die hochschul*lehre*
Interdisziplinäre Zeitschrift für Studium und Lehre

die hochschul*lehre* – Jahrgang 7-2021 (4)
Herausgebende des Journals: Ivo van den Berk, Jonas Leschke, Marianne Merkt, Peter Salden, Antonia Scholkmann, Angelika Thielsch
Dieser Beitrag ist Teil des Themenheftes *Evidenzbasierte Hochschullehre – Verbindungslinien zwischen Forschung und hochschuldidaktischer Praxis* (herausgegeben von Martina Mörth, Julia Prausa, Nadine Bernhard und Rainer Watermann).
Beitrag in der Rubrik Forschung
DOI: 10.3278/HSL2104W
ISSN: 2199–8825 wbv.de/die-hochschullehre



# Motivating durable learning through instructional design. Keynote held at 49. Annual Conference of the German Association for Educational Development (dghd2020)[1]

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## Abstract

What are the cognitive principles that improve training, teaching and learning? Learning begins with effortful and focused attention. This is both a conscious decision made by students and an important consideration for instructional design. In this article, I will discuss the "big three" study strategies (retrieval practice, interleaving and spacing) that have emerged from research in controlled lab and intervention studies in the classrooms. These strategies work together to directly set the stage for durable learning.

**Keywords:** Durable learning; attention; retrieval practice; interleaving; spacing effect

## Durch Lehr-Lern-Planung nachhaltiges Lernen fördern. Keynote auf der 49. Jahrestagung der Deutschen Gesellschaft für Hochschuldidaktik (dghd2020)

### Zusammenfassung

Welche kognitiven Grundlagen verbessern nachhaltiges Lehren und Lernen? Lernen beginnt mit bewusst gesteuerter und fokussierter Aufmerksamkeit. Das ist sowohl eine bewusste Entscheidung der Lernenden als auch eine wichtige Überlegung für die Gestaltung der Lehre seitens der Lehrenden. In diesem Artikel werde ich die „großen drei" effektiven Lernstrategien (aktives Wiederholen, inhaltlich verschachteltes Lernen und zeitlich verteiltes Lernen) diskutieren, die sich aus Forschung in kontrollierten Labor- und Interventionsstudien in Schulklassen und Lehrveranstaltungen herauskristallisiert haben. Diese Strategien ergänzen einander und schaffen die Voraussetzungen für dauerhaftes, nachhaltiges Lernen.

**Schlüsselwörter:** Nachhaltiges Lernen; Aufmerksamkeit; aktives Wiederholen; inhaltlich verschachteltes Lernen; zeitlich verteiltes Lernen

1 Transcribed and revised for publication by Martina Mörth

# 1 Supporting students to become lifelong learners

## 1.1 Challenges for instructors and students for durable learning

I am a professor of psychology, neuroscience and behavior at McMaster University in Hamilton, Ontario, Canada where I direct the Education & Cognition (EdCog) Lab. We are interested in studying attention, memory and learning in controlled lab settings. We are also interested in taking those findings and applying them to authentic learning conditions so that we can improve education and training through changes in instructional design. In addition to being a researcher, I am also a front-line instructor. I teach a large introductory psychology course with over 5,000 students enrolled each year. Personally, it is a real privilege to teach first-year students, because they are at the beginning of their academic journey and come in so excited and full of questions. My motivation is to help them to become critical consumers of information and lifelong learners. The bridge that connects my two roles in research and teaching is that I am trying to identify conditions that will lead to durable learning; that is, learning that endures beyond the upcoming quiz, beyond the final exam and perhaps even into the following years when there are other courses building upon foundations learned in my introductory psychology course.

On the first day of class, as I observe the students' nervous energy, I ask them to think about a time when they were not so concerned with grades and just wanted to figure out how things work. After a dramatic pause, I announce that I live with such a person. My daughter Monica is full of questions about how the world works. One day when she was about 6 years of age, she asked me one of those classic questions children ask their parents: "Does the light in the fridge go out when you close the door?" Rather than just reflexively giving her an answer, I challenged her: "I don't know, what do you think?" She thought about it for a moment and then, with a twinkle in her eye, said: "I don't know, but we are going to find out! Let's take everything out of the fridge, I will climb inside, you close the door and then I'll tell you what happens."

I loved this moment of pure curiosity. There was no grade assigned to solving this problem. She just wanted to figure out how things work. I tell my students to hold on to their intrinsic motivation for discovery, which will help them more than simply trying to memorize facts and use brute force methods to recall and recognize facts for a test.

The defining challenge for many students when they come to university is that they are expected to consume large volumes of information, across several different courses, and at a very different level and pace from high school. Whereas in the past, academic success was within reach by rote memorization, students soon learn that this strategy is no longer effective. As university instructors, we expect students to demonstrate what cognitive psychologists call *transfer of learning*: can students retain knowledge and demonstrate mastery by applying it to novel situations. With test questions that feature transfer of learning, you cannot simply memorize provided examples or definitions and hope to recognize them on the final exam. You really have to know what you are talking about.

Let's think about all the challenges that arise in a university course. How should instructors design their courses? How should students prepare for tests? The wrong decisions to these questions can lead to ineffective learning. These errors can be traced to the fact that humans (both instructors and students, alike) generally make poor metacognitive judgements about learning, especially about their own learning.

## 1.2 Intuitions about effective teaching influence educational practice

How do university instructors make decisions about how to teach their courses? Typically, they will teach courses the way they experienced teaching themselves. They rely on intuition and tradition to determine important pedagogical decisions about how they will design their course. Unfortunately, there are a number of misconceptions about learning that instructors hold on to. A good example is learning styles. That is the belief that you can psychometrically test your students and identify their preferred learning style like visual, auditory, kinesthetic – there are now dozens of other so-called learning styles identified (Deans for Impact, 2020) – and use this information to make critical decisions about teaching.

Teachers think that matching up their teaching to learning styles should lead to improved academic performance. On the surface, it's a sensible, almost meritocratic idea that *should* work. Unfortunately, there is no strong data supporting this idea (Pashler et al., 2008; Rohrer & Pashler, 2012; Kirschner & van Merriënboer, 2013). Nevertheless, even in the absence of scientific support, this concept remains highly influential. Learning styles and many other beliefs – like "people use only 10 % of their brains," "people do progress cognitively along a fixed progression of age-related stages," "people are right-brained or left-brained" – are not supported by data, but may still influence instructors to make decisions about their instructional resources.

### 1.3 The most popular learning strategies used by students are not the most effective

Let's think about the perspective that the students take to learn. What sort of study skills are commonly used to prepare for an upcoming examination? Dunlosky et al. (2013) conducted a meta-analysis of lab- and classroom-based studies to see the effectiveness of different methods used by students. The most popular methods that students choose include highlighting and rereading the notes and textbooks. These were the methods that students said that they relied on most heavily to prepare for an upcoming exam. Unfortunately, if you look across studies (ibd.), highlighting and rereading the notes or textbooks rate very low on actual utility.

Let's consider why students still might rely on this strategy. Imagine that you are a student, sitting at a desk, busy preparing for the exam, with your notes and textbook. You start with pages in front of you in one color and then after some amount of work you manage to change the pages into another color with a highlighter. At this point, it is clearly visible that hard work has taken place. In fact, you can feel good about seeing the direct evidence of physical labor, having changed the pages from one color to another! It feels good. You have put in the time, and there is a sense of *fluency* that you even feel as you can read these same sentences faster and faster. The danger is that it is very easy to confuse this newfound fluency, with true understanding. It can lead to the conclusion that you must really actually understand what you have been rereading over and over again, even if it is only a very surface level of understanding and the actual effort put in was very passive (Kornell & Bjork, 2007).

As I mentioned, the common link in my roles as a researcher and educator is trying to figure things out: The cognitive principles that improve training, teaching and learning that lead to durable learning that will stick with the students. In the remainder of the article, we will discuss two topics. First, learning begins with effortful and focused attention. Second, the big three study strategies directly set the stage for learning.

## 2 Learning begins with effortful and focused attention

This may seem like an obvious point, but I do want to spend some time considering that learning begins with effortful and focused attention. This is a conscious decision of the student, and it is also something that the instructor really needs to pay attention to themselves so that they can meaningfully direct the focus of attention in class.

### 2.1 Thinking deeply and slowly instead of fast and reflexively

In the book *Thinking, fast and slow,* Daniel Kahnemann (2011) summarizes a lifetime of research on human decision-making. If you want to learn more about how the mind works, this book is a very interesting read. He uses the metaphor of two different systems of thinking. There is system one, which is fast and automatic, unconscious, and there is system two, which is slower and more effortful. What I try to get students to engage in when they are studying in class is this system-two thinking. I want them to think deeply and I want them to think slowly.

An activity I propose on the first day of class is that I challenge my students with a question from the cognitive reflection test. There are three questions in this test, but I will just show you one question today:

> "I would like you to answer the following question. I would like you to pay attention and to think through slowly and come up with the answer to this question:
> A bat and ball together cost 1.10 dollars.
> The bat costs one dollar more than the ball.
> How much does each item cost?"

The feel-good, automatic, system-one answer would be "1 dollar and 10 cents", but that is incorrect! This actually results in a 90 cents difference. The correct answer is "5 cents and 1.05 dollars". How do we make this calculation? If the bat costs 1 dollar more than the ball, we are left with 10 cents (1.10 minus 1 dollar). We should then divide the difference of 10 cents between the two items: 5 cents for the bat and 5 cents for the ball, leaving us with 1.05 for the bat (1 dollar plus 5 cents) and 5 cents for the ball.

Although it's not a taxing math problem for university students, typically half of the class gets it wrong! After the explanation everyone understands. Then I ask the students: "If I ask this question on the final exam, would you get it right?" Everyone nods their heads – yes. But remember, I want students to demonstrate transfer of learning. I am not going to test their ability to memorize this specific example. I want them to apply their understanding in a novel context. So, I follow-up next with this question:

> "A BMW and a Tesla together cost 160,000 dollars.
> The BMW cost 100.000 dollars more than the Tesla.
> How much does each car cost?"

If you understood my explanation of the previous problem, this is the same question in a different context. The answer should be simple, but at least a good portion of the students still gets this question wrong! I hope this makes the point to my students that I really want them to think slowly and put effort into focusing their attention.

## 2.2 Divided attention leads to reduced gains in learning for self and peers

Distractions concern not just the individuals, but the entire class as a whole. This is an important point that we as a learning community all have to buy into. In her study, my collaborator Farina Sara (Sana et al., 2013) invited students to a lecture hall to listen to a lecture. They were taking notes and they were told that at the end of this lecture there would be a test. Throughout the lecture hall, there were some confederates, who were in on the experiment. They had a computer in front of them, and every once in a while the confederates started multitasking. They might send a message, check on Facebook, send an e-mail and then go back to paying attention to the lecture. The question here is: what is the impact of these multitasking peers on the rest of the participants of the lecture? Just by where they were sitting, some of these participants were in direct view of a multitasking peer, whereas other participants were not. We can compare these two groups on how well they did on a comprehension test at the end of the lecture.

We can see that there is a significant difference in comprehension just by having a view of someone who is occasionally multitasking and distracted in the lecture (cf. fig. 1). Participants with a view of a multitasking peer during the lecture scored significantly lower than participants with no view. A multitasking peer has a direct impact on the other learners. The point here is for the entire learner community in a lecture hall to actively choose to focus attention and be present for this time that we have agreed to come together. Sana et al. (ibd.) discuss these important issues in the classroom.

It does take effort to refrain from multitasking and focus on the lesson to be learned. This ability to *not* check your email and *not* go online at least for a while is an example of self-regulation. As a parent (and as a psychologist), I really appreciate the importance of self-regulation and it influences some of my parental decisions. A famous experiment called the marshmallow test (Mischel et al., 1989) measures self-regulation in children. You can offer a four-year-old one delicious marshmallow now or if she can wait 15 minutes, she gets a second marshmallow. This takes some self-regulation. You have to wait out the temptation of the immediate gratification of that instant marshmallow to benefit from the delayed reward. I tell my students: if a four-year-old can wait for 15 minutes, surely you can, too! If you can learn to wait 15 minutes, 30 minutes, perhaps an hour, there is a lot that you can get done single-tasking as opposed to multitasking.

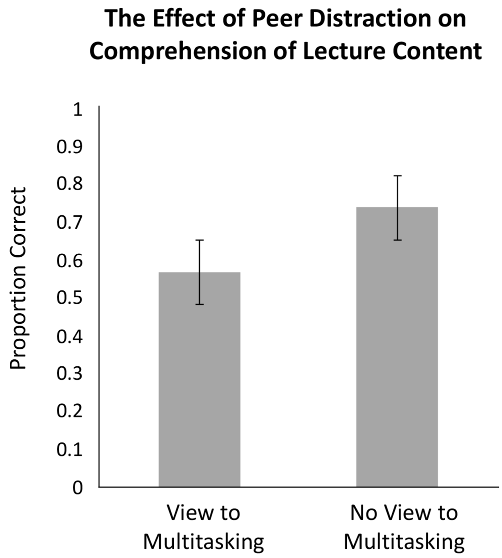


**Figure 1:** The effect of peer distraction on comprehension of lecture content (error bars represent standard error of the mean; n = 20 students per group; cf. Sana et al., 2013)

However, there is another challenge. During extended study periods (for example during a lecture) even if you start off with very high levels of attention, motivation and energy, they will naturally drop with the more time you spend on a task. One way we can measure reductions in attention is by determining the propensity for mind-wandering. Mind-wandering is a shift in attention away from a primary task towards unrelated secondary thoughts. At some point during a task, (the point indicated by the arrow in figure 2, after 40 or 50 minutes, with individual differences) there can be diminished returns. Even though you continue to invest time and effort, you will get less return on your investment. This might be an ideal time for a strategic break in a lecture for an active learning exercise, like a low-stakes quiz, discussion point, or demonstration (cf. Pachai et al., 2016).

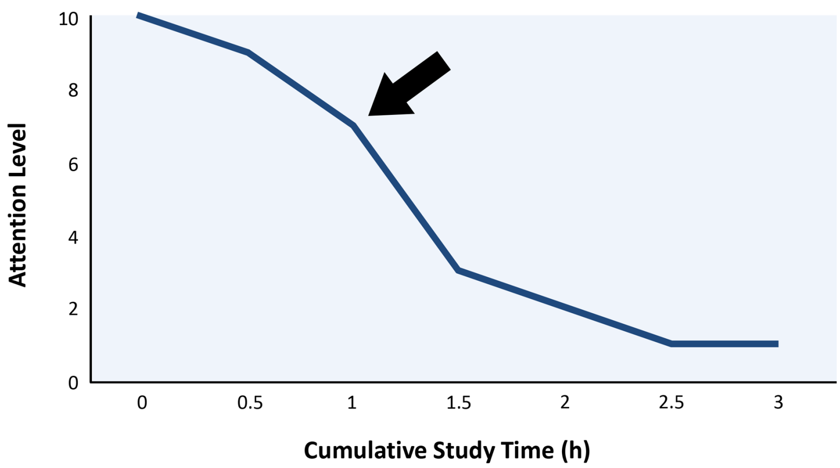


**Figure 2:** Drop in attention over time (Pachai et al., 2016)

## 2.3 Interaction between physical exercises and cognition

Think about a scenario in which there is a very long study or teaching session, for example, a three-hour-class in the evening. Typically, during these classes teachers give students two options: They can either have a couple of breaks and end at the scheduled time, or they can skip the breaks to push through and leave class earlier. The most popular answer as voted by the class typically is the second option, and people are challenged with trying to maintain attention through 2.5 hours without a break.

One area that we have been interested in is the idea of introducing strategic breaks especially during sustained study or learning periods. What should you do during a break? One type of break that we have been interested in is exercise breaks. Our research shows exercise breaks increase arousal. This is leading to better-focused attention. If you pay better attention there is a greater chance that you can encode information for long-term retention.

In one study (Fenesi et al., 2018) we had students of our introductory to psychology course study the course material for one week throughout 50-minute computer-based video lectures. The content of the course material was the neuroscience of form-perception, an area that students typically find to be quite challenging. The first group did not have a break. They just had to keep studying (*no-breaks group*). The second group had three strategic breaks to break up this extended study period. They got three 5-minute breaks during which they got to do something that they enjoyed: They played a computer game (*non-exercise-breaks group*). A third group, during the same breaks instead of playing the computer game, had to engage in exercise: in this case, it was High-Intensity Interval Training (HIIT) (*exercise breaks group*).

We measured students' ability to pay attention while they were supposed to be engaged in studying. The typical pattern for a group that had *no breaks* was a decline in attention from the first half to the second half of the study. The *non-exercise-breaks group* similarly showed a decline from the first to the second half of the study. Interestingly, these rewarding breaks had no impact on helping them to pay better attention during their study. However, the *exercise-breaks group* was able to maintain their attention from the first to the second half of the study (cf. fig. 3a).

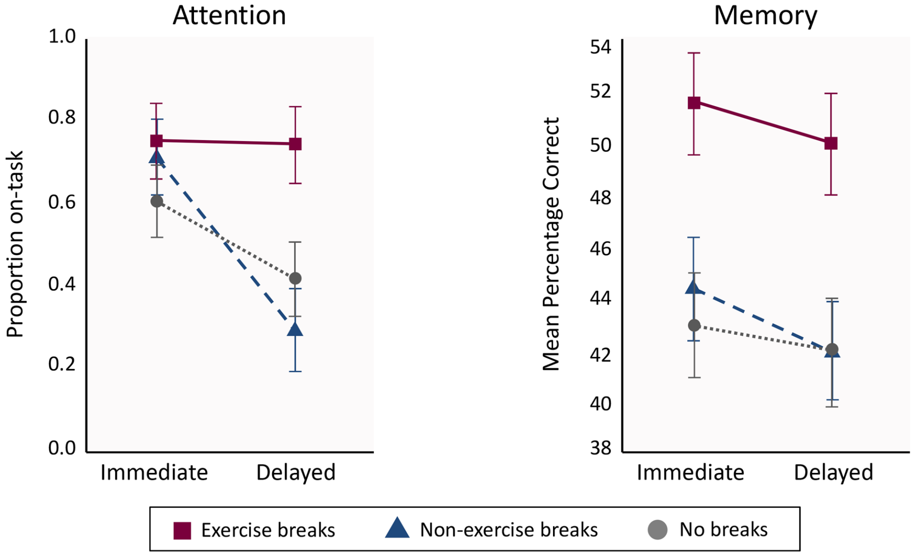


**Figure 3a and 3b:** Exercise breaks increased on-task attention (a) and improved memory (b) (Fenesi et al., 2018)

In this study, we were interested in seeing how better attention impacts memory. We gave students a comprehension test immediately after the study and brought them back to the lab two days later to see if there is a long-term effect on memory retention. We can see that the *no-break group* and *the non-exercise group* performed similarly. Groups who had the exercise breaks with HIIT training significantly outperformed the other groups immediately as well as two days later (cf. fig. 3b).

There are many open questions remaining, including, what is the minimal dose of effective exercise that could be interleaved with study to have this effect on attention, or, in other words, must it be the challenging HIIT? There are various examples of exercise and other breaks that would be interesting to examine including a stretching type break, socializing, nutritious snacks, mindfulness training, etc. Perhaps what good breaks have in common is that they are restorative in nature. When some of my faculty members are working all morning and for the lunch break, they are eating their lunch at their desks answering emails, I tell them that's probably not a true restorative break. They would be better off by actually changing the context and making a real break, coming back refreshed and having a better chance of focusing their attention in the afternoon.

In sum, we can say that learning begins with effortful and focused attention. Maintaining effortful and focused attention increases in difficulty with time on task. Some of our research suggests that to make studying and learning an active process, we might want to introduce activities such as active learning processes, quiz questions and in the case of very long learning sessions, including restorative breaks. One of the reasons we think exercise might be a good type of break is that it is a context shift, not just switching between one cognitive task to another. There might be some restorative aspect to the exercise break itself (cf. also Hayes, 2020).

## 3 The big three cognitive principles for durable learning

There are three study strategies that directly set the stage for learning. These strategies have emerged from controlled lab- and intervention studies in classrooms. I am talking here about *retrieval practice*, *interleaving* and *spacing*, and how they can work together to lead to durable learning.

### 3.1 Retrieval practice: to consolidate the initial memory

Students really like to read and reread (Dunlosky et al., 2013). In the experiment of Roediger and Karpicke (2006b) students had to read short passages. In one condition, they had to read the same passage once and then come back, read it again for five minutes, come back a third time and read it again for five minutes and finally come back a fourth time and read it again for five minutes (*SSSS-condition*). In a second condition, they read the same passage three times and on the fourth occasion, they had to practice retrieving the key points and concepts from that reading (*SSSR-condition*). In a third condition, students read that passage once and then they had to come back and practice retrieving the key points three additional times (*SRRR-condition*). Importantly here, the total time on a task was equal across all three conditions. One week later, when these students were tested, the research team could see which of these three strategies led to the best long-term retention.

If you ask the students to predict their results, they will think that they remember more of the passage that they read four times than the content of the passage they only read three times, and certainly more than the passage that they only read once. This makes intuitive sense with their chosen study habits. But, if you look at the actual final test performance, the passages they read four times (SSSS), were recalled only at 39 %, the passages with one retrieval practice (SSSR) were recalled at 57 % and when they practiced retrieving on three occasions (SRRR) the final test performance jumped up to 65 %.

This is the basic paradigm for *retrieval practice*, also known as the *testing effect*. There is some initial lesson, a final test and we can compare the benefits of simply restudying (S) or rereading the material to practicing retrieving that memory (R). This effect is a very robust and general phenomenon that has been demonstrated across a variety of different educational materials and academic programs (Cepeda et al., 2006; Carpenter & Pashler, 2007; Carpenter et al., 2009; McDermott et al., 2014; Agarwal et al., 2019). But why is the practicing of retrieval so important for learning, and how might retrieval practice work in a classroom? To answer the first question, we can state that testing directs attention to relevant information. When students are simply studying, they are focusing on rereading, which puts an emphasis on the input of information. This is surely a necessary part of learning, but many students fail to pay attention to any of the output of information. In the worst-case, the day of the test is the first time when they have to actually practice retrieving that information. Instead, building in retrieval practice during study engages some of the same cognitive processes that will be used during the final test, when they do have to retrieve this important information. At a theoretical level, retrieval of a memory itself helps to increase the strength of that memory for later recall and overall enhances the retention of that information (Roediger & Karpicke, 2006a).

Many different types of studies across controlled lab and classroom intervention studies have identified key factors critical for durable learning:

- Including retrieval practice in classes directly sets the stage for durable learning. Instructors can try to build in retrieval practice directly into their lessons, for example by using I-Clickers (Keough, 2012; Zhu & Urhahne 2018). I like to start off my lecture by asking students, what were the most important points that we talked about last lecture. Each student has time to think of the questions and answers them with his or her I-Clicker. I try to build that connection into our previous lesson.
- Repeated retrieval practice augments the benefit. The more retrieval you have, the better is the benefit for long-term retention of that information.
- Study sessions that include repeated retrieval practice can strengthen long-term retention.

Making errors is not a problem, since an important part of this would be to get corrective feedback so that they can pay attention to the actual correct solution and have a better strategy in the future. Also, the format of the retrieval practice does not really seem to matter. Using a variety of methods that challenge students probably leads to the best results. Especially encouraging is that evidence shows that the retrieval benefits are not limited to retention of the actual retrieved information, but also to all of the connected information around the tested concepts. Retrieving key concepts helps to retrieve directly and indirectly all concepts that are connected (Rohrer et al., 2010) and can even enhance the learning of subsequently presented new information (Pastötter & Bäuml, 2014).

## 3.2 Interleaving: to discriminate problem-solving methods

The second cognitive principle I want to talk about is *interleaving,* which can help students to discriminate different problem-solving methods. Imagine the following assignment (Kornell & Bjork, 2008): You have to learn to distinguish between the different artistic painting styles for a number of different artists. There are two different ways you can learn this. In one method I show you six samples from an artist called Pessani and then six samples from an artist named Wexler and then six different paintings from an artist named Hawkins and so on. This would be the *blocked method*. I am blocking all the samples by a specific artist. I can compare that with a different scenario called a *mixed set-up*, where I show you the paintings interleaved, all mixed up. You see one by Pessani, one by Wexler, one by Hawking, one by Cross, etc. In the blocked and mixed conditions, you will see the same total number of examples. The only difference is whether they are blocked by artist or all mixed up together.

On the final test, you are going to see some novel paintings. We want to see your ability to transfer your knowledge. You will see paintings you have not yet ever seen, and your job is to figure out which of the artists that you learned about had painted this particular novel example. If I asked which of these two methods one would prefer, most people would choose the blocked method. The blocked method feels right. Most textbooks are structured in a blocked way. When you are learning math and you are learning about fractions, all your practice questions are about fractions. In the study mentioned above the participants were asked, which of these two methods they thought would work better. Not surprisingly, most participants said "the blocked one." However, using the blocked method, participants performed at 35 % on the final test, while those who had to go through the much more difficult mixed or interleaved process significantly outperformed the others with 61 %, even though they had the same total number of trials.

Interleaved practice has been demonstrated to provide a better form of long-term retention across a variety of research paradigms (Carpenter & Mueller, 2013; Foster et al., 2019; Rohrer et al., 2015; Sana et al., 2017). Interleaved practices promote what is called *discrimination-based learning* (Rohrer, 2012; Sana et al., 2017). As you move from one practice question to another across concepts you have opportunities to compare and see what makes this concept the right answer to a particular type of practice question. In the blocked method, you become fluent by practicing the same concept A or B over and over again, which feels good but does not promote discrimination-based learning.

In practice, university studies are often organized as blocked rather than as interleaved study. Students who learn statistics, learn about the t-test and they do all the practice questions about the t-test and they become really good at answering this type of question. The next week they might learn about ANOVA and they do a bunch of practice questions about the ANOVA and they get really good at that. They become fluent. But the problem is that they do not really have opportunities to understand when a t-test or a different type of statistical test is appropriate! The real challenge typically is which type of statistic should I use in a given scenario: Here you have a novel data set – what actual test should I use? The act of choosing a strategy or concept is often the key to solving the problem. Students might learn to execute a strategy and make the calculation, but the real strength and the real challenge is choosing that strategy (Rohrer et al., 2014). A solution for learning math and statistical concepts would be to build-in interleaved practice assignments (for example, Foster et al., 2019; Rohrer et al., 2015). So, when a student completes chapter 2, assignment questions may focus on the calculations from chapter 2, but also include some questions which require calculations from chapter 1. This built-in interleaving promotes discrimination-based learning in practice. One modification that can be used to ease students into the process would be to use some sort of hybrid schedule, where you might start off with some blocked practice, but make sure that you actually build in interleaved practice as well. So, students have a chance to study and practice previously learned concepts (Yan et al., 2017; Yan & Sana, 2020).

### 3.3 Spacing: to strengthen long-term retention

Let's come to the third cognitive principle for durable learning: the *spacing effect*. Kornell (2009) compared one group of students who condensed their study to eight hours on one day to another group who studied the exact same hours, but spaced out their total study to two hours on each of four days. Although the total time on the task was constant between the two groups, the second group which spaced out study time performed significantly better than the first group on a final test. The spacing effect examines the optimal period between an initial study period and a final test with a variable retention interval between the retrieval event and the test.

Generally, having more spaced retrieval events seems to be important (Kornell, 2009). Depending on how long that retention interval is (1 week, 1 month, or 1 year), the optimal spacing effect seems to be about 10 to 20 percent of that retention interval (Cepeda et al., 2006). If you need to be able to retrieve information one week from now, an optimal spacing period between retrieval practices would be one day. If there is critical information that you must be able to recall with accuracy one year from now, ideally you can build this expanded schedule up to a two-month period. If students are to be able to transfer main concepts from an introductory lecture after finishing their degree, they should have the possibility to retrieve them in subsequent lectures within the curriculum. This spacing effect has been demonstrated across many types of research paradigms (Carpenter et al., 2012).

But why does spaced studying promote durable learning? Remember when you study, things become very fluent. An important part of refining your memory is that there is some forgetting of details between one studying event and the next. While you are retrieving the details, until the next retrieval event, there is some forgetting and then you have to practice retrieving those specific memories, whereas if you take the same total amount of study time and you amass it into one study period, there is no opportunity for any forgetting of details. Instead, you might just come away with the sense of fluency mentioned above.

Translational research has identified key factors critical for durable learning:

- Including spaced reviews in classes directly sets the stage for durable learning. Spaced reviews in class are something that I try to incorporate across my teaching. I have recurrent themes in various different lectures and so we revisit concepts across the term. I try to build parallels and

connections across the entire course. An optimal period might be about 10 to 20 percent of that final retention interval. Depending on when you need to actively retrieve that information.
- Attention remains elevated due to effortful retrieval during spaced practice.
- Study sessions, if organized and planned beforehand, can strengthen long-term retention: One type of schedule students can use is an expanded spaced study schedule. What we are trying to do with that is to alter the trajectory of our forgetting curves (Ebbinghaus, 1885): Your initial time to retrieval period is short and then you can start expanding that up to 10 to 20 percent of the final retention interval. With the passage of time, you forget some of the details of what you have learned, and then you can have a first reminder that helps you to recall that information. Then you can delay the next retention interval further and further and expand the schedule if our goal is to retain the information for a very long period from our current session.

### 3.4 How can we combine interleaving, spacing and retrieval to promote learning?

In a classroom-based study, students were engaged in 10 different practice assignments over 10 weeks (Rohrer et al., 2014). After a delay of two weeks, there was a surprise test on all the concepts that were tested across these assignments. There were two different types of assignments: Some of these assignments were blocked. So, students only learned about concept D. Some of these weekly assignments were interleaved: While you were learning concept D, the practice forms you got were about concept D, but they also brought in questions about concepts A, B and C. Fig. 4a shows an example of this interleaved practice assignment, where students were learning about percentage. The first five questions of this assignment were about percentage. The remaining eight practice problems drew upon questions from previously learned lessons. They required strategies the students learned in previous lessons.

If we look at the data on the surprise test where students were tested on all the concepts, we can see that students performed significantly better on concepts that were taught using the interleaved assignments than on concepts they were taught only with the blocked assignment (fig. 4b).

Four problems on the current lesson (i.e., same strategy)

1. What number is 25% of 52?
2. What percent of 72 is 18?
3. What percent of 140 is 7?
4. What number is 10% of 90?
5. Graph the equation. $y = 3x + 1$

One problem on each of 8 previous lessons (i.e., different strategies)

6. Find the area of a circle with radius π.
7. Solve for $x$. $9(1 + x) = 5(x + 9)$
8. Find the slope of a horizontal line.
9. Simplify. $(-5)^3$
10. Simplify. $3(4 + 2) - 7$
11. Simplify. $2\frac{1}{5} \div 3\frac{1}{3}$
12. Simplify. $\frac{3}{8} - \frac{1}{5}$

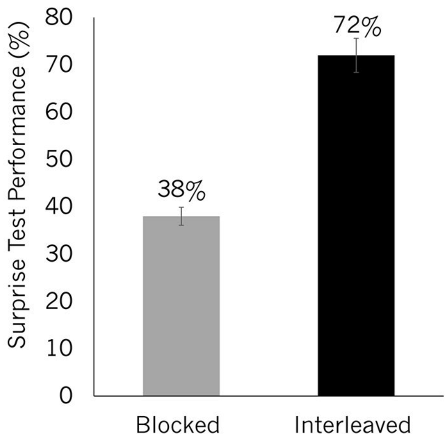


**Figure 4a and 4b:** An example of a combined spaced and interleaved practice assignment (4a). The test performance of the interleaved assignment was significantly better than in the blocked assignment (4b) (cf. Rohrer et al., 2014)

## 4 Similarity with habits leading to a healthy lifestyle

At the end of this keynote, I would like to draw your attention to the similarity between learning habits and habits, which lead to a healthy lifestyle. I am sure you can think of a number of things you should do for a healthy lifestyle: Eat healthy, sleep enough and regularly get some physical exercise, etc. But are you actually doing these things regularly by yourself? You might not actually be doing them. If you ask a human being: Do you want to do something more difficult or less difficult, they often choose the less difficult choice.

Even when students are convinced with data, that some learning practices are good, they sometimes need that extra little push. We are just human beings, and it is hard to do something that feels more difficult. In literature, it is called a "desirable difficulty" (Bjork & Bjork, 2011). That's why I am doing activities like the following: As students are preparing for a midterm exam I say: "There is a midterm in this class on Friday. I want you to get your calendar right now and see how much time you have left this week to prepare for this midterm." I want students to come up with some sort of number of hours available and commit to it. Next, I ask them to divide this number by three or four and then schedule these retrieval practice periods directly into their calendars, right now. Simple and silly as it sounds, but many students tell me that if they did not do this right then on the spot in the classroom, they would not have done it by themselves. With that extra little push, they did it, and now this strategy is something that they might try in their other courses as well.

There are these two different levels for other lifestyle habits. You know what you have to do to eat a healthy diet and to get enough physical exercise. But, if you were part of a group that meets three times a week or you had a personal coach, you definitely would be doing the exercises and you would be eating healthy. Students, I think, similarly need this extra push from their academic coach to moderate their habits.

Theoretically, our memory seems to have an infinite capacity. There is no reported case of a person's memory becoming completely full. The relevant questions are how you can make learning more efficient and how we can keep motivation high. Those seem to be the rate-limiting steps and the practical questions that we are trying to deal with. When I am talking to students, I tell them that I am trying to make their learning as efficient and enjoyable as possible. Students are very busy. I recognize that my course is not the only course that they are taking. Finally, I hope that the lessons that they are learning about durable learning will be used not only in my course but extend to their other courses, and indeed, start their journey as a life-long learner.

## Acknowledgement

The work cited from my research was completed in collaboration with my co-director of the Education & Cognition Lab, Dr. Faria Sana.

I would like to thank Martina Mörth, Berliner Zentrum für Hochschullehre (BZHL), for the transcription of the keynote and for assistance with preparing the manuscript.

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**Zitiervorschlag:** Kim, J.A. (2021). Motivating durable learning through instructional design. International Keynote held at 49. Annual Conference of the German Association for Educational Development (dghd). *die hochschullehre*, Jahrgang 7/2021. DOI: 10.3278/HSL2104W. Online unter: wbv.de/die-hochschullehre