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**Banking on Adaptive Questions to Nudge Student Responsibility for Learning
in General Chemistry**

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Abstract

In this case study from the University of Maryland, Baltimore County (UMBC), we explore if and how students can be nudged to take responsibility for their learning through one of the university's largest courses, CHEM 102 "Principles of Chemistry II." To do so, Dr. Tara Carpenter leveraged the campus' Blackboard learning management system (LMS) in Spring 2021, and then added the RealizeIt adaptive learning platform in Fall 2021 and Spring 2022 to implement a pedagogy of "spaced practice," in which students have time to study, forget, re-acquire, and reorganize new knowledge or content. Specifically, Carpenter leveraged large pools or "banks" of questions to guide students in their "time on task" practice and application of key concepts needed to perform well on high-stakes, summative exams.

Overall, in comparing CHEM 102 final grade data between Fall 2020 and Fall 2021, we see there is not a statistically significant relationship between the treatment (i.e., course design) and reduced DFW (drop, fail, or withdraw) rates. However, if we disaggregate final grade data, we see there is an overall statistically significant increase in As ($p < .01$) and decrease in Cs ($p < .05$) and Ds ($p < .05$). Notably, all of this gain from increasing As appears to be from students of color (SOC), who demonstrate a nearly 4x advantage over their non-redesigned course peers in attaining this grade ($p < .001$), while White students demonstrated no statistically significant gain in this area. Based solely on whether students used the spaced practice environment Carpenter designed, we also see that a model predicting final grades after only 14 days into the semester is 83% accurate.

Introduction

How do we help new college students learn how to learn? If as the saying goes, “nobody learns from a position of comfort,” can first-year students honestly and accurately self-assess what they currently know, understand, or do? And be disciplined enough to put in the time and effort to develop or strengthen what they may lack? Perhaps more importantly, can they be nudged into taking responsibility for doing so, especially if their initial interest or ability alone is insufficient to be successful? If so, what can faculty do, in the design and delivery of their courses, to help initiate or accelerate student engagement? Finally, what, if anything, can learning analytics and adaptive learning do to help *both* faculty and students in their teaching and learning roles?

In this case study from the University of Maryland, Baltimore County (UMBC), we explore these questions through one of the university’s largest courses, CHEM 102 “Principles of Chemistry II,” with a typical Spring enrollment of 550-600 students (just under 200 in Fall). After 18 years’ experience teaching the course as well as guiding, even exhorting students in how to learn and succeed in it, Dr. Tara Carpenter wondered if students simply did not know how to do so independently. So, in the middle of Spring 2021 – armed with a pedagogical theory of change and innovative, pandemic-driven digital skills and experience – she designed an incentive model and personalized learning environment in UMBC’s Blackboard LMS to help students not only pass the exams, but also take responsibility for preparing for them.

Frequently known as “spaced practice,” in which students have time to study, forget, re-acquire, and reorganize new knowledge or content, Carpenter leveraged large pools or banks of questions to guide students in their “time on task” practice and application of key concepts needed to perform well on high-stakes, summative exams. She also incorporated her spaced

practice pedagogy into a pilot of the RealizeIt adaptive learning platform in Fall 2021 and Spring 2022. In addition to scaling her bird's eye view on student engagement, Carpenter and her chemistry department colleagues are also taking a closer look at if – and how – students are taking lessons learned in her course to the next one that requires it, CHEM 351 “Organic Chemistry” (Carpenter, 2022).

Pedagogical Influences

To better understand Carpenter's methodology of spaced practice and the role learning analytics and adaptive learning have played in implementing and refining it, we first need to understand her pedagogical influences. To do so, we will focus on how we learn to learn and think about our thinking, often known as “metacognition,” the role that memory (and forgetting) plays in doing so, and finish with why spaced practice – unlike cramming – is literally about the time we give our brains to discover, process and organize new knowledge, skills, or abilities.

Metacognition

In 2016, Carpenter joined a UMBC Faculty Development Center (FDC) book discussion about Sandra McGuire's (2015), *Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation*. A year later, she attended McGuire's on-campus keynote presentation (2017) at UMBC's annual “Provost's Symposium on Teaching and Learning.” In both her book and UMBC talk based on it, McGuire argues that faculty need to intentionally and explicitly introduce students to metacognition, or thinking about thinking, by showing and telling them about Bloom's taxonomy of learning (see Figure 11.1): “Don't just assume they've seen Bloom's [taxonomy] or understand it,” said McGuire, who also co-authored with her daughter, Stephanie, a student-focused book about metacognition, *Teach Yourself How to Learn* (2018).

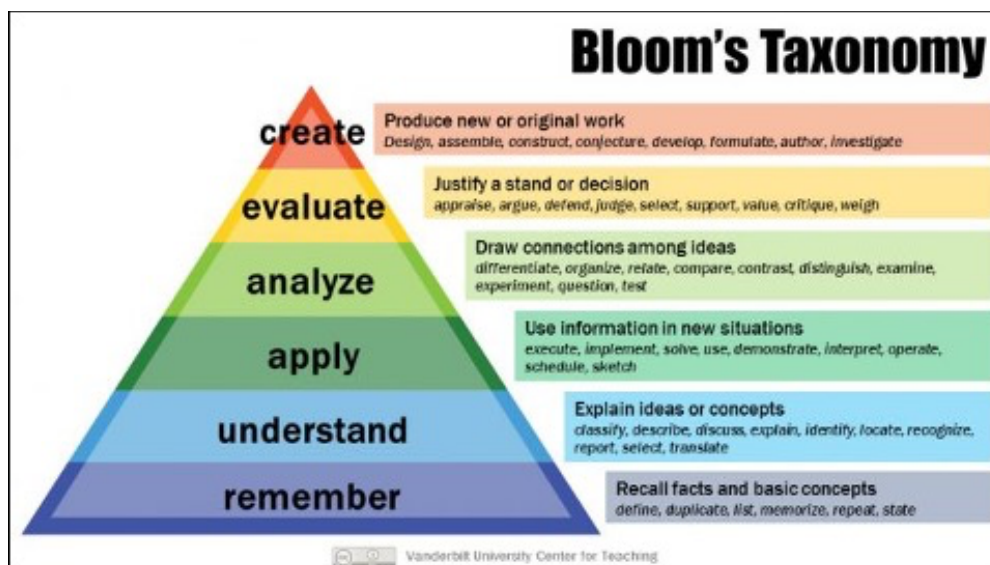


Figure 11.1: Bloom's Taxonomy. Creative Commons by 2.0 Generic, Courtesy Vanderbilt University Center for Teaching. <https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy>

“Reading [McGuire’s] book essentially changed the way I view teaching and learning and changed how I view course design,” says Carpenter, who had long seen incoming students repeat what they were conditioned to do in high school: memorize, regurgitate (for an exam), and promptly forget (after it). “Most of them just aren’t prepared for the rigors of college because they simply don’t understand the difference between memorization and learning.”

Along with her colleague, Dr. Sarah Bass, who teaches CHEM 101, and also leveraged the same large-question-bank approach to online, “open note” exams during the pandemic (Bass et al., 2021a, 2021b; Fritz, 2020), Carpenter became much more intentional about introducing students to metacognition, delivering McGuire’s recommended lecture on the topic, and taking time in class to encourage student reflection on their own learning, especially after exams (Carpenter et al., 2020). She even began sending individual, personalized emails, highlighting effective strategies for specific students who seemed to be struggling, which is remarkable given the class size.

The Ebbinghaus Forgetting Curve

Despite her encouragement and guidance, Carpenter saw new students continue to struggle and fall behind. As her own pedagogical awareness evolved, she began to focus on why cramming doesn't work for students as a strategy for long-term learning and retention, based on the work of German psychologist Herman Ebbinghaus (1850 – 1909), who spearheaded the research of memory by studying his own (Ebbinghaus (1885), 2013).

Specifically, Ebbinghaus famously memorized a set of 2,300 random three-letter combinations and then tracked, consistently, how long it took for him to forget them, only consulting the list after he could not recall anything. He found that after memorizing and immediately demonstrating 100 percent recall, by 19 minutes he could only recall 60 percent of the list, but by 31 days he could still recall just over 20 percent (see Figure 11.2).

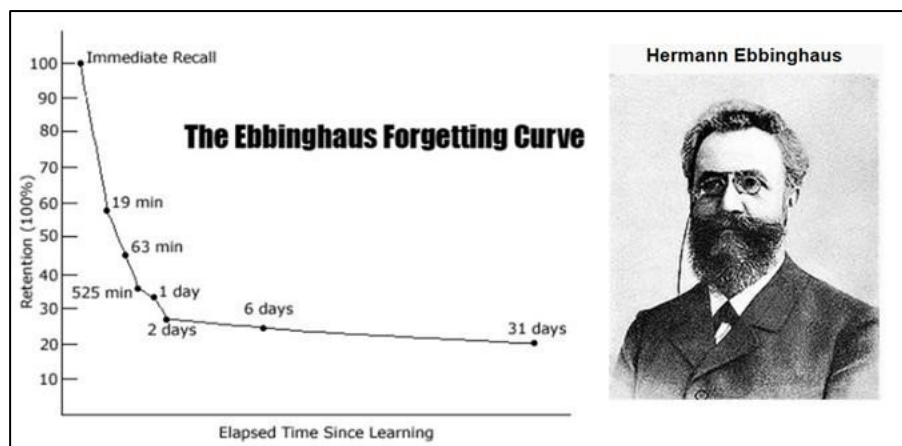


Figure 11.2: The Ebbinghaus Forgetting Curve.
Image source: <https://images.app.goo.gl/kW4ZZy6K2Lmx9hBi6>

Ebbinghaus' work has sometimes been criticized for lacking external validity because he only studied himself. However, a 2015 study replicated his findings (Murre & Dros, 2015). Also, since as Ebbinghaus found, that rote-learned memories fade soon, it is worth noting Cathy N. Davidson's (2012) excellent distillation of the brain science of attention, which shows how we are literally trained from birth to pay attention to things that matter and filter out those that do not. As humans, we need this filtering to prevent sensory overload and to promote mastery,

which comes through trial and error, repeated exposure, and intuitive application of key concepts in different contexts. In other words, when we forget rote-acquired, short-term memories, it's likely a sure sign that our brains have not deemed them to be sufficiently important enough to be committed to long-term retention.

The Learning Curve (via Spaced Practice)

Though he's most widely known for his forgetting curve, Ebbinghaus' attempts to overcome it also give us a more familiar concept, the learning curve, which ideally occurs when we move on from relying on memory alone to recall facts and concepts when needed. Specifically, Ebbinghaus found that he forgot less after repeated exposures to the same material, albeit in regular, even smaller periods than his initial acquisition by rote memorization alone and separated or "spaced" out over time, such as 1 day, 1 week, 1 month, 3 months, etc. (see Figure 11.3).

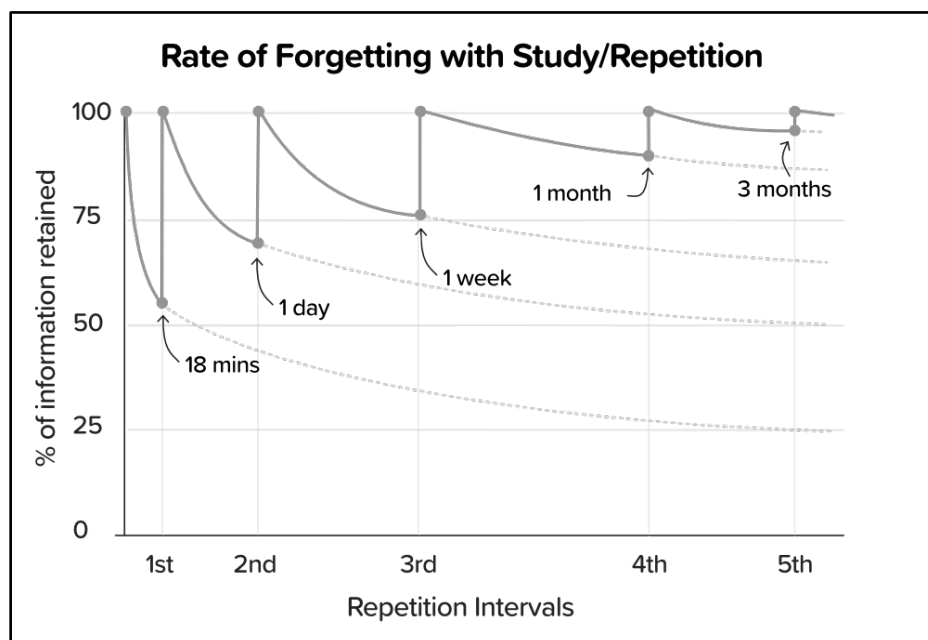


Figure 11.3: An "Ideal" Learning Curve.
Image source: <https://images.app.goo.gl/xMnsJRM5ButPVJYt6>

Though it may vary in name, the principles behind spaced practice – initially frequent and regular review of key concepts and content via smaller study sessions vs. single, long-cramming sessions – find support in the scholarship of teaching and learning, including as “divided practice” (Weimer, 2002), “distributed practice” (Cepeda et al., 2006), “goal directed practice” (Ambrose et al., 2010), and “deliberate practice” (L. Nilson & Zimmerman, 2013). More recently, we see “spaced practice” (Dunlosky & Rawson, 2015; Hodges, 2015; Miller, 2014) emerge as a consensus term, including in for-profit and non-profit adaptive learning environments like Duolingo (Munday, 2016) and Khan Academy (Gray & Lindstrøm, 2019), respectively.

Methodology

Again, Carpenter recognized the effects of the Ebbinghaus forgetting curve in many of her incoming students, especially their slavish adherence to cramming for exams instead of following her advice to adopt better, time-tested, and proven learning strategies. But despite the evidence and even her own encouragement, student behaviors and approaches to their own learning did not change.

“What if they just don’t know how,” she wondered. “What if they're just so overwhelmed by learning how to learn, that they can't pull this off on their own, partly because of immaturity or time management, etc.?”

With these questions in mind, and based in part on her Fall 2020 use of large question banks to design online, “open-note” exams during the pandemic-pivot to remote instruction (Fritz, 2020), Carpenter began constructing a schedule for spaced practice over spring break of the Spring 21 term, and allowed her students to opt-into it for the remaining three exams. If students opted in, they did not need to complete the regularly scheduled homework as this would

take its place. As an incentive to opt in, students were offered 10 percentage points extra credit towards the first exam where spaced practice was offered, if needed. For the remaining two exams, no extra credit was offered, but the homework assignments continued to be replaced by the spaced practice for students who opted in.

Specifically, Carpenter began writing iterations of practice questions for individual units in her course that she wished students would see and could answer. Having written her own exam questions for years, she found the transition to writing practice questions herself – instead of using publishers’ homework questions – to not be very difficult. But her focus was not on “definition” kinds of questions (per Bloom’s lowest “remembering” level of learning). Instead, she focused on higher-level thinking that required students to apply concepts or solve math-related problems that relied on conceptual understanding. To help with question variety, she used Blackboard’s “calculated question” format to change the numeric variables in a question stem or prompt (see <https://tinyurl.com/bbcalcquestion>). She also randomized the order of the questions students would see in each spaced practice lesson.

However, Carpenter had to solve another key problem: lack of time for her students to space their practice when she had an exam every three weeks for the rest of the term. So, she made up her own schedule based loosely on an “ $N + 2$ ” sequence, where the first iteration or exposure to unit practice may occur on day “zero” followed by another iteration on days 2, 5 and 7, respectively. These might also overlap with another unit’s practice schedule, such that students were literally practicing every day, albeit not the same material two days in a row. For an example, see Figure 11.4.

Open at 6am	Due at 6am	Unit 17 (Polyprotic Acids)	Unit 18 (Buffers)	Unit 19 (Titrations)	Unit 20 (K _{sp})	Unit 21 (Lewis Acid Base)
		12 Questions	10 Questions	10 Questions	16 Questions	8 Questions
		30 min	50 min	100 min	no timer	no timer
4/5	4/6					
4/6	4/7	8				
4/7	4/8		2			
4/8	4/9	8	4			
4/9	4/10		6			
4/10	4/11	10	7			
4/11	4/12		8			
4/12	4/13		8	2		
4/13	4/14	12		4		
4/14	4/15			6		
4/15	4/16		9	8		
4/16	4/17	12			4	
4/17	4/18			10	7	
4/18	4/19		10		10	
4/19	4/20	12			13	
4/20	4/21			10		
4/21	4/22		10		16	4
4/22	4/23			10		6
4/23	4/24	None Due. It is recommended that you take the PLCP under testing conditions. Review as needed.				
4/24	4/25	12	10	10	16	8
4/25	4/26	None Due. It is recommended that you take the PLCP under testing conditions. Review as needed.				
4/26	4/27	LCP 5				

Figure 11.4: CHEM102 Students' Spaced Practice Schedule Before Learning Checkpoint 5, Spring 21

Based on the manually intensive nature of her practice question development process, and with a desire to personalize student learning even further, Carpenter agreed to pilot the RealizeIt Learning adaptive learning platform in Fall 21 and Spring 22, based largely on the positive experience and recommendation from colleagues at the University of Central Florida (UCF), who use and support it, and have also published their experiences (Dziuban et al., 2017, 2018, 2020). This required an initial export of Carpenter's own question pools from Blackboard and import into RealizeIt that was not entirely automatic or without cleanup. Also, Carpenter

now faced her own steep learning curve to master a new assessment authoring platform, which she did over repeated practice and support.

Finally, with the use of RealizeIt in Fall 21 providing a near infinite supply of variable questions and answers, Carpenter essentially was able to implement her spaced practice content *and* schedule across an entire term. She kept the same exam questions, given over the course of five Learning Checkpoints (LCPs) as she'd done using six LCPs in Spring 21, but interestingly, she did not make Spaced Practice optional. It was now required as the homework system for CHEM 102, which was understandable not only for her perceived benefits to all students (based on the Spring 21 experiment) but also her own considerable time and effort to create the Spaced Practice environment in RealizeIt. She just didn't have time to have students using another, publisher-based homework system, which she understandably abandoned for Fall 21, since she could now author her own questions for both practice *and* exam environments.

Findings

In this section, we summarize findings from Carpenter's experimental implementation of spaced practice during the middle of the Spring 21 term using Blackboard and also describe its full implementation in Fall 21 using RealizeIt Learning. We also share results from an interesting experiment in which Carpenter, working with instructors in the next course requiring hers, CHEM 351 "Organic Chemistry," surveyed students who had been enrolled in her Spring 21 version of CHEM 102, to see if and how they carried the lessons learned from their use of spaced practice into CHEM 351 in Fall 21.

Note: By default, to avoid content duplication, UMBC's Bb LMS course shells combine multiple sections of the same course taught by the same. As such, CHEM 102H (Honors section, $n \sim 25$) are always combined with the larger CHEM 102 LMS course shell. However, in the

analysis that follows, only the “FA21” findings alone specifically *excluded* Honors students for methodological reasons supporting inferential analysis. By contrast, Honors students were *included* in the “SP21” and “SP21/102 to FA21/351” progression findings, which are mostly descriptive in nature.

CHEM 102 (Spring 21)

Six exams were given to 558 students in CHEM 102 in Spring 21. Exams 1 - 3 were given using traditional “one-and-done” homework, in that students were not required to review questions from prior unit modules in the assignments. For exams 4 -6, students were given the opportunity to participate in Carpenter’s spaced practice implementation, with 64.5% completing them for all remaining exams, 13.9% completing for at least two exams, 7% completing for just one exam and 14.4% not completing any spaced practice. Overall, students who participated in spaced practice performed better on exams than students who did not (see Figure 11.5).

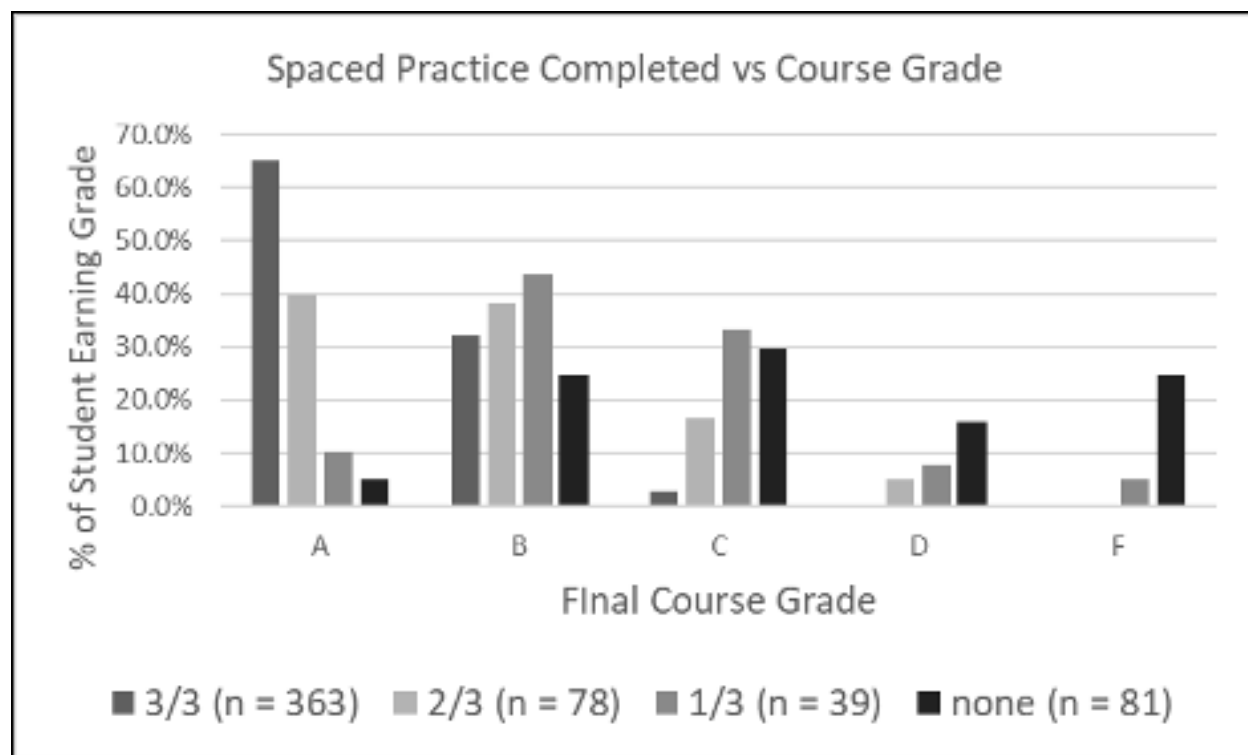


Figure 11.5: CHEM 102 Final Grade by Spaced Practice Completion of Last Three Exams, Spring 21

Additionally, based on prior research on the “strength of relationship” between UMBC student engagement in the LMS, particularly duration or time spent, and final grades (Fritz et al., 2021), we see that all students were dramatically more engaged after spring break, but especially those earning higher final grades (see Figure 11.6).

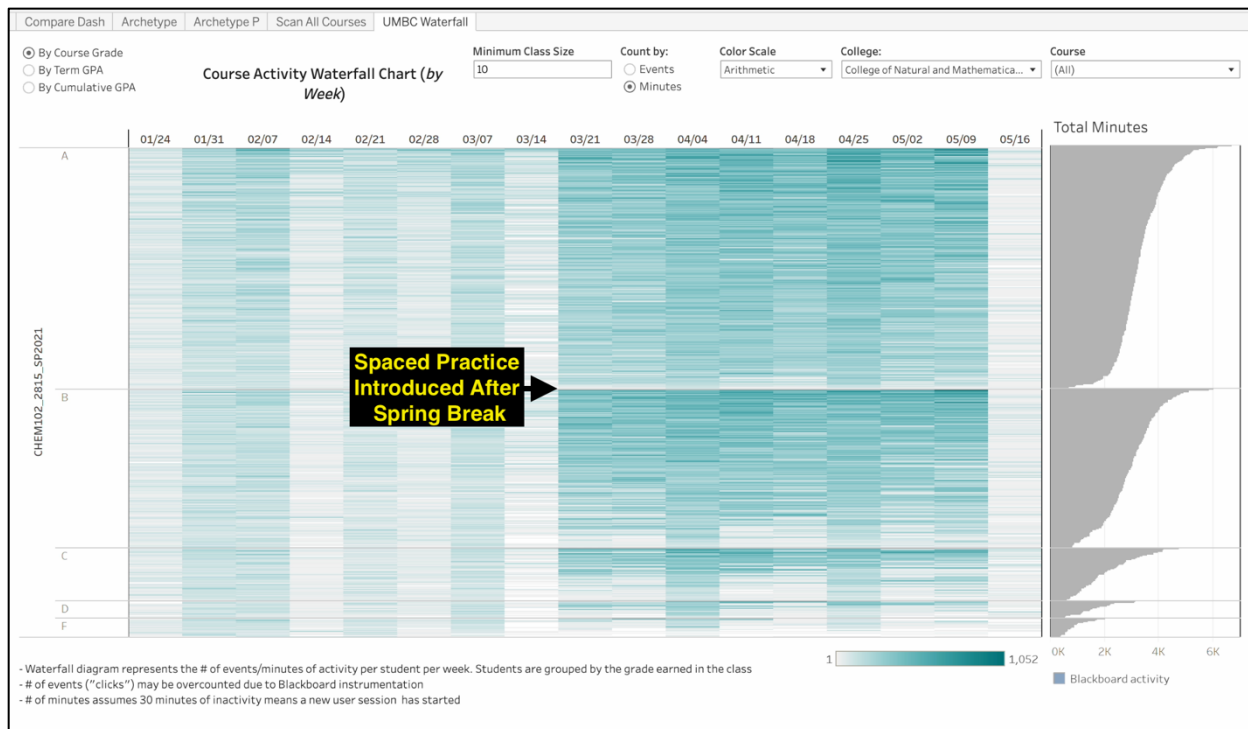


Figure 11.6: CHEM 102 “Waterfall” chart in which every row is a student, every column a week in the semester, and each cell’s “color” density is based on time spent (e.g., darker = more time). For a larger, color version of this image, see the presentation slides from Fritz et al., 2022, in the references.

CHEM 102 (Fall 21)

Again, in Fall 21, Carpenter not only implemented her spaced practice pedagogy during the entire term, but also used the RealizeIt adaptive learning platform for the first time. Accordingly, it is more appropriate to compare her Fall 21 course outcomes with those from Fall 20. Additionally, while CHEM 102 is offered every fall and spring term, the largest enrollment is always in the spring, since it is part of the two-semester general chemistry sequence.

In doing so, we see that there was not a statistically significant relationship between the treatment (i.e., course design) and overall DFW rates between Fall 20 and Fall 21. However, if we disaggregate the final grade data, we see that there is an overall statistically significant increase in As ($p < .01$) and decrease in Cs ($p < .05$) and Ds ($p < .05$) in Fall 21 (see Figure 11.7)

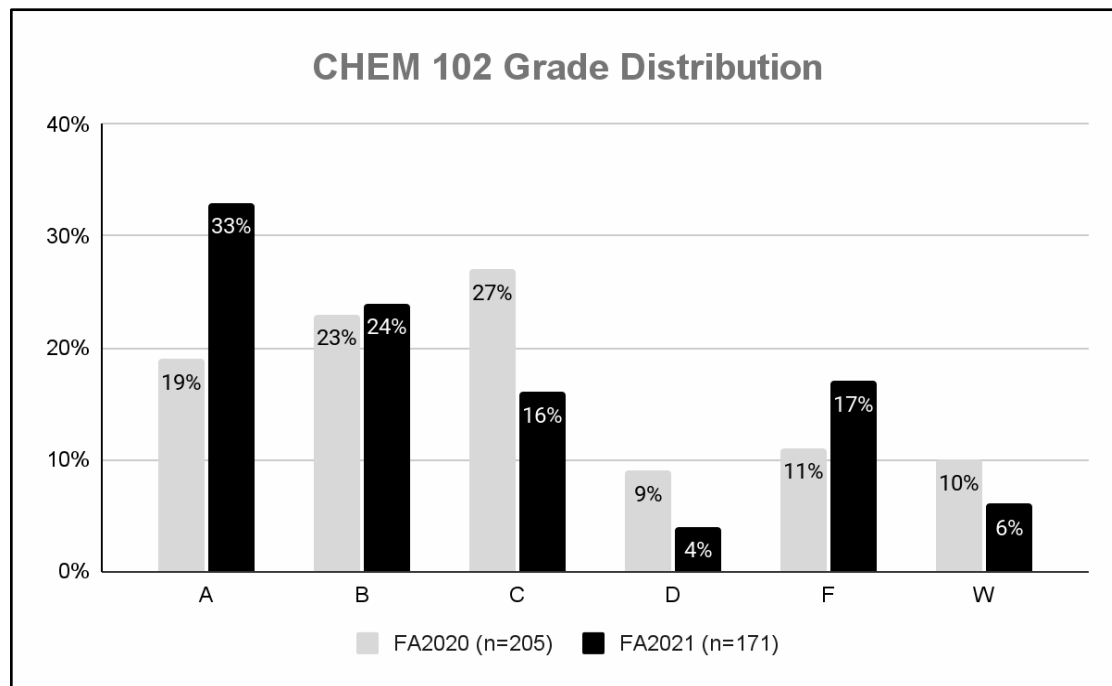


Figure 11.7 CHEM 102 Grade Distribution (Fall 20 to Fall 21)

Notably, all of this gain from increasing As appears to have been from students of color (SOC), who demonstrated a nearly 4x advantage in attaining this grade ($p < .001$) over their peers who completed the course prior to the redesign, while White students demonstrated no statistically significant gain in this area. Figure 11.8 below illustrates the breakdown of percentage of grades earned by term and White vs. SOC.

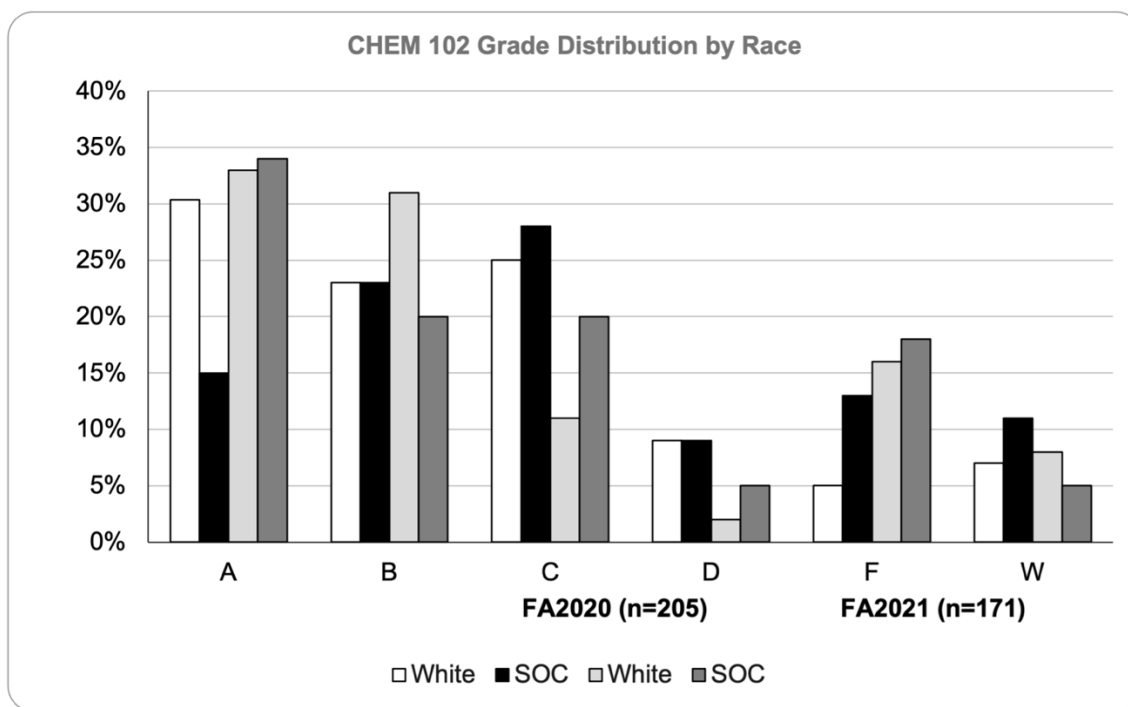


Figure 11.8: Chem 102 Grade Distribution by Term and Race (SOC = Students of Color)

There does appear to be an upward trend in Fs, although not statistically significant when comparing the past two terms. There are no statistically significant, notable grade distribution trends for female or transfer students. Non-STEM students, however, have a statistically significant advantage earning As over their class peers.

There also seem to be some inflection points during students' in-term learning. If we consider how students learning check points (LCPs) rank compared with their peers (i.e., as z-scores), we see that there is a statistically significant 34% reduction in DFWs if students improve from the first to second LCP ($p < .01$), along with a 2.4x increased likelihood of earning an A for all students, and 3.4x for African American students in particular. Considering inflection points later in the term, we see there is a 39% reduction in students' chances of earning a DFW if there is improvement from LCP 4 to LCP 5 ($p < .01$). Although controlling for race, gender, STEM major, academic status, high school GPA, and Math SAT scores in these models only accounts

for 10% of the total variance, it does appear that growth within the semester may be contributing to academic gains in course grade distribution.

Additionally, when we look at student engagement data from RealizeIt, including duration or time spent, and completion of spaced practice modules, we see a compelling insight into one of Carpenter's key goals for the course: students taking responsibility for their own learning. For example, Figure 11.9 shows final grades earned by those students who did (or did not) complete daily spaced practice modules in RealizeIt (similar to Figure 11.6, every row is a student and every column is a daily spaced practice module in RealizeIt, with the color corresponding to final grade earned).

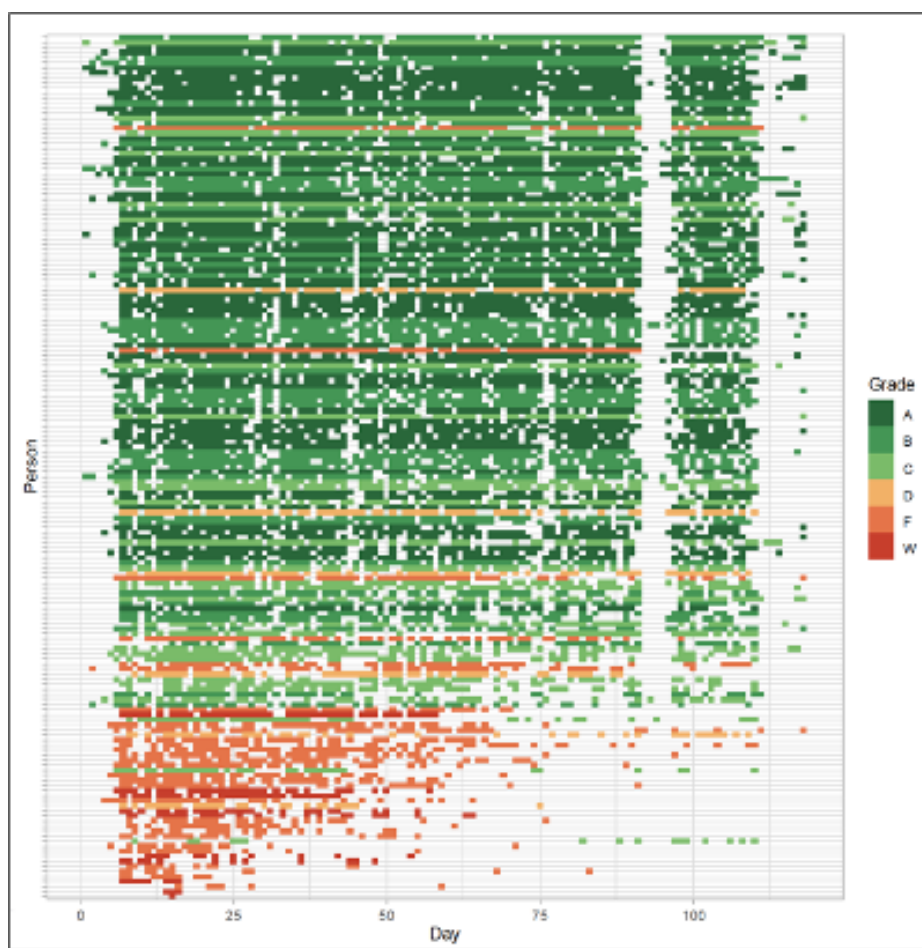


Figure 11.9: CHEM 102 Spaced Practice Modules Completed in RealizeIt by Final Grade Earned (Fall 21). For a larger, color version of this image, see the presentation slides linked in Carpenter (2022), in the references.

We also observe that after only 14 days into the Fall 21 term, a model trained only on actual student usage in RealizeIt was 82.6 percent accurate in correctly predicting ABC and DFW final grades for all students (83% precision).

Overall, the data indicate that Carpenter's spaced practice implementation in RealizeIt appeared, at the very least, to be doing no harm, and when evaluating the implementation alongside grade distribution there seem to be certain advantages, particularly when considering students of color and non-STEM students.

CHEM 102 (Spring 21) Students in CHEM 351 (Fall 21)

Finally, based on a small UMBC learning analytics "mini-grant" (Fritz, 2021), Carpenter proposed to survey students in her Spring 21 version of CHEM 102 to see if and how they carried their spaced practice "lessons learned" into and through the next course requiring hers, CHEM 351 "Organic Chemistry." She presented her findings during a UMBC Learning Analytics Community of Practice meeting on March 10, 2022 (2022), which included the following:

- Overall, 305 of Carpenter's 558 students from her Spring 21 CHEM 102 course enrolled in the Fall 21 version of CHEM 351 "Organic Chemistry."
- Of these, 266 students went "all in" using spaced practice in CHEM 102, and 91 percent earned a C or better in CHEM 351.
- By contrast, of the 15 students who opted out of using space practice in CHEM 102, 46 percent went on to earn a DFW in CHEM 351. Admittedly, these are low Ns to generalize any further.

Carpenter also surveyed her Spring 21 CHEM 102 students before and after their enrollment in the Fall 21 version of CHEM 351 and learned the following: While 78% of pre-

survey respondents indicated they would use spaced practice in CHEM 351, only 34% of the post-survey respondents indicated that they had actually done so. In other words, students valued spaced practice in CHEM 102, but were unable or unwilling to use it on their own in CHEM 351.

Carpenter analyzed students open-ended responses to the post-survey (n=216 participants) and found common themes explaining why and how students struggled to implement spaced practice in CHEM 351 (See Table 11.1):

Common Themes	% response (n = 216)
Planning it out, finding material	50%
Time	28%
Accountability	20%
Less helpful in CHEM 351	2%

Table 11.1: Post-survey responses of CHEM 102 (SP21) students in CHEM 351 (FA21)

Carpenter found one student's comments to be particularly telling and representative of all students' comments she observed (**bold** emphasis added):

- *The biggest challenge in carrying out Spaced Practice (SP) was **formulating my own types of questions** that integrated the many learning objectives (LOs) [for CHEM 351 "Orgo"].*
- ***Translating LOs [learning objects] into challenging questions** was very difficult.*
- ***Creating a practice schedule** that followed the class schedule closely was a bit difficult to do.*
- ***Any tips that could help us in creating an appropriate SP schedule** for a given section of units before an exam, would be very helpful.*
- *Many students in class chats spoke of their problems actually **forming a SP schedule** despite really wanting to continue the great studying technique.*

Discussion

As we reflect on this UMBC case study, a few key questions emerge from Carpenter's implementation and refinement of spaced practice in CHEM 102. First, why do some students *strongly resist* spaced practice in CHEM 102 at the start of the semester and then (surprisingly) *embrace* it by the end? The Scholarship of Teaching and Learning (SoTL) literature and practice includes frequent examples of student resistance to active learning in the classroom, but spaced practice is largely a solitary activity students do (or don't) pursue on their own time, outside of class. Even if shown the evidence from prior, successful cohorts, could it be that incoming students are learning more, but liking it less? If so, how should faculty respond, if at all, given student agency and responsibility for learning? Whose problem is this to solve?

Second, what might help students be more successful in implementing spaced practice in CHEM 351 after successfully doing so in CHEM 102? To be sure, Carpenter rolled up her sleeves and scaffolded an anti-cramming approach to learning that incoming college students may not be familiar with or even like. But at some point, they do have to learn how to learn (in college) and not all faculty can be expected to implement and sustain Carpenter's approach to course design. Or could they?

Finally, what is the *least* amount of spaced practice "time on task" spent per unit that students need to do to be successful in CHEM 102, and become proficient in self-regulating their own learning in CHEM 351? This is where we want to further study the data and patterns of behavior associated with student engagement in RealizeIt. While the goal for spaced practice still must be quality over quantity, Carpenter has found that initial student resistance is based on a perception (concern) over the number and amount of time spent on unit module spaced practice sessions. To date, however, Carpenter has relied on the first exam's results to quell student protest.

“When they see that – unlike what they are used to – they aren’t cramming for exams and are largely ready for them in CHEM 102, the vocal minority quiets down pretty quickly” says Carpenter.

There is, however, a small group of students who continue to spend inordinate amounts of time doing spaced practice without the results they (and Carpenter) would like to achieve (see especially Figure 11.9 above, where some D and F students were just as active or more so than their higher performing peers). This is where Carpenter comes back to McGuire’s focus on metacognition.

“Some students, for whatever reason, really struggle to think critically and objectively about their own thinking,” says Carpenter, who has noticed these students might be using spaced practice only to further aid their prior approaches to rote memorization instead of learning.

“They can recognize a problem similar to one they’ve seen before, and even recall a pattern or process of steps to follow, but don’t recognize new variables, or that I’ve changed the problem from focusing on boiling point or freezing point, or from an acid to a base, for example. They will simply try to repeat what they did in spaced practice instead of doing what’s required by the current problem they are presented on the exam.”

Next Steps

Going forward, there are three key directions we could imagine pursuing further: 1) fully implementing adaptive learning in RealizeIt, 2) Developing a way to make spaced practice more flexible through the use of contract or specifications grading, and 3) working within the Chemistry department’s general chemistry curriculum to phase students’ discovery and maturation with spaced practice across 3-4 courses. We describe each in more detail below.

Fully Implement Adaptive Learning in RealizeIt

At the time of this writing, we have finished the Spring 22 implementation of RealizeIt in CHEM 102. We have mostly worked through some growing pains from the first implementation in Fall 21, and the midterm exam results included an average grade of 79%. It should be noted that Carpenter switched back to a midterm & final exam structure but incorporated the same questions from her prior iteration of six learning checkpoint (LCP) exams in SP21 and five LCPs in Fall 21. Partly this was due to the effort she was putting into grading, which is always a factor to consider in a high-enrollment STEM course. Still, despite this change, she saw a similar correlation between student practice behaviors and their exam performance (see Figure 11.10).

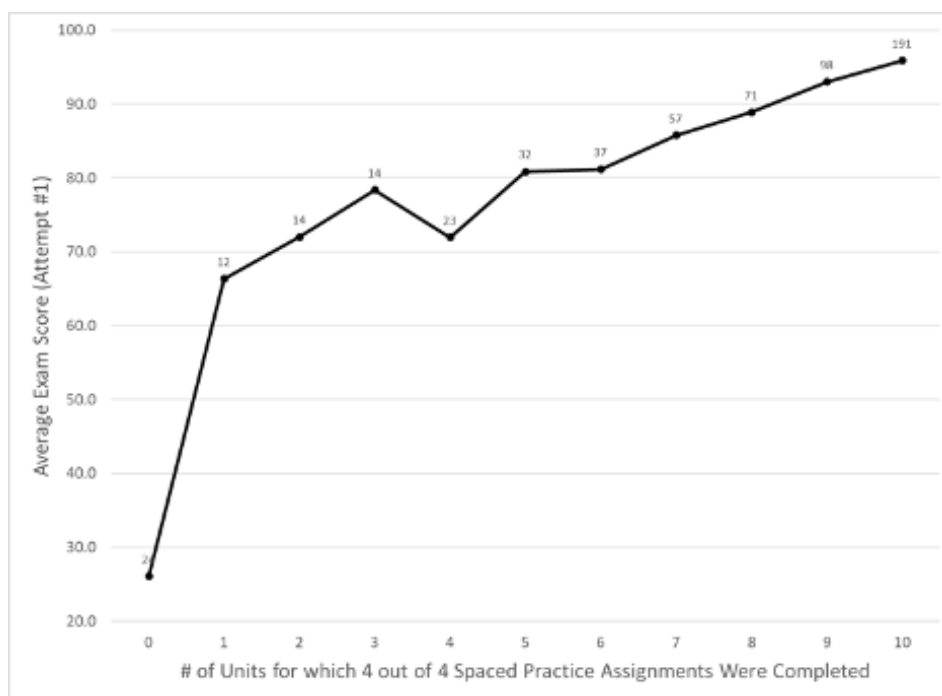


Figure 11.10: CHEM102 Midterm Exam Grade by Spaced Practice Completion, Spring 22

As stated earlier in the methodology, during the first phase of implementing Carpenter's spaced practice pedagogy using RealizeIt, she mostly relied on its algorithmic power to generate nearly infinite numbers of practice question & answer sets, over and above what she had been doing using Blackboard's "calculated question" type. This was a time savings to her, as the instructor, but as the implementation of RealizeIt settles out, we would like to more fully take

advantage of its adaptive learning capabilities to personalize and remediate the kinds of questions students need to be solving, as demonstrated by their weaknesses in the spaced practice RealizeIt environment itself, preferably well before they take their midterm and final exams. In this way, individual students aren't simply amassing practice all students see, they are focusing on remediating specific demonstrated weaknesses and (hopefully) improving in areas necessary to improve their specific exam scores.

Perhaps also, as students see these benefits of personalization for themselves, especially earlier in the term, their acceptance of and motivation to use spaced practice will change from being primarily extrinsic (for points) to intrinsic (for learning how they learn).

Increased Flexibility in Spaced Practice

In the transition from Spring 21 to Fall 21, Carpenter not only changed adaptive technologies (from Blackboard to RealizeIt), but also changed her incentive model for her spaced practice design. Specifically, use of spaced practice was optional in Spring 21, and required in Fall 21. Some students balked initially – and loudly – but Carpenter's Fall 21 course design decision reflected a key learning goal and challenge: How could she appeal to or even develop students' intrinsic motivation to want to learn how to learn if they were extrinsically and primarily motivated by points needed to get a certain course grade?

Carpenter had all the evidence she needed that space practice worked, but students had to be willing to put in the time on task practice. So, not wanting to deny an effective treatment to any student who might not initially understand or value its impact, she decided to require it. With many students focusing on how assignments will affect their grade more than how they will help them learn, the sheer volume of assignments can cause resistance from students.

One way Carpenter has imagined giving students some autonomy over their learning path is through use of “specifications grading” or simply “specs grading,” based on the work of Linda B. Nilson (2015), who argues that current approaches to grading engender “hair-splitting” and should be simplified by structuring assessment around the effort students are willing to expend for a desired grade that is aligned with the instructor’s learning goals. Sometimes known as “contract grading,” there is also heavy use of rubrics in “specs grading,” because the level of effort expected for a grade is clearly delineated in advance of the student’s attempt.

“The issue with traditional grading is that it puts the emphasis on points and supports the students’ extrinsically motivated approach to learning,” says Carpenter, who has not only dealt with student quibbles over a fraction of a point, but has seen the clear disconnect among students between the assessments they are completing and the goal of learning. “Additionally, not every student wants an A. If I can clearly outline what a student needs to do to demonstrate a B or C performance, and they do not need to stress about points, everyone’s stress level can come down a bit.”

Incorporating Spaced Practice Across the General Chemistry Curriculum

While few faculty would probably be willing to do what Carpenter does in a course as large as CHEM 102, her efforts have not gone unnoticed. In fact, based largely on a 25-minute screencast video of her approach to using large question banks to administer online, “open note” exams during the pandemic (Fritz, 2020), many faculty in large, STEM courses have followed suit in developing and leveraging their own exam question banks. Additionally, four Biology faculty recently leveraged their own exam question banks – as well as student laptops and campus wifi – to turn a large ballroom used to socially distance students during the pandemic

into an ad hoc testing center to administer online exams when Spring 22 classes returned to campus (Fritz, 2022).

However, based on the results of her survey of CHEM 102 students who valued spaced practice in Spring 21 but struggled to implement it on their own in the Fall 21 instance of CHEM 351, she has imagined a longer runway of sorts in which students might be introduced to and become proficient with the method. Specifically, what if students were introduced to a light version of spaced practice in CHEM 101, immersed in it in CHEM 102 (as she is doing now with RealizeIt), and then guided or transitioned into a more self-directed or self-regulated approach in CHEM 351? To be sure, her chemistry colleagues would need to be “on board,” and the specifics of each approach would need to be fleshed out further, especially when only one of the three courses currently uses RealizeIt. But perhaps like Ebbinghaus’ ideal learning curve, maybe spaced practice is not something one can learn immediately but must be consciously and regularly implemented to be retained.

To help, as part of her 2022 UMBC learning analytics mini grant renewal (Fritz, 2022), Carpenter recently recorded a brief (36 min) workshop demo of why and how to set up spaced practice (see <https://youtu.be/ILJGSsBySyA>). She coordinated with the CHEM 351 instructors beforehand, and the optional workshop was offered to any students currently enrolled in the Fall 22 version of CHEM 351, including those she taught in CHEM 102 in Spring 22. About 100 students attended.

Conclusion

Throughout Carpenter’s teaching career, the key pedagogical challenge she has strived to overcome is moving new students from being primarily extrinsically motivated (for points) to become more intrinsically motivated (to learn how they learn). Doing so at the scale of her

typical course enrollments is challenging. And yet, while her spaced practice innovation did not appear to significantly change CHEM 102's Fall 20 to Fall 21 DFW rate, which is a typical metric used to gauge effectiveness of student success interventions, it is remarkable that the *distribution* of the course's higher grades did change significantly – and dramatically. Not only were there more As and fewer Cs in Fall 21 than Fall 20, but students of color were 4x more likely to have earned them, which is remarkable in a high-enrollment gateway STEM course at a public university.

So, what is it about the design of Carpenter's course, exam and practice environments that might be working for more students? We are continuing to explore this question, which has also been supported by a small grant from Every Learner Everywhere to promote "Equity in Digital Learning," which Carpenter has participated in. Again, one group of students Carpenter is especially interested in helping, regardless of background, are those who actually do put in the effort and time on task in the learning environments she designs, but still do not perform well. She fears they'll become discouraged and give up, but firmly believes these students need to focus more on their metacognitive "thinking about their thinking" skills.

"I tell these students to learn – not just memorize – as if they were going to teach the course," says Carpenter. "It isn't just that they need to practice, prepare, or calculate better. They need a different mindset about what they're being asked to do, especially if problem variables or context change from what they saw in practice."

Indeed, as McGuire might suggest, improving students' abilities – and motivation – to honestly and accurately assess what they currently know, understand, or can do could be the ultimate expression of improving their metacognition.

Finally, one benefit of higher education's pandemic-pivot to digital learning may be more faculty becoming savvier and more capable of expressing their pedagogy and course design at scale, regardless of the course's delivery or mode of instruction. Interestingly, despite it becoming more possible to return to campus, Carpenter, and many of her UMBC faculty colleagues who developed large exam question pools are continuing to offer their exams online. Well, if it is relatively easy for faculty to develop large numbers of exam questions to assess students, could it even become trivial for them to do so to help students practice and prepare for them, too?

Indeed, UMBC Physics Lecturer Cody Goolsby-Cole, who also received a 2022-23 UMBC learning analytics mini-grant (Fritz, 2022), leveraged his own LMS question banks to create practice questions that were ungraded, in terms of points contributing to a final grade, but including correct and incorrect answers displayed to students. During the first six units of his Spring 22 course, PHYS 122 "Introductory Physics II," he found students earning a 70% on the practice questions earned an average of 92% on the exam that followed. Students who did not use practice questions earned an average exam grade of 77%. He plans to build out and assess this practice environment further, including practice exams, to see if and how more students might use and benefit from it.

If we could create learning environments in which faculty can model and assign both exam and practice questions -- with good feedback for each, and maybe even adapted to students' specific, demonstrated weaknesses -- then students could get more exposure to the mindset and skills needed to also demonstrate and improve their own self-regulated learning by creating more predictable and effective exam practice. Perhaps we could also begin to encourage students to not only predict likely exam questions -- based on their experience in the course up to

that point – but also predict the likely, plausible answers, something we have dabbled in for another course (Braunschweig & Fritz, 2019). In this context, students could also be encouraged to "compare notes" with peers, which might take some of the exam prep burden off of faculty alone via exam reviews, etc. If so, this could illustrate the highest form of Bloom's taxonomy where students create a learning artifact with knowledge and skills they've applied from adaptive practice and exam learning environments.

All we'd need next is a Holodeck!

References

- Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching*. John Wiley and Sons.
- Bass, S., Carpenter, T., & Fritz, J. (2021a, May 18). *Promoting Academic Integrity in Online, Open-Note Exams without Surveillance Software*. ELI Annual Meeting, Online.
<https://events.educause.edu/eli/annual-meeting/2021/agenda/promoting-academic-integrity-in-online-opennote-exams-without-surveillance-software>
- Bass, S., Carpenter, T., & Fritz, J. (2021b, October 27). *Promoting Academic Integrity in Online: "Open Note" Exams without Surveillance Software* [Poster]. Educause Annual Conference, Philadelphia.
<https://events.educause.edu/annual-conference/2021/agenda/promoting-academic-integrity-in-online-open-note-exams-without-surveillance-software>
- Braunschweig, S., & Fritz, J. (2019, March 1). *Encouraging Student Metacognition by Predicting Exam Q&As* [Poster]. Provost's Teaching & Learning Symposium, UMBC.
<https://umbc.box.com/exampredictposter>
- Carpenter, T. S. (2022, March 10). *Do students carry lessons learned to the next course?*
<https://doit.umbc.edu/analytics/community/events/event/101268/>
- Carpenter, T. S., Beall, L. C., & Hodges, L. C. (2020). Using the LMS for Exam Wrapper Feedback to

- Prompt Metacognitive Awareness in Large Courses. *Journal of Teaching and Learning with Technology*, 9(1), Article 1. <https://doi.org/10.14434/jotlt.v9i1.29156>
- Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin*, 132(3), 354–380. <https://doi.org/10.1037/0033-2909.132.3.354>
- Davidson, C. N. (2012). *Now you see it: How technology and brain science will transform schools and business for the 21st century*. Penguin Books. <https://www.penguinrandomhouse.ca/books/306330/now-you-see-it-by-cathy-n-davidson/9780143121268>
- Dunlosky, J., & Rawson, K. A. (2015). Practice tests, spaced practice, and successive relearning: Tips for classroom use and for guiding students' learning. - PsycNET. *Scholarship of Teaching and Learning in Psychology*, 1(1), 72–78.
- Dziuban, C., Howlin, C., Johnson, C., & Moskal, P. (2017, December 18). An Adaptive Learning Partnership. *EDUCAUSE Review*. <https://er.educause.edu/articles/2017/12/an-adaptive-learning-partnership>
- Dziuban, C., Howlin, C., Moskal, P., Muhs, T., Johnson, C., Griffin, R., & Hamilton, C. (2020). Adaptive Analytics: It's About Time. *Current Issues in Emerging ELearning*, 7(1). <https://scholarworks.umb.edu/ciee/vol7/iss1/4>
- Dziuban, C., Moskal, P., Parker, L., Campbell, M., Howlin, C., & Johnson, C. (2018). Adaptive Learning: A Stabilizing Influence across Disciplines and Universities. *Online Learning*, 22(3), 7–39.
- Ebbinghaus (1885), H. (2013). Memory: A Contribution to Experimental Psychology. *Annals of Neurosciences*, 20(4), 155–156. <https://doi.org/10.5214/ans.0972.7531.200408>
- Fritz, J. (2020, October 29). Promoting Academic Integrity in Online Testing. *UMBC Division of Information Technology*. <https://doit.umbc.edu/news/?id=97023>
- Fritz, J. (2021, July 22). Five Faculty Receive UMBC Learning Analytics Mini Grants. *UMBC Division of Information Technology*. <https://doit.umbc.edu/analytics/news/post/111234/>

- Fritz, J. (2022, March 3). Four Biology Faculty Give 1st Exam In-class AND Online. *UMBC Division of Information Technology*. <https://doit.umbc.edu/post/117418/>
- Fritz, J., Penniston, T., & Sharkey, M. (2022, February 17). *How do UMBC Course Designs Correlate to Final Grades* [Show & Tell]. Learning Analytics Community of Practice, UMBC. <https://tinyurl.com/umbclacop021722>.
- Fritz, J. (2022, October 21). 2022-23 Learning Analytics Mini Grant Recipients Announced. *DoIT News*. <https://doit.umbc.edu/post/128655/>
- Fritz, J., Penniston, T., Sharkey, M., & Whitmer, J. (2021). Scaling Course Design as a Learning Analytics Variable. In *Blended Learning Research Perspectives* (1st ed., Vol. 3). Routledge. <https://doi.org/10.4324/9781003037736-7>
- Gray, J., & Lindstrøm, C. (2019). Five Tips for Integrating Khan Academy in Your Course. *The Physics Teacher*, 57(6), 406–408. <https://doi.org/10.1119/1.5124284>
- Hodges, L. C. (2015). *Teaching Undergraduate Science: A Guide to Overcoming Obstacles to Student Learning* (1st ed.). Stylus Publishing (Kindle Edition).
- McGuire, S. (2017, September 22). *Get Students to Focus on Learning Instead of Grades: Metacognition is the Key!* 4th Annual Provost's Teaching & Learning Symposium, UMBC. <https://fdc.umbc.edu/programs/past-presentations/>
- McGuire, S., & McGuire, S. (2015). *Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation* (Kindle Edition). Stylus Publishing. <https://sty.presswarehouse.com/books/BookDetail.aspx?productID=441430>
- McGuire, S., & McGuire, S. (2018). *Teach Yourself How to Learn*. [Stylus Publishing \(Kindle Edition\).
https://styluspub.presswarehouse.com/browse/book/9781620367568/Teach-Yourself-How-to-Learn](https://styluspub.presswarehouse.com/browse/book/9781620367568/Teach-Yourself-How-to-Learn)
- Miller, M. D. (2014). *Minds online: Teaching effectively with technology*. Harvard University Press. <https://www.hup.harvard.edu/catalog.php?isbn=9780674660021>
- Munday, P. (2016). The case for using DUOLINGO as part of the language classroom experience. *RIED*:

- Revista Iberoamericana de Educación a Distancia*, 19(1), 83–101.
<https://doi.org/10.5944/ried.19.1.14581>
- Murre, J. M. J., & Dros, J. (2015). Replication and Analysis of Ebbinghaus' Forgetting Curve. *PLOS ONE*, 10(7), e0120644. <https://doi.org/10.1371/journal.pone.0120644>
- Nilson, L. B. (2015). *Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time*. Stylus Publishing.
<https://styluspub.presswarehouse.com/browse/book/9781620362426/Specifications-Grading>
- Nilson, L., & Zimmerman, B. J. (2013). *Creating self-regulated learners: Strategies to strengthen students' self-awareness and learning skills*. Stylus Publishing.
- Weimer, M. (2002). *Learner-centered teaching: Five key changes to practice*. John Wiley & Sons.