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Mastering Chemistry educator study investigates impact of homework frequency at University of Cincinnati

School Name University of Cincinnati, Cincinnati, OH	**Timeframe** Fall 2015–Fall 2016
Course name Organic Chemistry I	**Submitted by** Allan Pinhas, Professor
Course format Face to face	**Results reported by** Betsy Nixon, Pearson Customer Outcomes Analytics Manager
Course materials Modified Mastering Chemistry for *Organic Chemistry* by Wade	

Key Findings

- After changing Modified Mastering Chemistry homework to increase the number and frequency of assignments but including all of the same homework problems, final exam and semester exam averages were significantly higher than the reported prior semesters.
- For Fall 2016, when students were grouped based on the median of their exam 1 score, students who were below the median but earned a Mastering Chemistry homework score above the median ended up with exam averages comparable to the group of students who scored above the median on exam 1 but earned a Mastering score below the median.
- For Fall 2016, students who scored below the median on exam 1 but above the median on Mastering Chemistry homework were the only group that ended with a higher final exam average than their exam 1 average.
- When extra credit points were assigned to the introduction to Mastering assignment, designed to help students learn to use the program, a higher percent of students attempted it, and the instructor did not receive as many technical questions at the start of the semester.

Setting

- Type: Public Research University
- Enrollment: 44,000 undergraduate and graduate
- Location: Urban
- Average retention rate: 86 percent
- Financial aid: 84 percent

About the Course

Professor Allan Pinhas joined the faculty at the University of Cincinnati in 1982. He is a physical-organic chemist and primarily teaches the first semester of Organic Chemistry but has also taught the second semester. In addition, he teaches a course entitled Introduction to Forensics, a forensic chemistry course taken by non-STEM students in Arts and Sciences and by Criminal Justice majors.

Organic Chemistry I is a two-semester, four-credit course which includes a three-credit lecture and one-credit recitation. Students are not required to take a separate lab. However, most students do take the lab since Chemistry, Biology, and Chemical Engineering programs require it. In addition, medical and pharmacy schools require that students have taken it before admission. Approximately 80-85 percent of students do take the lab concurrent to the lecture.

Organic Chemistry I topics include theories of structure and bonding, stereochemistry, introduction to spectroscopy, as well as the nomenclature, synthesis, reactions, and properties of classes of organic compounds, such as alkanes, alkenes, alkynes, alkyl halides, alcohols and ethers, utilizing a mechanistic approach.

Lecture is held twice each week, and recitation is offered every day, Monday through Thursday with students attending one recitation a week. Students who take the course are enrolled primarily in health-related programs, such as Pre-Pharmacy; Biology, often Pre-Med; and Chemical and Biomedical Engineering. Approximately 10 percent of students who enroll in the course are Chemistry majors. To enroll in Organic Chemistry I, a student must have earned a C- or higher in General Chemistry II; to enroll in Organic Chemistry II, a student must earn a C- or higher in Organic Chemistry I.

Challenges and Goals

Pinhas believes that Organic Chemistry tends to be a challenging course for most students. Because of the difficulty of the class, discussion among faculty in the department has focused on the role of technology to enhance learning. A 2015 Journal of Chemical Education article, "Pencil–Paper Learning Should Be Combined with Online Homework Software", published by Pinhas and his colleague, David Smithrud, stated that "a student's success in a chemistry course is strongly correlated to on-task studying of the material through solving homework problems. With large undergraduate class sizes, such as the ones at the University of Cincinnati, hand-grading of homework problems and providing students with valuable feedback is impractical."[1] Because of the importance of problem-solving practice and timely feedback to students, the instructors have utilized digital homework since 2006, with two different non-Pearson digital homework systems used until 2014.

As Pinhas and his colleague noted in their paper, "Online homework has succeeded in getting students of all abilities to complete homework problems. We find that students spend many minutes on each problem and take advantage of the hints and the repeated attempts. What needs to be improved are the examination scores for about half of the students who have earned 90% or more of the online homework points."[2] He believes one of the main challenges still to be addressed

is understanding how to make sure that performance on the homework problems translates into success on the exams.

Beginning in Fall 2015, the department adopted Mastering Chemistry, basing the decision primarily on the technology rather than selecting a textbook and using the technology that accompanied it. An analysis of the data from Fall 2015 and Spring 2016 was initially conducted. This educator study documents the findings from that period, along with the subsequent changes to Mastering Chemistry homework for Fall 2016, and the follow up analysis of the results for that semester.

Implementation

During this period of time, Pinhas recommended students purchase an organic chemistry textbook to use for reference, and he provided a list of recommended texts. In the future, based on student feedback, Organic Chemistry, by Wade, will be the recommended text to make it easier to provide references to reading and information. Access to Mastering Chemistry is required to do the assigned homework problems.

Components of the course include:

Exams: Three paper-and-pencil exams and a final are administered during the semester. The exams are closed book and closed note with no make-up allowed. In addition, students are not allowed to use a calculator but may use molecular models. Due to the nature of Organic Chemistry, the exams are cumulative; however, each exam concentrates on the most recent material covered since the prior exam. Exams are comprised of open-ended problems and mirror the type of Mastering problems assigned for homework. The same type of exams in use now were used prior to adoption of Mastering Chemistry.

Recitation: Students attend one recitation each week for a 55-minute period. During the first week of class, each recitation section is divided into groups of six students. Students select their own groups and remain in that group throughout the semester. The recitation grade is based on group work only. In each recitation, an instructional cycle occurs that begins with the teaching assistant (TA) handing out a problem that each group works on for about five minutes. When the problem is completed, the group gives their written answer to the TA. One group presents their work and answer to the class for discussion. Once this is completed, a new problem is given to the groups. All work in recitation is done via paper-and-pencil. Students receive full credit for recitation problems if they are in attendance during the session.

Mastering Chemistry: In the semesters prior to adoption of Mastering Chemistry (MC), the online homework consisted of 15 assignments comprised of multiple choice questions. Student feedback was that 15 assignments were too many, in particular because some were due during exam weeks. When Mastering Chemistry was adopted, the change was initially made to give five homework assignments. The MC items assigned were open-ended problems requiring students to draw, rather than multiple choice questions. Pinhas found that type of homework tended to take students more time to complete which was another reason for fewer assignments. He also thought that with a lower number of assignments, students would take more time to work through and understand the problems, which should ultimately help them do better on exams. Based on the results showing exam averages did not increase during that period and that Mastering best practices recommend

smaller, more frequent assignments, the number of MC assignments was changed to 10 for Fall 2016. The 10 MC homework assignments for Fall 2016 contained the same content as the prior five but were broken up into smaller assignments with more frequent due dates. Students were given unlimited attempts, and the Mastering default settings were in place regarding hints. Assignments were due at 7:00 p.m. on the Friday of the week due.

The Introduction to Mastering assignment, intended to provide students with a tutorial on the mechanics of using and submitting answers in Mastering, was optional in Fall 2015 and Spring 2016. Beginning in Fall 2016, Pinhas gave extra credit for completion of this assignment.

Pinhas also shared his research findings with students regarding the benefits of handwriting solutions to homework problems. He strongly encouraged students to first write out their work and then submit the answers in Mastering for scoring. He told students that studies have shown those who work that way tend to do better on the exams than those who only work digitally. This is supported by a variety of research approaches which have shown that doing work by hand can be more efficient[3] and effective for creating longer-term learning.[4] However, written solutions for the Mastering assignments were not required nor collected for grading.

Optional paper-and-pencil homework: There were no formal paper-and-pencil homework assignments. Pinhas told students that it is beneficial to work the problems at the end of each chapter in whichever textbook a student has access to in order to develop their problem-solving skills. In addition, students had a problem set posted on Blackboard for each topic covered in the course. He also provided a PDF of additional exercises based on chapter problems and problems from prior exams for more practice. These were not required, but Pinhas strongly suggested that students work these problems as well. The answers to practice problems were not posted so students needed to meet with Pinhas or a TA to check on their solutions. The goal of this was to encourage students to work the problems without checking first for the solution. In addition, if a student finds their answers are not correct, they can review the problem with the instructor or TA who can help them understand their misconceptions.

Assessments

- 50% Lecture exams (3)
- 33.3% Final exam
- 8.3% Mastering Chemistry
- 8.3% Recitation

Results and Data

The changes made to the Mastering homework for Fall 2016 were designed to engage students more frequently, with the goal of enhancing learning and increasing exam scores. The analysis conducted was intended to understand the effect of the change. Specifically, would having more frequent, smaller assignments lead to better learner outcomes than having the same content in fewer, larger assignments? To examine this, the Fall 2016 data with 10 Mastering assignments was compared to the prior two semesters with five longer, less frequent MC assignments.

Connection to Learning Science

The approach Pinhas adopted corresponds to a large body of research on memory and learning. Specifically, research into the cognitive mechanisms underlying the effect of spacing of homework and test memory benefits suggests that when knowledge is somewhat more difficult to retrieve from memory, as it is after a delay, the act of retrieval itself strengthens that memory, making it more likely to be successfully retrieved in the future. One implication of this is that giving students more opportunities to recall information, such as by spacing the same amount of content out over more homeworks, creates stronger memories.[5] In addition, the effect is stronger when students write in their response, compared to answering a multiple-choice question.[6]
Mastering homework for Fall 2016 included:

- An increased number of assignments so students would practice and recall the concepts more frequently;
- Open-ended problems requiring drawing that matched the type of questions on exams and were the same Mastering questions used the prior two semesters; and
- A recommendation to students to hand-write solutions prior to inputting their answers online for scoring.

Since students would get immediate feedback after submitting their answer in Mastering, they could then continue working on the problem if their answer was not correct. These practices are well-aligned with the cognitive mechanisms of memory and learning and would be expected to lead to better learner outcomes.

Exams

Figure 1 presents exam data from all three semesters Mastering was in use. Students in Fall 2016 had an exam 1 average that fell between the averages for Fall 2015 and Spring 2016. The average was significantly higher than Spring 2016, but the Fall 2015 exam 1 average was significantly higher than Fall 2016. By exam 2, the Fall 2016 average was significantly higher than the prior two semesters and remained significantly higher through the final exam. The semester average for all exams for Fall 2016 was 59 percent compared to 48 and 50 percent the prior two semesters. It is important to note that there may be variables impacting these results which are difficult to measure, such as motivation and study skills, and assumes the difficulty of exam problems were comparable.

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Average exam scores for Organic Chemistry, Fall 2015–Fall 2016

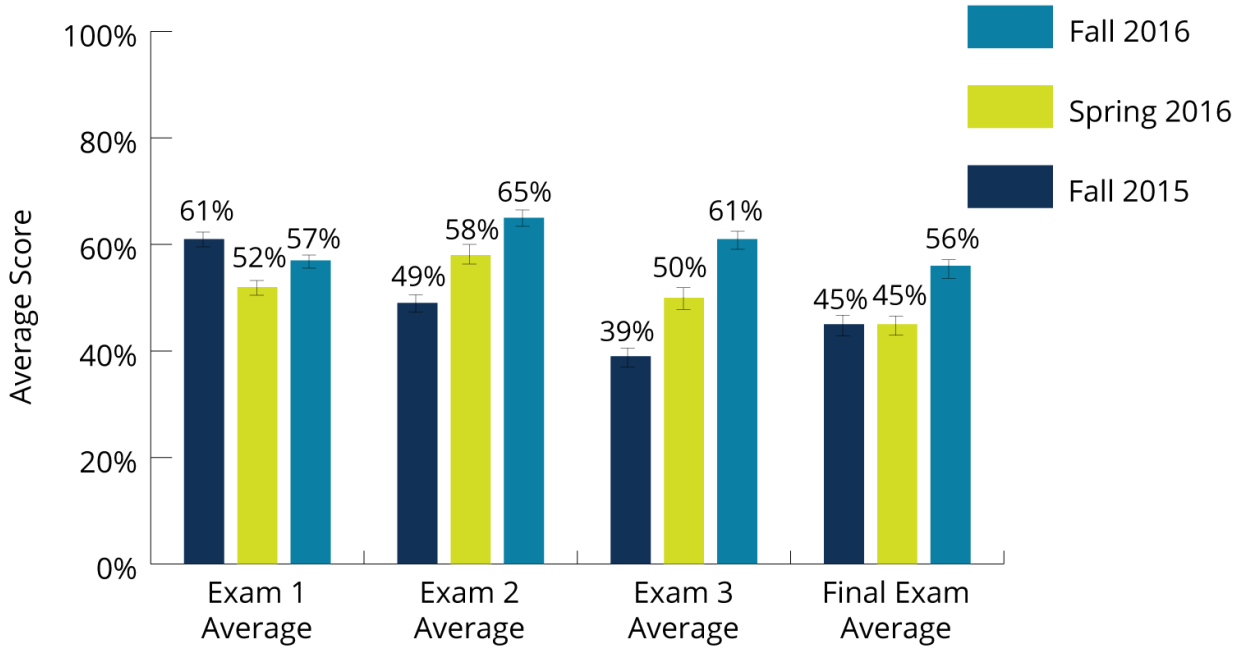

Figure 1. Fall 2016 (*n*=184); Spring 2016, (*n*=158); Fall 2015 (*n*=142), Err Bars=Stand Err; *p*<.05

Connecting homework to exams

In Pinhas and Smithrud's Journal of Chemical Education article, they reported on correlation values between homework and exam averages. The same analysis was done for the semesters in which Mastering was in use. For Fall 2015 and Spring 2016 combined, the correlation between Mastering Chemistry homework and exam averages was *r*=.40, and for Fall 2016, it was slightly higher with *r*=.47. These findings mirror those reported in their earlier published study.

The prior research published by Pinhas and Smithrud talked about the need to increase test averages for the group of students who are earning high homework scores (90 percent or higher), but are not earning comparable exam scores. An additional analysis looked at this group of students. After the increase in the frequency of Mastering homework assignments, those students had higher exam averages and exam median scores than the students for Fall 2015–Spring 2016 (figure 2). In addition, table 1 shows that a higher percentage of students in Fall 2016 had a Mastering homework average of 90 percent or higher, but a lower percentage of students had exam averages below 50 or 70 percent compared to the prior semesters. In Fall 2016, the percentage of students with a 90 percent or higher MC average and less than 50 percent exam average dropped by 18 percentage points, and by 10 percentage points for those with an exam average less than 70 percent. While these data show an improvement, there remains a group of students who are not performing comparably on homework and exams, so further evaluation on ways to address these students is recommended.

Average and median exam scores based on Mastering Chemistry averages

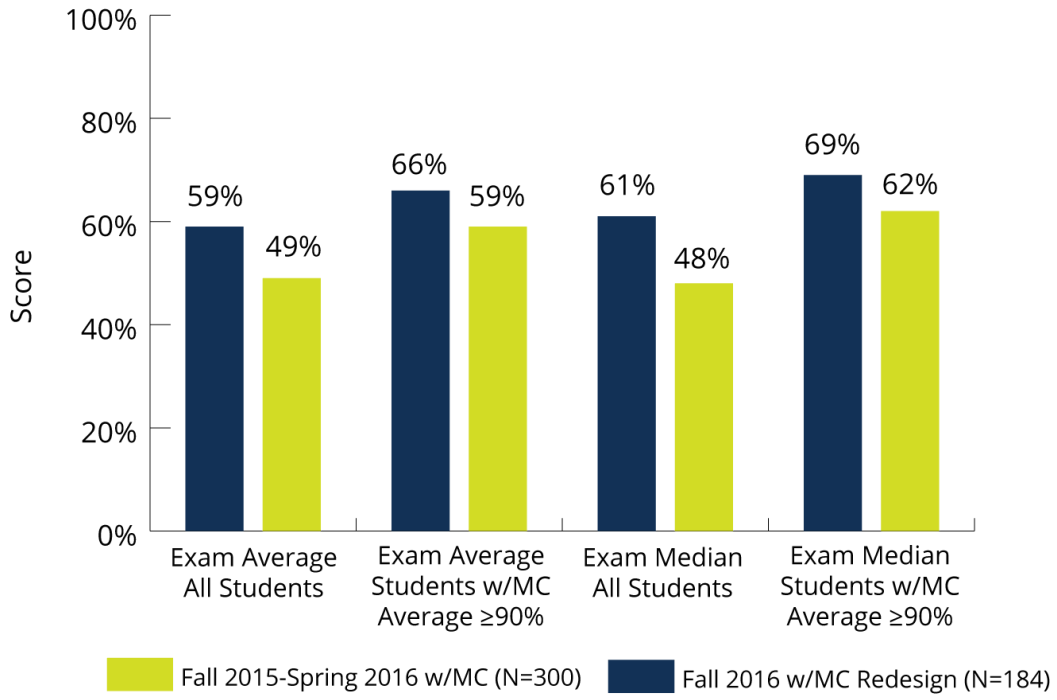

Figure 2. Fall 2016 (*n*=184); Fall 2015–Spring 2016 (*n*=300)

Exam averages based on Mastering Chemistry averages

	Fall 2015–Spring 2016	Fall 2016
Percent of students w/exam average <50%; MC ≥90%	58%	40%
Percent of students w/exam average <70%; MC ≥90%	64%	54%
Percent of total enrolled students earning an average of 90% or higher on MC homework	32%	50%

Table 1. Exam averages based on Mastering Chemistry average

A final analysis looked at student homework and exam performance using the exam 1 median score as a baseline. The first exam in this course was primarily a review of General Chemistry. Organic Chemistry concepts, and in particular the reactions and reaction mechanisms, start at exam 2. This means that exam 1 tends to test how much information a student has retained from their General Chemistry courses.

For this analysis, students were first placed into two groups: group 1 was at or above the exam 1 median score of 60 percent; and group 2 was below the median. These two groups were each then

divided based on the median Mastering Chemistry homework score of 89 percent. While this analysis attempts to look at exam 1 as a baseline, it should be noted that three MC homework assignments (30%) were to be completed prior to exam 1. The groups were as follows:

- HE1/HHW = At or above 60 percent on exam 1/At or above 89 percent on MC homework
- HE1/LHW = At or above 60 percent on exam 1/Below 89 percent on MC homework
- LE1/HHW = Below 60 percent on exam 1/At or above 89 percent on MC homework
- LE1/LHW = Below 60 percent on exam 1/Below 89 percent on MC homework

Figure 3 presents the findings, which include:

- The HE1/HHW and HE1/LHW groups had statistically equivalent exam 1 scores.
- The LE1/HHW and LE1/LHW groups had statistically equivalent exam 1 scores.
- The HE1 groups diverged at exam 2 with the HHW group earning a significantly higher exam 2 average than the LHW group with a 10 percentage point difference, and having a final exam average significantly higher with a 13 percentage point difference.
- The LE1 groups diverged at exam 2 with the HHW group earning a significantly higher exam 2 average than the LHW group with a 12 percentage point difference, and having a final exam average significantly higher with a 13 percentage point difference.
- The HE1/LHW and LE1/HHW groups were 25 percentage points apart on exam 1. The LE1/HHW group began closing the gap at exam 2 and ended with a final exam average difference of three percentage points, not a significant difference (p=.28).
- The only group to see an increase from exam 1 to their final exam average was the LE1/HHW group with a nine percentage point increase. It's important to note that this is almost a whole letter grade improvement for a group of students that may be considered at-risk after the first exam. It provides evidence that students can improve if they are willing to put forth the effort and utilize the resources for learning.

This analysis shows that regardless of where students started at exam 1, those students who scored higher on the Mastering homework went on to have higher exam averages than the comparable group of students who scored lower on Mastering.

Organic Chemistry exam averages based on Mastering Chemistry homework scores, Fall 2016

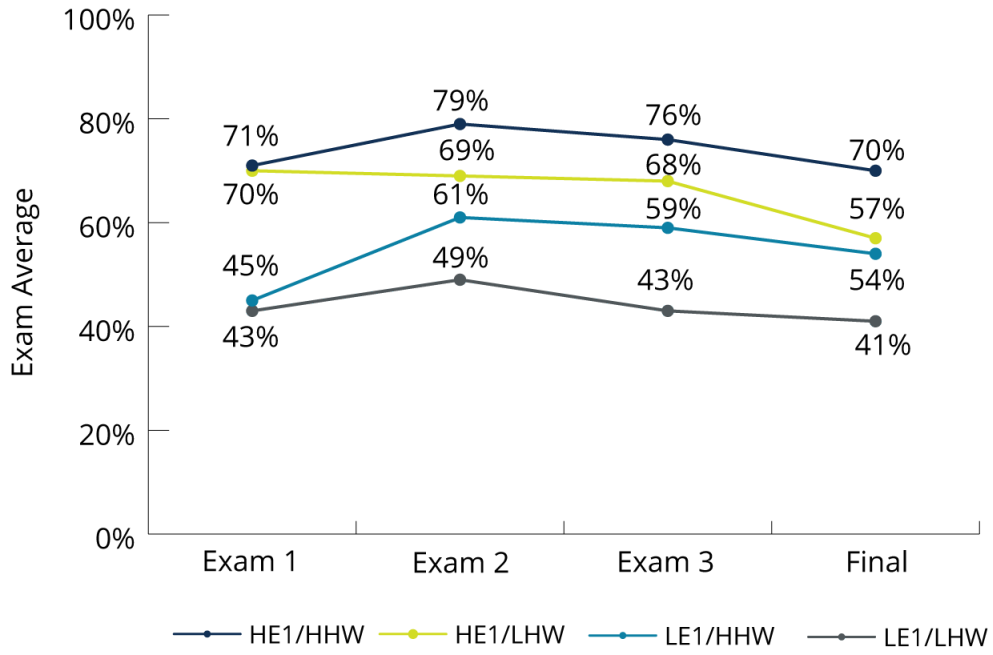

Figure 3. HE1/HHW, (*n*=59); HE1/LHW, (*n*=34); LE1/HHW (*n*=38); LE1/LHW (*n*=53)

The Student Experience

The Introduction to Mastering assignment is designed to help students understand how to answer question formats they will likely encounter in Mastering homework, so it is a recommended best practice to assign this first before students start the regular MC homework. Pinhas assigned the Introduction to Mastering homework as optional in Fall 2015 and Spring 2016. The data showed that 37 and 39 percent of students respectively had a score of 0, indicating they likely did not attempt it. For the Fall 2016 semester, Pinhas offered a few points of extra credit, and only nine percent of students earned a 0, with the majority of the students completing the assignment.

While it does not provide specific organic chemistry concepts, completing the assignment likely means that students will be able to start working immediately on the first Mastering homework rather than spend time trying to figure out how to use the program and submit answers in the correct format. In Fall 2016, when more students did the assignment, Pinhas found he had fewer questions from students about the mechanics of Mastering, which saved him time not addressing technical issues or specifics about using the program.

Conclusion

Pinhas recognizes that Organic Chemistry is a difficult course for students, and feels it is important to continue to analyze results and evaluate how technology is implemented in the course to enhance learning. From 2006 through 2016, three different digital homework programs were used, with Mastering Chemistry in use beginning Fall 2015. Pinhas and his colleague reported on the results through 2014 in the Journal of Chemical Education article referenced above, and the results

from Fall 2015–2016 are reported in this educator study. The adoption of Mastering Chemistry enabled instructors to assign open-ended drawing problems that replicated the type of problems asked on exams, rather than using multiple choice questions for homework. After the first two semesters, an analysis of results was conducted, and changes were made in Fall 2016 based on Mastering best practices.

The Mastering best practices that Pinhas addressed with the adoption of Mastering Chemistry and subsequent implementation changes include:

- Require the "Introduction to Mastering" assignment to help students get off to a better start.
- Give homework problems that mirror the type and content of problems encountered on exams.
- Evaluate course results each semester, and use the information to make decisions about future changes.
- Shorten homework assignments and increase their frequency.

Pinhas wanted to understand if having more frequent, smaller assignments would lead to better learner outcomes than having the same content in fewer, larger assignments. To examine this, the Fall 2016 data with 10 Mastering assignments were compared to the prior two semesters with five longer, less frequent MC assignments. While other factors can impact performance, such as motivation and study skills, results for the Fall 2016 semester showed higher exam averages than the prior semesters. The increase in exam scores may be supported by the theory of spaced practice and retrieval practice, well-established areas in the Learning Sciences.

In addition, students who scored higher on Mastering homework had higher exam averages than comparable students who scored lower on homework. The correlation data from this period replicates the results published in Pinhas and Smithrud's prior study, showing a group of students who continued to do well on digital homework, but who did not perform comparably on exams. However, the percentage of students in that category was lower for Fall 2016 when more frequent, smaller Mastering homework was assigned than in the prior reported semesters. Pinhas did not teach the course in Spring 2016, but plans to continue to evaluate results in the future.

1 Pinhas, A. and Smithrud, D. (2015). Pencil−Paper Learning Should Be Combined with Online Homework Software. Journal of Chemical Education, 92: 1965-1970.
2 Ibid.
3 Anthony, L., Yang, J. & Koedinger, K. R. (2008). How handwritten input helps students learning algebra equation solving. Retrieved from http://reports-archive.adm.cs.cmu.edu/anon/hcii/abstracts/08-100.html, accessed February 23, 2017.
4 Mueller, P. A., & Oppenheimer, D. M. (2014). The Pen Is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking. Psychological Science, 25(6): 1159-1168.
5 Pavlik, P. I., Jr., & Anderson, J. R. (2005). Practice and forgetting effects on vocabulary memory: An activation-based model of the spacing effect. Cognitive Science, 29: 559-586.
6 McDaniel, M.A., Wildmana, K., Anderson, J. (2012). Using quizzes to enhance summative-assessment performance in a web-based class: An experimental study. Journal of Applied Research in Memory and Cognition, 1: 18–26.