the two semester ACS General Chemistry Examination (at the end of one semester), with all time for labs restored. In subsequent teaching of "two semester general" and "preparatory" chemistry, Don found the homework tutorials, *if adapted* (see below), provided more class time for demonstrations, discussions, and problem solving.

In 2010, Dr. Judy Hartman joined our project to help in researching cognitive studies on ways to promote conceptual understanding. The recommendations of cognitive science differ from some of the reform strategies that have been the proposed in science education for the past 20 years, as we describe below.

Our tutorials now cover most topics in both general and "college preparatory" chemistry. Posted on the *ChemReview* website for free student use, the lessons received 220,000 "visits" during

2011-2012. Evaluations by both faculty and students can be viewed at results (with student spelling corrected and references to their inability to understand their textbook, etc., deleted, but otherwise shown as received). We believe this response is evidence that students can learn traditional lecture content during homework.

In 2012, W. W. Norton offered to handle publishing (which we found to be not for amateurs) of printed texts instructors had requested. Reviews of the "prep chem" text are at AmazonReviews. General chemistry tutorials are also available in both ebook and paperback, and inspection copies of all are available to instructors (details at the end of this document).

The first two chapters of the ebook are permanently posted for free student use (and for possible homework assignments) at Ch1and2 . Viewing a few pages of that file at this point may be helpful in the discussion that follows.

Flipping Issues

In our experience, whatever method you choose to flip a part of lecture to homework, these questions will arise.

1. What knowledge does the student need to solve problems?
2. Why do so many students have trouble with calculations?
3. How do you get students to read or watch *anything*?
4. For already overworked instructors, how do we ease the burdens of flipping?
5. How can we keep up with research on flipping?

What follows are our views on these questions, based on our experiments and research.

Memorization and Working Memory

Cognitive science is the study of how the brain works and how it learns. During the 1990's, when technology to study the brain was less developed, researchers in cognition often disagreed on whether students were better able to solve math and science problems by learning reasoning skills or by memorizing facts and algorithms. Since 2001, however, cognitive science has reached a consensus on this issue.

Research has now measured and verified that when solving a problem, "working memory" (where the brain solve problems) can utilize *all* information that can be recalled *automatically* from long-term memory, but only about 3-5 elements of knowledge, for a brief time, that are not well memorized. One goal of initial learning must therefore be to "memorize to *automaticity*" the core knowledge of a discipline. *Fluency* (fast, accurate recall) overcomes the brain's bottleneck: the severe constraints in working memory when manipulating information that is not well memorized (see *Clark* and *NMAP* references below).

Experts in a discipline have constructed a vast web of relationships among elements of knowledge in their long-term memory: a deep conceptual framework: That knowledge is called into working memory automatically by cues during problem solving. For a student to learn to "think like a scientist," the first step is to move new knowledge into long-term memory. Then, as relationships are discovered by applying memorized knowledge in new contexts, conceptual understanding is constructed over time. Cognitive scientists generally agree that to become an expert in a technical field requires about 10 years of study.

In the references listed below, researchers describe why initial memorization is essential for learning math and science. Although we might prefer not to have to ask our students to thoroughly memorize material, cognitive experts emphasize the necessity that we do so in order to guide students in learning.

Cognitive science also offers strong support for "flipping." Memorization of facts and procedures can be accomplished during study time, so that more of the limited time when instructors are with students can be devoted to active learning. Inquiry guided by instructors can create vivid links between elements of knowledge that books and videos cannot match, and those associations are the substance of understanding.

Math

Another impetus to flip, supported by cognitive science, is to build student skills in math. Chemistry is a quantitative science. General chemistry assumes background knowledge including one prior year of high school chemistry -- plus *12* years of mathematics including arithmetic, fractions, algebra, exponents, and logarithms.

Between 1990 and 2012, before working memory was widely understood, K-12 math standards in most American states (and some other nations as well) discouraged math memorization (see *BCCE* in the references). Because automaticity is critical in problem solving, the result has been, as you have likely noted, many students in the current generation have difficulty with the math of scientific calculations.

The solution we adopt in our lessons is to review math topics during homework, just before they are needed for chemistry. Math both with and without a calculator is included because *mental math* understanding is critical in retaining what is learned. We have found that pretests help to individualize instruction: students can skip past topics they know and focus on review they need.

Math and Prep Chem

For general chemistry students, in our experience a brief structured review of the math required for a chemistry topic suffices to "refresh the memory" in the skills needed for calculations. However, math test score data (see *BCCE*) indicate that it is likely that a significant percentage of students in the current generation will need more than a quick review to attain the automaticity in computation that the pace of general chemistry requires.

Many colleges offer sections of "preparation for general chemistry." Our suggestion would be that "prep chem" include a strong component of "prep for the *math* of chem." As one example, if "prep chem" includes a thorough base 10 and natural logarithm review, it will build skills that are essential when working with the equations of second semester general chemistry.

Homework Completion

OK, reality check. How do you get students to *complete* homework on time, so you can conduct higher-level activities in lecture? In our group, Don Dahm has experimented with tutorial flipping in engineering, general, GOB, and "prep chem" both at Rowan and community colleges. Don's advice:

1. Students need a *system* that rewards "distributed practice" (working on homework several times a week), with *frequent* quizzes on homework that *count* substantially. Quizzes should be easy if homework has been completed, but quite difficult if not.

2. Classes with weaker backgrounds need more frequent quizzes and quiz questions closer to the content of the homework assignments.

3. In strong classes, you can assign the homework, quiz, and go directly to higher level topics. In less-well-prepared classes, homework may need to be a "second lecture on content."

4. If homework problems are *gradually* more challenging, but can be done with help from the text, research predict students will find them motivational, and they seem to do so.

5. Online homework, due before each class, can help -- but is no substitute for "closed notes" quizzes requiring that fundamentals be memorized (but I permit a student-made "formula sheet" on a comprehensive exam).

6. In flipping, be prepared to adjust your structure for each course -- each year. Students react better if you move from initially high to lower structure than the other way around.

Equity

To move parts of lecture to homework, students must have time for study. College students working part-time may need to be advised that 2-3 study hours per class hour is expected for science majors, but with financial aid increasingly limited, equity is a real concern.

In high school, students from low income families may have less access to individual computers or spaces for quiet study. For all high school students, who are "in-class" for more hours per week than in college, some "flipped homework" may need to include work done in class at the end of a long "block."

If you have experience with solutions to equity concerns, we hope you will share them this forum or, at a later date, in posts on flipping on our blog (see below).

Reducing Costs

Reducing course-materials cost is one way to assist students financially. We consider our ebook to be a non-ideal combination of text and computerized tutorial, but the simplified format results in a low cost PDF. For instructors writing their own materials, this “screen and print” ebook method is one way to produce “on-screen PDF tutorials” with a “paper to keep or hand-in” option.

Easing the Burden on Instructors

When evaluating materials that move lecture content to homework, key factors are effectiveness, time required from instructors, and cost. Choosing activities for class time is more complex.

A vast quantity of excellent active learning materials exist, but among them, which fit the level of your students, motivate, and develop conceptual understanding? Which are practical and safe given your teaching space, class size, class length, prep time, re-prep time between classes, recitation and lab availability, access to an assistant, and stockroom? What do other instructors say in evaluating the activity? For your particular situation, answers will take time to gather.

So -- pace yourself. If you can move a part of lecture content to homework, and spend more time in class guiding students in solving tough problems, or get in a few additional wet chem demonstrations, or try *any* new activities during a semester, that’s real progress.

Keeping Up and Sharing

As more instructors flip and share their learning, flipping will become easier. As one resource, for instructors interested in flipping and cognitive science issues in first-year (all pre-organic) chemistry, we have set up a blog (see below) with an invitation to you to discuss, debate, and share your experiences and views. The ChemEd-L and AP Chem bulletin boards are marvelous resources, but we hope a space with a more specific focus may also help in flipping.

Summary: Why Science Favors Flipping

In “well-structured” domains such as chemistry, studies in cognitive science favor the following instructional sequence:

1. To introduce each topic, instructors guide activities that create student interest.

2. Instructors identify background knowledge, facts, and algorithms needed to solve topic problems. Students commit these to memory so that they can be recalled automatically.

3. Students automate problem-solving procedures by extensive practice that applies new knowledge in a variety of contexts.

4. As instructors guide activities that highlight relationships among memorized elements of knowledge, students construct a conceptual framework that promotes domain fluency.

By moving parts of steps 2 and 3 to study time, flipping speeds learning.

No matter what methods you choose for instruction, our recommendation would be: Embrace the gift of cognitive research. When teaching and study become better aligned with our new knowledge of how the brain works, our students and their society will benefit.

Resources:

1. **Blog:** More on flipping and cognition in first-year chemistry (with comments and questions encouraged!) will be posted at CogBlog .

2. **Tutorials:** Inspection copies of our lessons, as paperbacks or ebooks, for both general and preparatory chemistry, are available to college and high school instructors from W. W. Norton.

    - For "Preparation For College Chemistry" courses, see: PrepChemPaperback .

    - Request general chemistry paperbacks by ISBN at GenChemPaperbacks .

    - For the 39 chapter general chemistry "screen and print" ebook: GenChemEBook

    For high school and AP chemistry, licenses are available for class sets of ebooks.

3. **Quizzes:** For instructors using the tutorials with classes, editable weekly quizzes are available on the content of both the preparatory and general chemistry lessons.

4. **Activities:** Challenging problems that can be worked in class with instructor guidance are available for all chapters of the general chemistry tutorials. Contact Hartman@usna.edu for samples and details.

5. **BCCE: On math computation** skills of the current generation, see BCCEmath .

6. **References** on how the brain solves problems:

    - **Clark:** "**The Human Brain** – Learning 101: " A 4-page non-technical summary of research in cognition, on pages 8-11 of *Putting Students on the Path to Learning* at Brain.

    - **NMAP:** On math (but applies to chemistry, too): Pages 4-xi and 4-2 to 4-8 in *The Report of the Task Group on Learning Processes* in the *Final Report of the National Mathematics Advisory Panel* (2008) at NMAP .

    - **Willingham:** For summer reading, *Why Don't Students Like School* by cognitive scientist Daniel Willingham, a 240 page paperback for under $20.

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