Deans for Impact

THE SCIENCE OF LEARNING

Second Edition

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THE SCIENCE OF LEARNING

About **THE SCIENCE OF LEARNING**

The purpose of *The Science of Learning* is to summarize the research from cognitive science related to how students learn, and connect this research to its practical implications for teaching and learning. This resource identifies six key questions about learning that should be relevant to every educator. Deans for Impact believes that, as part of their preparation, every teacher-candidate should grapple with — and be able to answer — the questions in *The Science of Learning*. Their answers should be informed and guided by the existing scientific consensus around basic cognitive principles. And all educators, including new teachers, should be able to connect these principles to their practical implications for the classroom (or wherever teaching and learning take place).

The first edition of *The Science of Learning* was developed in 2015 in close collaboration with Dan Willingham, a cognitive scientist at the University of Virginia, and Paul Bruno, an education professor and former middle-school science teacher. This second edition of *The Science of Learning* was developed in partnership with Veronica Yan, a cognitive and educational psychologist at The University of Texas at Austin. We are greatly indebted to the reviewers who provided thoughtful feedback and comments on early drafts, including Janell Blunt, Emily Fyfe, Jim Heal, Dylan Kane, and Katherine Muenks.

This edition's updates include the addition of potential pitfalls that teachers should be aware of and a new section on supporting students to take charge of their own learning. Each of the preexisting sections have also been updated to reflect the most current research. *The Science of Learning* does not encompass everything that new teachers should know or be able to do, but we believe it is part of an important — and evidence-based — core of what educators should know about learning. We expect to periodically revise *The Science of Learning* to reflect new insights into cognition and learning.

About **DEANS FOR IMPACT (DFI)**

DFI is a national non-profit organization committed to ensuring that every child is taught by a well-prepared teacher. DFI supports educator-preparation programs to bring the science of learning into teaching practice; partners with policymakers to ensure pathways into teaching are instructionally-focused, practice-based, accessible, and innovative and responsive; and equips leaders with the tools to address today's most pressing challenges in educator preparation. Guided by principles of learning science, DFI aims to help aspiring and early-career teachers create rigorous and affirming classrooms where all children thrive.

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1 HOW DO STUDENTS UNDERSTAND NEW IDEAS?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
Students learn by connecting new knowledge to what they already know.[1]	• A well-sequenced, knowledge-rich, curriculum is important to ensure students have the prior knowledge they need to master new ideas.[2, 3, 4] • Teachers can prepare students for new learning by asking them to recall what they already know about related and foundational ideas; teachers can also prompt students with questions before learning to cue them to what relevant information they will need to attend to.[5] • Teachers can use analogies to map a new idea onto one that students already know. But analogies are effective only if teachers elaborate on them, direct student attention to how prior understanding is connected to what is to be learned, and attend to possible misconceptions the analogy might induce.[6, 7, 8, 9]	• Teachers should not assume that students having prior knowledge is enough. They should activate prior knowledge (e.g., through retrieval) and support students to integrate what they already know with new learning.[10]
Students have limited working memory capacity that can be overwhelmed if given too much information at once or if tasks are cognitively too demanding.[11]	• Making content explicit through carefully paced explanation, modeling, and examples can help ensure that students are not overwhelmed.[12] (*Note: "explanation" does not mean teachers must do all the talking.*) • Teachers can use multiple modalities to convey an idea (i.e., speaking while showing a graphic). If the two types of information complement one another (e.g., showing an animation while describing it aloud), learning is enhanced. If they are split (e.g., speaking aloud with different text displayed), attention is divided and learning is impaired.[13]	• Seductive details (non-essential words, pictures, sounds, "fun facts," funny stories) aimed at making content more interesting to students can backfire, by drawing attention away from the to-be-learned material. Visual and descriptive elements should

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1 HOW DO STUDENTS UNDERSTAND NEW IDEAS?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
	• Teachers can familiarize students with core components and terminology before launching into the full lesson. This can reduce cognitive load and make it easier to understand relationships and build mental models.[14] • Teachers can use "worked examples" - a step-by-step demonstration of how to perform a task or solve a problem - as one way of reducing cognitive load. Worked examples should be used to build conceptual understanding (e.g., by providing explanations for the steps), not just procedural copying (where steps are simply copied without thinking about why they work).[15]	help students understand underlying ideas and concepts being taught; they should not be merely decorative or fun.[16, 17, 18, 19]
Cognitive development does not progress in a fixed sequence at age-related stages. Understanding does not happen all at once or just one time; the mastery of new concepts happens in fits and starts.[20, 21]	• Content should not be kept from students because it is "developmentally inappropriate." This term implies there is a biologically inevitable course of development and that this course is predictable by age. To answer the question "is the student ready?", it's best to consider, "has the student mastered the prerequisites?"[3, 22]	• Teachers should not assume that learning something well one time is enough. Rather, they can make sure that foundational or prerequisite knowledge is reinforced periodically, even after moving on from the lesson.[23, 24]

2 HOW DO STUDENTS LEARN AND RETAIN NEW INFORMATION?

PRINCIPLE | **PRACTICAL IMPLICATIONS FOR THE CLASSROOM** | **PITFALLS TO BE WARY OF**

Principle

To learn, students must transfer information from working memory (where it is consciously processed) to long-term memory (where it can be stored and later retrieved). For long-term knowledge to be useful, students have to think about meaning. [25, 26]

Practical implications for the classroom

- Teachers can assign students tasks that require the students to explain (e.g., answering questions about how or why something happened) or meaningfully organize material. These tasks focus students' attention on the meaning of content, and encourage them to organize and connect it to what they already know.[27, 28]
- In using concrete examples to help students make sense of an idea or concept, teachers can (a) provide multiple, varied examples, and (b) give students opportunities to practice applying the information in multiple varied ways, so that students do not only understand the information in a single context.[29]
- For hard-to-remember content, teachers can help students learn to impose meaning through use of mnemonics (e.g., ROY G. BIV for the order of colors in a rainbow).[30]

Pitfalls to be wary of

- Teachers should not expect students to apply concepts meaningfully without appropriate prior knowledge or a well-designed prompt. Instead, teachers should support students to build background knowledge and provide clear prompts and task supports so students can apply concepts meaningfully.[31]
- Teachers should not assume that mnemonics are a replacement for meaning. Mnemonics act as an organizational anchor, laying the foundation to allow students to engage with the more difficult concepts that build on the facts contained within the mnemonics.

Principle

Practice is essential to long-term learning, but not all practice is equivalent. [32, 33, 34, 35]

Practical implications for the classroom

- Effective practice:
  - Is spaced out over time. Spacing intervals can be relatively shorter for newer information (e.g., hours or days) to maintain a higher level of success; as information becomes better learned, the spacing intervals can get longer (e.g., weeks and months).[36, 37]
  - Requires effortful thinking and overt retrieval (e.g., asking students to write down their own answer, self-quizzing, or teaching peers rather than just bringing something to mind). Retrieval from memory should be challenging but doable; students have to work to reconstruct the knowledge, and that effort strengthens the memory and makes it easier to access in the future.[38, 39, 40, 41]
  - Is interleaved (i.e., the order of different types of questions is mixed up) and cumulative (i.e., adds practice with new skills to previously learned material). Practice of newer and more complex concepts often benefits from some blocked practice (i.e., one problem type at a time) initially, but should move to interleaved, spaced practice once initial fluency is achieved.[42, 43, 44, 45]
  - Is varied. Having a lot of practice across different types of problems can help students develop fluent pattern recognition skills and strengthen retention.[46]

Pitfalls to be wary of

- Posing questions to the class and calling on a few volunteers to respond only ensures those few students have meaningfully engaged with the learning; teachers have no way of knowing if students who did not raise their hands have thought meaningfully about the content. Teachers need to engage each student in retrieving information from their own memories.[47]
- It is not effective for students to practice only recalling concept-term definitions.[48] If the teacher expects students to apply knowledge, they can make sure students practice application.
- Retrieval practice does not have to look like a test and should not be high-stakes or feel evaluative. Instead, teachers can use low-stakes practice opportunities (e.g., think-pair-share, teaching a peer, fill-in-the-blanks, or concept mapping).[49] Teachers can frame it for what it is: practice.

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2 HOW DO STUDENTS LEARN AND RETAIN NEW INFORMATION?

PRINCIPLE | **PRACTICAL IMPLICATIONS FOR THE CLASSROOM** | **PITFALLS TO BE WARY OF**

Principle

Effective feedback is essential for learning. [50, 51]

Practical implications for the classroom

- Good feedback:[52, 53, 54, 55]
  - Is specific and clear feedback that answers for the student "Where am I at and where do I go from here?"
  - Is focused on the task rather than the student.
  - Is explanatory and focused on improvement rather than merely verifying performance.
  - Contains information on strategies for planning, monitoring, and reflection (e.g., "What strategies did you use? What other strategy could you try?", "How did your progress align with the timeline that you set?") and for managing emotions and motivation (e.g., "This is challenging work, and it makes sense that it takes time. Let's look at the first step together.", "This looks like a lot, so let's break it into one small step at a time.").
- The timing for delivering feedback depends on the goal. Targeted practice of a skill benefits from immediate feedback that allows correction and further attempts within the same session. When students are already relatively proficient with concepts, delayed feedback (e.g., feedback that is not immediate) can be better at strengthening retention.[56, 57, 58]

Pitfalls to be wary of

- Teachers should be aware of how dynamics in the student-teacher relationship might impact how feedback is received. Certain types of feedback (e.g., "you are too smart to be making these simple mistakes", "X isn't your strength, focus instead on Y") might activate ego-threat (i.e., feel evaluative or judgmental).[59, 60, 61]

3 HOW DO STUDENTS SOLVE PROBLEMS AND TRANSFER LEARNING TO NEW CONTEXTS?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
Each subject area has some set of facts that, if committed to long-term memory, aids problem-solving by freeing working memory resources and illuminating contexts in which existing knowledge and skills can be applied.[62]	• Teachers will need to teach different sets of facts at different grade-levels. For example, the most obvious (and thoroughly studied) sets of facts are math facts and letter-sound pairings in early elementary grades. For math, memory is much more reliable than calculation. A child who stops to calculate may make an error or lose track of the larger problem.[63, 64] The advantages of learning to read by phonics are well established.[65, 66]	• Teachers should not assume that general skills should be taught absent domain-specific knowledge: In every subject, what looks like "skill" is actually built on knowledge (e.g., strong readers aren't just good at decoding—they have background knowledge and vocabulary that help them make sense of text). Teachers can prioritize systematic knowledge-building within each domain to support deeper learning.[67, 68, 69, 70]
The transfer of knowledge of skills to a novel problem requires both knowledge of the problem's context and understanding of the problem's underlying structure.[71, 72]	• Teachers can ensure that students have sufficient background knowledge to appreciate the context of a problem.[73, 74, 75]	• Teachers should not assume that skills trained on one domain will naturally transfer to a different domain.[76, 77] For example, a student might learn to identify the "main idea" in reading passages, but later struggle in science class to explain the key takeaway from a lab experiment. Even though both tasks involve finding a central idea, the skill doesn't automatically transfer because it is tied to different content and ways of thinking. Teachers can support students to identify where there's a common underlying structure in these two different contexts that enables them to transfer knowledge appropriately.
We understand via examples, but it's often hard to see the unifying underlying concepts in different examples.[78]	• Teachers can have students compare problems with different surface features that share the same underlying structure. For example, a student learning to calculate the area of a rectangle via a word problem using a table top may not immediately recognize this knowledge is relevant in a word problem that asks them to calculate the area of a soccer field.	• Teachers may notice students being tempted to skip the step of problem identification and jump straight to problem-solving. For example, a student reads the problem "Lena has 7 apples and buys 5 more." Then writes 7 - 5 = 2.

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3 HOW DO STUDENTS SOLVE PROBLEMS AND TRANSFER LEARNING TO NEW CONTEXTS?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
	By comparing the problems, students perceive and remember the underlying structure.[73, 74, 79, 80, 81, 82, 83, 84] • When teaching a new problem type, teachers can start with concrete examples and then gradually "fade out", replacing the concrete examples with symbolic and abstract representations (e.g., mathematical equations) to help students recognize the underlying structure of problems.[85] • For multi-step procedures, teachers can encourage students to identify and label the substeps required for solving a problem. This practice makes students more likely to recognize the underlying structure of the problem and to apply the problem-solving steps to other problems.[86, 87] • Teachers can ask students to analyze and explain the steps of both correct and incorrect worked examples. In particular, analyzing erroneous examples (e.g., highlighting mistakes in a process) and non-examples (e.g., defining the boundaries of what a concept is not) can strengthen conceptual understanding. At the earliest stages of learning, however, it may be better to start with only correct examples before introducing incorrect examples for analysis.[88, 89, 90, 91, 92] • Teachers can provide structured worked examples for beginners and then shift toward more independent problem solving as students become more proficient.[93, 94]	The student skipped the step of identifying the problem type (this is a combine/add situation, not a separate/subtract one) and defaulted to a procedure that was incorrect. Teachers can break activities down to explicitly foster problem identification first.
There isn't only one way to solve a problem. Grasping the deeper conceptual understanding behind a problem can enable students to select the strategy most conducive to finding the solution.[95, 96]	• Teachers can introduce students to multiple strategies for solving a problem and give students interleaved practice in flexibly and adaptively selecting from a repertoire of strategies to solve a problem.[97] • Teachers can make sure that students understand why it is important to be able to have multiple strategies and to be flexible in using them (rather than just applying their favorite strategy).[95]	• Students sometimes rely on less efficient strategies for solving a problem even after they have developed deep conceptual understanding. Teachers should ensure students know why they should leverage the most efficient strategies for solving a problem, once they have deep conceptual understanding.[98]

4 WHAT MOTIVATES STUDENTS TO LEARN?

PRINCIPLE | **PRACTICAL IMPLICATIONS FOR THE CLASSROOM** | **PITFALLS TO BE WARY OF**

Principle: Students engage more deeply when they are focused on mastery and feel that they can succeed in their learning environments.[99, 100]

Practical implications for the classroom

- Teachers can motivate students to learn by:
  - Involving students in decision-making (e.g., choice of projects, setting rules for collaboration)
  - Setting meaningful and optimally challenging tasks
  - Giving clear expectations, using rubrics or examples as needed
  - Giving helpful and intentional feedback (both positive and negative), focused on individual progress.[101, 102, 103, 104]
- Motivation is supported by both growth-oriented language (e.g., "I believe that everyone can learn a lot in this class") and growth-focused course structures and policies (e.g., focusing feedback on strategies for improvement and providing opportunities for low-stakes practice and grade recovery).[105, 106]
- Teachers can convey high expectations. When given in a context of support and care ("I'm giving you this feedback because I know you can do better"), constructive feedback can actually be more motivating than positive feedback.[107, 108]

Pitfalls to be wary of

- Even if teachers communicate explicitly about their belief in students' potential, these messages can be undermined by other features of the learning context (e.g., comparing students, penalizing early mistakes harshly).[109] Teachers should make sure that what they say and how they act are consistent.
- It is not enough for teachers to foster environments that encourage students to believe in themselves and put in effort; teachers must provide students with appropriate practice opportunities, resources, and effective strategies to engage meaningfully with the learning content.[110, 111]
- Overly praising students for mediocre work can send a signal that the teacher does not believe they can do any better. Teachers must provide specific, constructive feedback aligned to high expectations.[112, 113]

Principle: Intrinsic motivation driven by a sense of autonomy and interest leads to better long-term outcomes than motivation controlled by rewards/punishments.[114]

Practical implications for the classroom

- Intrinsic motivation is supported when students have a sense of agency in the classroom (e.g., giving choices where appropriate, incorporating student input, feedback, and/or personal interests into learning activities, minimizing controlling practices, such as being overly directive, or harshly punishing them).[99]

Pitfalls to be wary of

- Students can be overwhelmed by too many choices. When teachers present choices to students (e.g., of assignments), they must be relevant to the learning goal, have a clear structure, and a rubric aligned with the learning objectives.[121]

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4 WHAT MOTIVATES STUDENTS TO LEARN?

PRINCIPLE | **PRACTICAL IMPLICATIONS FOR THE CLASSROOM** | **PITFALLS TO BE WARY OF**

Practical implications for the classroom (continued)

- It is unlikely that students can always be intrinsically motivated. If there are tasks or content that students are not intrinsically motivated for, teachers can:
  - Increase the perceived usefulness of learning (e.g., by showing quotes from past students or having them come up with their own reasons).[115, 116, 117, 118]
  - Create situational interest in the task or content (e.g., meaningful projects, group competitions).[119]
  - Provide extrinsic rewards (e.g., bonus points for participation).[120]

Pitfalls to be wary of (continued)

- Providing extrinsic rewards, especially for things that students are already interested in, can undermine their intrinsic motivation (e.g., a student intrinsically motivated to read doing a competitive "reading challenge" might make reading feel more like a "chore" and thus, undermine their motivation).[122, 123] Teachers can provide extrinsic rewards for activities where students are not already intrinsically motivated.

Principle: Students are more motivated when they believe that they belong and are accepted in their environments.[124]

Practical implications for the classroom

- Teachers can foster a sense of belonging in the classroom (e.g., learning about their students, expressing care, and giving students opportunities to form supportive relationships with their classmates).[125, 126, 127]
- Teachers can reassure students that doubts about belonging are common and will diminish over time.[107, 128]

Pitfalls to be wary of

- Group work intended to encourage collaboration in the learning environment can backfire if not structured well (e.g., one person doing all the work).[129] Teachers can design intentional structures for group work aligned with factors that both support a sense of belonging and facilitate meaningful engagement between individuals (e.g., individual contributions matter, completion requires all participants to contribute, group size is manageable, roles are clear).

Principle: Motivation does not always have to precede learning: building up knowledge and skill can build motivation.[130, 131]

Practical implications for the classroom

- Motivation grows when students experience success and it can fade if students aren't actually getting better. Teachers can build and sustain motivation by breaking complex tasks into manageable steps, providing models and guided practice, and sequencing tasks so success is likely early on.[104]

Pitfalls to be wary of

- Teachers should not assume that motivation guarantees learning. Motivation can drive effort, but learning depends on acquiring and practicing knowledge and skills.

5 HOW DO STUDENTS LEARN TO TAKE CHARGE OF THEIR OWN LEARNING?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
Self-regulated learning involves a cyclical process of planning (e.g., goal setting, choosing task strategies), monitoring (e.g., assessing progress, adjusting strategies), and self-reflection (e.g., reflecting on effective strategies).[132] Self-regulated learners actively manage their own learning, enabling them to learn more effectively and independently over time.	• When students get stuck, teachers can ask “What else can you try?” or “What resources could you use?” rather than jumping into help right away. This fosters an orientation to think strategically for oneself.[133, 134] • Teachers can take on a dual role, not just teaching content but also teaching students how to take control of their own learning.[135] For example, teachers can give students problems, discuss and form plans for how to tackle them, ask students to track their own progress over time, and ask them to reflect on their resources and strategies.[136, 137]	• Learners are not always accurate in knowing when they have learned and when they have not. They may be misled by feelings of fluency and become overconfident (“if it feels easy right now, I’m sure I will remember it later!”). Teachers can implement opportunities for delayed practice (e.g., trying to recall information again after a week), a more reliable signal of learning.[138]
Students should understand that they learn by putting in effort and challenging themselves. Learning should not feel easy.[139, 140]	• Teachers can reinforce that learning requires building connections and mental models in one’s own head and that takes time (e.g., “this is what learning feels like”; “it’s hard because I’ve designed it that way”, and “this is what will help you grow your skills”). Building understanding in one’s own mind requires that students are doing the work themselves.[141, 142, 143, 144] • Teachers motivate students to engage in “productive struggle” by explaining how the activities support students’ learning, drawing attention to improvement (“none of you knew how to do this a month ago!”), not penalizing early mistakes, and using mistakes as an opportunity for learning.[142]	• Simply making work harder doesn’t improve learning. To help students engage meaningfully with challenging content, teachers should leverage activities that ensure challenge is purposeful, aligned to what students know, and supports learning progress.[145, 111]

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5 HOW DO STUDENTS LEARN TO TAKE CHARGE OF THEIR OWN LEARNING?

PRINCIPLE	PRACTICAL IMPLICATIONS FOR THE CLASSROOM	PITFALLS TO BE WARY OF
	• Teachers can engage students in tasks that will allow them to reliably monitor their own learning (e.g., retrieval practice and explanation).[138, 146, 147]	
Establishing effective habits can sustain self-regulated learning even in the absence of motivation.[148, 149]	• Teachers can actively support their students in developing effective habits. For example, teachers can create retrieval practice routines (e.g., “write down what we learned last class,” “teach this concept to a classmate”) to help students both strengthen and monitor their learning.[150, 151] • Teachers can model for students how to use effective strategies in their own study time and set assignments focused on building good habits.[152, 153]	• Teachers should not rely on routines for the sake of routines. When it comes to retrieval practice, routines must be effortful, focused on recall rather than recognition, spaced over time, paired with feedback, and connected to meaningful content to support learning.

6 WHAT ARE COMMON MISCONCEPTIONS ABOUT HOW STUDENTS THINK AND LEARN?

MISCONCEPTION	PRACTICAL IMPLICATIONS FOR THE CLASSROOM
Humans do not use only 10% of their brains.[154]	Learning is the result of sustained cognitive work, not unlocking unused capacity. Learning requires integrating new information with prior knowledge, strengthening neural connections through repetition, and retrieving information over time.[141, 155]
Students do not have different "learning styles" and people are not preferentially "right-brained" or "leftbrained" in the use of their brains.[156, 157]	There are general strategies that are effective for everyone. For example, learning is supported when information is represented both visually and verbally, and hence teachers can support this with effective use of multimedia principles.[158]
Novices and experts cannot think in all the same ways.[159, 160]	Teachers might find themselves under the 'curse of knowledge' – what is obvious to them is not always obvious to their students and that is a gap that should be bridged through instruction.[161] The nature of optimally supportive instruction changes as students become more knowledgeable. Worked examples, shorter spacing between repetitions, more blocked practice, and more teacher-generated content are appropriate early on. As students become more knowledgeable, practice problems, self-explanation, longer spacing intervals between repetitions, interleaved practice, and more student-generated content are appropriate.[37, 145]
Memorization is not just rote regurgitation; memory supports new learning and deeper conceptual understanding.[162]	"Understanding is remembering in disguise": Learning means storing knowledge in long-term memory, which is a primary goal of instruction. When students build strong long-term knowledge, they free up mental capacity to tackle more complex thinking. However, this only happens when information is practiced repeatedly and spaced out over time.[111, 162]
Productivity is not the same as competence; performance is not the same as learning.[163]	Completion of assignments and absence of errors does not necessarily equate to long-lasting learning. There are many strategies which support short-term performance (e.g., cramming, blocked practice, reliance on hints or open-book notes) that inflate the appearance of learning without deepening meaningful, longer-lasting learning. Do not get fooled by "illusions of learning."[138, 163]

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