LEARNCHEME.COM: TEACHING/LEARNING RESOURCES FOR CHEMICAL ENGINEERING

John L. Falconer, Janet deGrazia, J. Will Medlin, and Katherine McDanel
University of Colorado Boulder • Boulder, CO 80309-0596

The LearnChemE site (<www.LearnChemE.com>) provides teaching/learning resources for chemical engineering courses for both faculty and students. Various aspects of these resources were described previously,[1–3] but significant additions and improvements have been made since those articles were published. The purpose of this article is to make faculty aware of the resources available. The LearnChemE site provides resources to help faculty implement active learning and flipped classrooms. Most faculty do not have time to create these resources, and many are not familiar with active-learning approaches that improve student learning. A strong justification for active learning was provided by Freeman, et al.[4]; they analyzed 225 studies that compared STEM courses that used active learning in class to those that used traditional lecturing. Performance on exams and on concept inventories increased by 0.47 of a standard deviation when instructors used active learning, *whereas students in the traditional lecture courses were 1.5 times more likely to fail*. The LearnChemE site also helps students supplement their textbooks and classroom materials. A representation of part of the LearnChemE home page in Figure 1 displays the drop-down menus to indicate the resources available: screencasts (and interactive screencasts), interactive simulations, student resources (how to study/how to learn suggestions, Polymath files, and screencasts), and faculty resources (ConcepTests, course packages). We briefly discuss best practices for using the tools.

SCREENCASTS

More than 1,550 screencasts, which are short screen captures of a tablet PC with narration, are available for 14 courses (listed in the drop down menu in Figure 1), although the number of screencasts for each course varies widely. These screencasts provide: brief introductions of a topic, concept, or diagram; demonstrations of applying key concepts to solve problems; or tutorials on software usage. Figure 2 shows a snapshot of a screencast; most of the text and equations in screencasts are hand written. The screencasts take advantage of combined visual and audio delivery of information. Students use screencasts on their own, without instructor involvement, but instructors can assign them as supplements to reading, as required viewing before class (flipped classroom), or as helpful guides for homework assignments. They can be assigned for exam reviews, where students attempt to solve posed problems on their own and then view the screencast as needed and at their own pace.

Previous studies have documented that screencasts are effective tools for improving student learning, and they offer clear advantages over textbooks for delivery of certain types of information.[5–9] In textbooks, diagrams and referring text are in different locations on a page (or even on different pages), and this places significant demands on working memory, which can result in cognitive overload.[10] Screencasts present diagrams and narration at the same time, and this has been shown to enhance learning.[11] Bergmann and Sams[12] found that students who watched screencasts outperformed students who had traditional lectures. A meta-analysis study by the Department of Education[13] found that students in courses that used both online learning and face-to-face instruction performed better than students with only face-to-face instruction.

The screencasts on <www.LearnChemE.com> were played/downloaded more than 5 million times in the last 12 months, and more than 19 million times since inception. They are

John L. Falconer *is the Mel and Virginia Clark Professor of Chemical and Biological Engineering and a President's Teaching Scholar at the University of Colorado Boulder. He has taught courses in thermodynamics, kinetics/reaction engineering, and catalysis. His research is in the areas of zeolite membranes and heterogeneous catalysis. He has directed the effort at the University of Colorado Boulder to prepare screencasts, ConcepTests, interactive simulations, and course packages for chemical engineering courses.*

Janet L. deGrazia *is a teaching professor in the Department of Chemical and Biological Engineering at the University of Colorado Boulder. She teaches a number of courses in the department. Her interests lie in curricular innovations and the use of technology in education.*

J. Will Medlin *is the Denver Business Challenge Endowed Professor at the University of Colorado. He teaches courses in kinetics, thermodynamics, and material and energy balances. His research interests are in the area of surface science and heterogeneous catalysis.*

Katherine P. McDanel *is a professional research assistant in the Department of Chemical and Biological Engineering at the University of Colorado Boulder. She obtained her B.S. in chemical engineering from North Carolina State University in 2010 and her M.S. in chemical engineering from Purdue University in 2011. She joined the LearnChemE team in 2012 and assists in material development and website management.*

organized by topics for a given course and by commonly used textbooks. The screencasts are organized by playlists for various courses on our YouTube channel (<https://www.youtube.com/LearnChemE>), which has more than 71,000 subscribers. Many screencasts contain links within the screencast to other, related screencasts. As much as possible, they are independent of a given textbook.

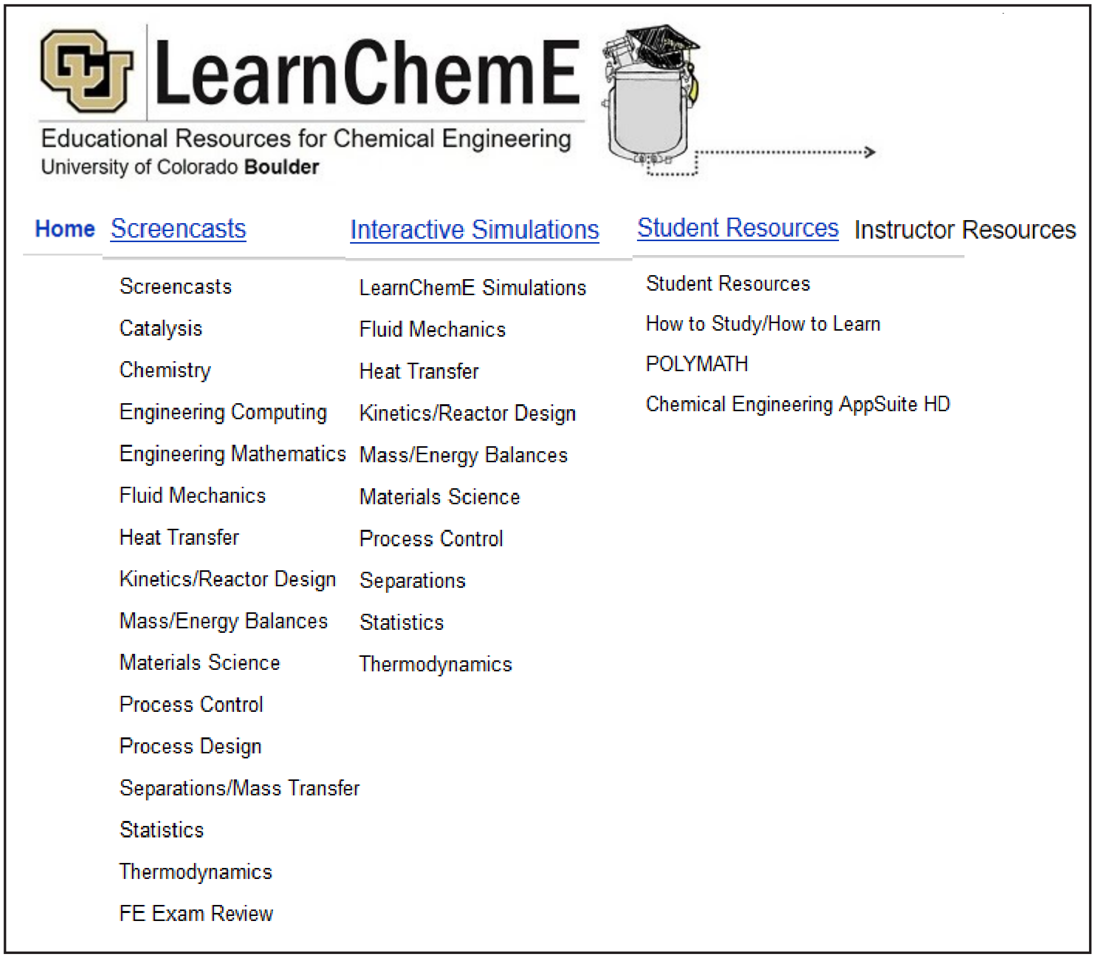

Figure 1. *A section of the LearnChemE homepage with the dropdown menus displayed.*

Screencasts prepared or updated in the last few years incorporate principles from research on e-learning.[11] These principles include:

- *Keeping the screencasts short. Almost all screencasts are less than 10 minutes long, and many are less than 5 minutes.*
- *Not reading text that is on the screen and not adding written text that repeats narration.*
- *Describing complex visuals with audio only.*
- *Only including essential information that supports learning goals. This means avoiding nice-to-know information, engaging information, or decorative visuals.*
- *Using first- and second-person pronouns when speaking.*

All but the most recently prepared screencasts have been manually closed-captioned, which makes them more accessible for those with hearing impairment and for those whose native language is not English. Although YouTube generates closed-captioning, the resulting text is not accurate.

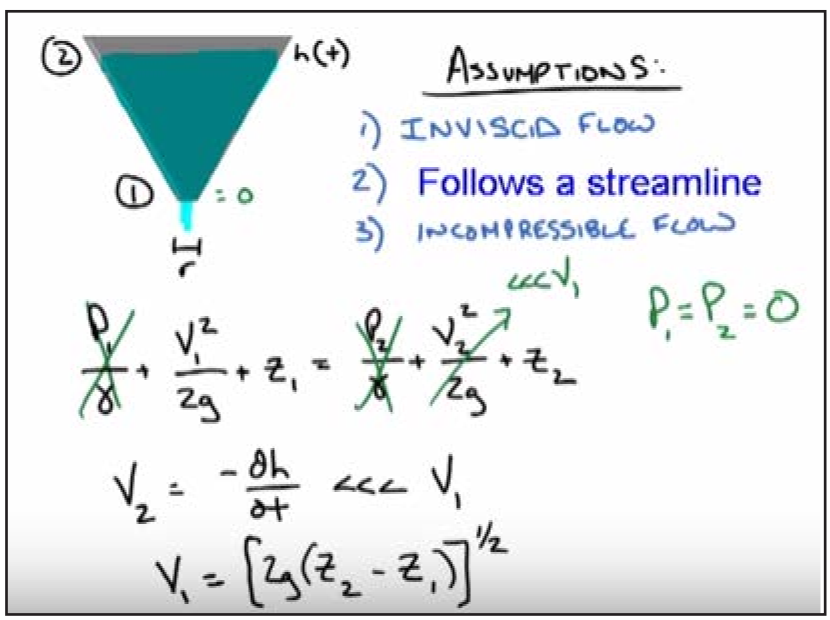

Figure 2. *Snapshot of a screencast for fluid mechanics.*

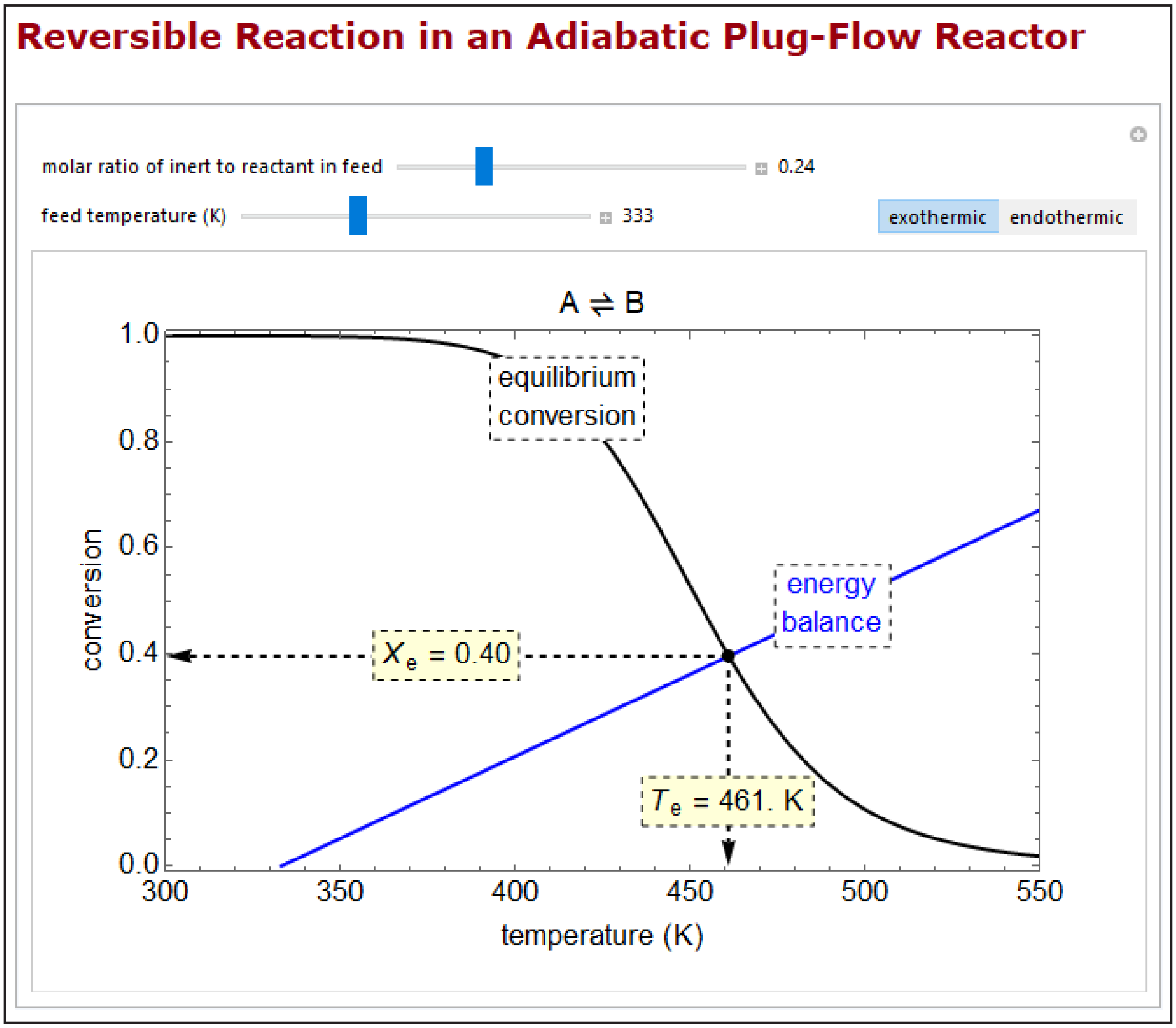

Figure 3. *Snapshot of an interactive simulation for kinetics (<https://www.colorado.edu/learncheme/kinetics/ReversibleReactionAdiabaticPFR.html>).*

Approximately 100 screencasts are interactive; these consist of ConcepTests (see below) that students answer by selecting an answer within the screencast. This selection opens another video that corresponds to that answer. If a student selects the correct answer, an explanation is given. If he/she selects an incorrect answer, a hint is usually given, and the student can select another answer from within that video. Thus, interactive screencasts provide students with the opportunity to practice with feedback in tackling difficult conceptual problems.

INTERACTIVE SIMULATIONS

The LearnChemE site contains more than 160 interactive simulations, which are effective for demonstrating complex system behavior; they allow the user to manipulate variables and receive instant feedback on how these changes affect the system. Because users manipulate simulations at their own speed, fewer demands are placed on working memory, and students can focus on understanding.[14] Interactive simulations are used extensively in physics education,[15] and student interaction with simulations has been found to have positive effects on learning.[16] Podolefsky, et al. showed that they promote self-directed inquiry and exploration.[17]

As with screencasts, interactive simulations provide useful tools that can be accessed directly by students. They are also excellent tools for use during class time and for homework assignments. For example, students can be asked during class time to predict how a complex system behaves when some parameter changes; these predictions can then be tested in simulated "experiments" to provide immediate visual feedback. Figures 3 shows a snapshot of an interactive

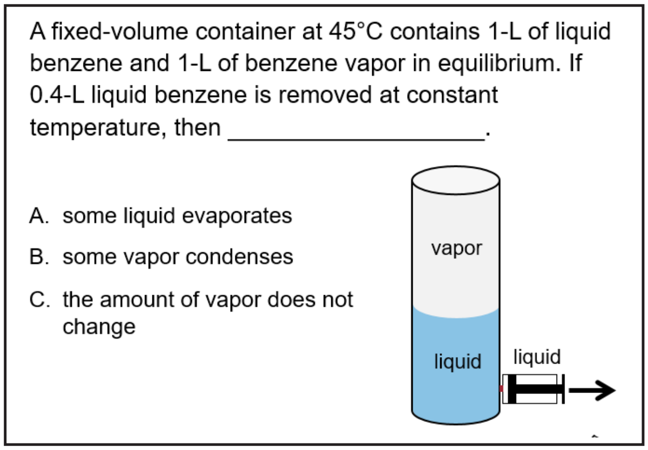

Figure 4. *A thermodynamics ConcepTest.*

simulation example for kinetics. To get a better feel of what this interactive simulation is like, please visit the web page. Students can also use simulations on homework assignments to answer questions about effects of changing key system variables; they can then be asked to develop explanations for the full range of observed trends, allowing them to focus on the underlying concepts rather than detailed calculations. Questions that are more complex can focus on the governing equations, for example, by asking students to justify changes in the shape of generated curves, the relative rates of change of certain variables, etc.

Figure 1 lists the courses that have interactive simulations. Some simulations are listed under more than one course. For example, many phase equilibrium simulations are useful for thermodynamics, material and energy balances, and separations. Almost all the simulations were programmed using Mathematica, and they are available as CDF files so that a Mathematica license is not required to use them. Instead, a free CDF player can be downloaded from the Wolfram demonstration project website (<http://demonstrations.wolfram.com/topics.html>), where the simulations can also be downloaded. A few MATLAB simulations are also available on the LearnChemE site. Many simulations on LearnChemE have accompanying screencasts that demonstrate their use.

FACULTY RESOURCES

More than 2,000 ConcepTests are available for seven courses; five of these courses have more than 200 ConcepTests. These multiple-choice questions do not involve calculations, and they require understanding rather than memorization of facts. They are ideal for use in class with student response systems (clickers) and peer instruction. The questions (without the multiple-choice answers) are excellent exam questions and homework problems; students must supply an answer and an explanation. Figure 4 is an example of a thermodynamics ConcepTest.

Studies have shown ConcepTests and peer instruction[18–20] dramatically improve functional understanding. Typical engineering courses emphasize solving quantitative problems, so students have difficulty applying the knowledge to new situations.[21] Using student-held clickers with ConcepTests and peer instruction increases students' conceptual understanding and challenges their misconceptions.[20,22] This approach creates a more engaged learning environment, and provides the instructor (and students) with instant feedback about student understanding.

ConcepTests are incorporated into complete course packages for thermodynamics, material and energy balances, and kinetics. These course packages use a flipped-classroom approach with evidence-based instructional methods, and they incorporate research on how people learn. These course materials are organized in Microsoft OneNote so that instructors can easily customize them. The course packages include daily class notes that use ConcepTests and peer instruction, partially solved problems, suggested screencasts and interactive simulations, learning objectives, assignments and exams (both with solutions), and directions on how to use the packages. Faculty can request access to the ConcepTests and course packages by emailing LearnChemE@gmail.com.

STUDENT RESOURCES

This section contains resources on how to study/how to learn, including screencasts, a PDF summary of the literature, and links to references and useful websites. Many students and faculty are unaware of the most-effective study methods, which are described in a number of books published in the last few years.[23–25] McGuire and McGuire report the significant improvements by students who utilized these study methods.[26]

This section also contain links to 21 screencasts that demonstrate how to use Polymath (<http://www.polymath-software.com/>) and the corresponding Polymath program files used in the screencasts. Polymath applies numerical analysis techniques to solve linear, nonlinear, and differential equations, and to do data analysis and regression.

ACKNOWLEDGMENTS

The resources on the LearnChemE site were prepared with support from the National Science Foundation (Grants DUE 0920640, DUE 1322300, DUE 1244183), the Engineering Excellence Fund at the University of Colorado (CU), the CU Chemical and Biological Engineering Department, the CU College of Engineering and Applied Sciences, the CU Chancellor's office, and Shell. Faculty at the University of Colorado Boulder prepared the majority of screencasts and ConcepTests, but faculty at other Universities who contributed are listed on the website. Rachael Baumann at the University of Colorado Boulder prepared the majority of the interactive simulations, and undergraduates who also contributed are listed on the website.

REFERENCES

1. Falconer JL (2007) ConcepTests for a Chemical Engineering Thermodynamics Course. *Chem. Eng. Educ.* 41:107–114.
2. Falconer JL, Nicodemus G, Medlin JW, DeGrazia J, McDanel K (2014) A Thermodynamics Course Package in OneNote. *Chem. Eng. Educ.* 48:209–214.
3. Falconer JL (2016) Combining Interactive Thermodynamics Simulations with Screencasts and Conceptests. *Chem. Eng. Educ.* 50:63–69.
4. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP (2014) Active Learning Increases Student Performance in Science, Engineering, and Mathematics. *Proc. Natl. Acad. Sci.* 111:8410–8415. doi:10.1073/pnas.1319030111
5. Musallam R (2010) *The Effects of Using Screencasts in a Multimedia Pre-Training Tool to Manage the Intrinsic Cognitive Load of Chemical Equilibrium Instruction for Advanced High School Chemistry Students*, Doctor of Education thesis, University of San Francisco.
6. Green G (2012) How to Flip an Entire School, <http://edudemic.com/2012/10/how-to-flip-an-entire-school/>.
7. Toto J, Booth K (2008) Effects and Implications of Mini-Lectures on Learning in First-Semester General Chemistry. *Chem. Educ. Res. Pract.* 9:259–266. doi:10.1039/b812415a
8. Oehrli JA, Piacentine J, Peters A, Nanamaker B (2011) Do Screencasts Really Work? Assessing Student Learning Through Instructional Screencasts. In: A*CRL Conference*. pp. 127–144, <http://www.ala.org/acrl/sites/ala.org.acrl/files/content/conferences/confsandpreconfs/national/2011/papers/do_screencasts_work.pdf>.
9. Lloyd SA, Robertson CL (2011) Screencast Tutorials Enhance Student Learning of Statistics. *Teach. Psychol.* 39:67–71. doi:10.1177/0098628311430640
10. Muller DA (2008) *Designing Effective Multimedia for Physics Education*, PhD thesis, University of Sydney, Australia.
11. Clark RC, Mayer RE (2011) *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*. John Wiley and Sons, San Francisco.
12. Bergmann J, Sams A (2008) Remixing the Chemistry Class. *Learn. Lead. with Technol.* 1:22–27.
13. Means B, Toyama Y, Murphy R, Bakia M, Jones K (2010) *Evaluation of Evidence-Based Practices in Online Learning: a Meta-Analysis and Review of Online Learning Studies*, U.S. Department of Education at <https://www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf>.
14. Beaulieu JR (2012) *A Dynamic, Interactive Approach to Learning Engineering and Mathematics*, Masters thesis, Virginia Polytechnic Institute, http://hdl.handle.net/10919/32165.
15. Wieman CE, Adams WK, Perkins KK (2008) PhET: Simulations That Enhance Learning. *Science* 322:682–683.
16. Bodemer D, Ploetzner R, Feuerlein I, Spada H (2004) The Active Integration of Information during Learning with Dynamic and Interactive Visualisations. *Learn. Instr.* 14:325–341. doi:10.1016/j.learninstruc.2004.06.006
17. Podolefsky NS, Perkins KK, Adams WK (2010) Factors Promoting Engaged Exploration with Computer Simulations. *Phys. Rev. Spec. Top. - Phys. Educ. Res.* 6:20117. doi:10.1103/PhysRevSTPER.6.020117
18. Mazur E (1997) *Peer Instruction: A User's Manual*. Prentice Hall, Upper Saddle River, NJ.
19. Smith MK, Wood WB, Adams WK, Wieman CE, Knight JK, Guild N, Su TT (2009) Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science* 323:122–124.
20. Duncan D (2005) *Clickers in the Classroom*. Addison Wesley, San Francisco.
21. McDermott LC (2001) Oersted Medal Lecture 2001: "Physics Education Research—The Key to Student Learning." *Am. J. Phys.* 69:1127–1137. doi:10.1119/1.1389280
22. Crouch CH, Watkins J, Fagen AP, Mazur E (2007) Peer Instruction: Engaging Students One-on-One, All at Once. *Res. Reform Univ. Phys.* 1:1–55.
23. Oakley B (2014) *A Mind for Numbers: How to Excel at Math and Science*. Tarcher/Penguin, New York.
24. Carey B (2015) *How We Learn: The Surprising Truth about When and Where and Why it Happens*. Random House, New York.
25. Brown PC, Roediger III HL, McDaniel MA (2014) *Make it Stick: The Science of Successful Learning*. Harvard University Press/Belknap, Cambridge, MA.
26. McGuire SY, and McGuire S (2015) *Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation*, Stylus Publishing, Sterling, VA. ❐