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**SCIENCE**  
OF LEARNING

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Second Edition

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## 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 become self-regulated learners. Each of the preexisting sections has 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

Students learn by connecting new knowledge to what they already know.<sup>1</sup>



## PRACTICAL IMPLICATIONS FOR THE CLASSROOM

- A well-sequenced, knowledge-rich curriculum is important to ensure students have the prior knowledge they need to master new ideas.<sup>2,3,4</sup>
- 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.<sup>5</sup>
- 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 analogies might induce.<sup>6,7,8,9</sup>



## PITFALLS TO BE WARY OF

- 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.<sup>10</sup>

Students have limited working memory capacity that can be overwhelmed if given too much information at once or if tasks are cognitively too demanding.<sup>11</sup>

- Making content explicit through carefully paced explanation, modeling, and examples can help ensure that students are not overwhelmed.<sup>12</sup> (*Note: "explanation" does not mean teachers must do all the talking.*)
- Teachers can use multiple modalities to convey an idea (e.g., 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.<sup>13</sup>

- Adding details such as "fun facts" or funny stories to content can backfire by drawing attention away from the to-be-learned material. Visual and descriptive elements help students understand underlying ideas and concepts being taught; they should not be merely decorative.<sup>16,17,18,19</sup>

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# 1

## HOW DO STUDENTS UNDERSTAND NEW IDEAS?



### PRINCIPLE



### PRACTICAL IMPLICATIONS FOR THE CLASSROOM



### PITFALLS TO BE WARY OF

- Teachers can define key ideas and vocabulary words before launching into full lessons. This can reduce cognitive load and make it easier to understand relationships between ideas.<sup>14</sup>
- 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 by providing explanations for each step.<sup>15,16</sup>

- When using worked examples, avoid procedural copying – that is, where steps are simply copied by students without thinking about why they work. Make the thinking behind each step visible and prompt students to make connections between the procedure and the underlying concept.

**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.**<sup>21,22</sup>

- 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?”<sup>3,23</sup>

- Teachers should not assume that learning something once is enough. Rather, they can make sure that knowledge is reinforced periodically, even after moving on from the lesson.<sup>24,25</sup>

## 2

## HOW DO STUDENTS LEARN AND RETAIN NEW INFORMATION?



## 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.<sup>26,27</sup>



## 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.<sup>28,29</sup>
- 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.<sup>30</sup>
- For hard-to-remember content, teachers can help students learn to impose structure through the use of mnemonics (e.g., ROY G. BIV for the order of colors in a rainbow).<sup>31</sup>



## PITFALLS TO BE WARY OF

- Teachers should not expect students to apply concepts meaningfully without appropriate prior knowledge. Instead, teachers should support students to build background knowledge and provide clear prompts and task supports so students can apply concepts meaningfully.<sup>33</sup>
- 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.

Practice is essential to long-term learning, but not all practice is equivalent.<sup>33,34,35,36</sup>

- Effective practice:
  - Is spaced out over time. Spacing intervals can be relatively shorter for newer information (e.g., hours or days); as information becomes better learned, the spacing intervals can get longer (e.g., weeks and months).<sup>37,38</sup>
  - Requires effortful thinking and overt retrieval (e.g., asking students to write down their own answer, self-quiz, or teach peers rather than just bringing something to mind). Retrieval from memory should be challenging but doable; students' effort strengthens the memory and makes it easier to access in the future.<sup>39,40,41,42</sup>
- 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.<sup>48</sup>
- It is not effective for students to practice only recalling concept-term definitions.<sup>49</sup> If the teacher expects students

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## 2

## HOW DO STUDENTS LEARN AND RETAIN NEW INFORMATION?



## PRINCIPLE



## PRACTICAL IMPLICATIONS FOR THE CLASSROOM



## PITFALLS TO BE WARY OF

- 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 benefits from blocked practice (i.e., one problem type at a time) initially, but should move to interleaved, spaced practice once initial fluency is achieved.<sup>43,44,45,46</sup>
- Is varied. Having a lot of practice across different types of problems can help students develop fluent pattern recognition skills and strengthen retention.<sup>47</sup>

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).<sup>50</sup> Teachers can frame it for what it is: practice.

Effective feedback is essential for learning.<sup>51,52</sup>

- Good feedback:<sup>53,54,55,56</sup>
  - Is specific and clear.
  - Is focused on the task rather than the student.
  - Is explanatory and focused on improvement, not just verifying performance.
  - Contains information on strategies for planning, monitoring, and reflection (e.g., "What other strategy could you try?" or "How did your progress align with the timeline that you set?")
  - Gives strategies for managing emotions and motivation (e.g., "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.<sup>57,58,59</sup>

- 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).<sup>60,61,62</sup>

## 3

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



## PRINCIPLE

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.<sup>63</sup>



## PRACTICAL IMPLICATIONS FOR THE CLASSROOM

- 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.<sup>64,65</sup> The advantages of learning to read by phonics are well-established.<sup>66,67</sup>



## PITFALLS TO BE WARY OF

- 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.<sup>68,69,70,71</sup>

The transfer of knowledge and skills to a novel problem requires both knowledge of the problem’s context and understanding of the problem’s underlying structure.<sup>72,73</sup>

- Teachers can ensure that students have sufficient background knowledge to appreciate the context of a problem.<sup>74,75,76</sup>

- Teachers should not assume that skills trained on one domain will naturally transfer to a different domain.<sup>77,78</sup> 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.<sup>79</sup>

- 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. By

- 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

comparing the problems, students perceive and remember the underlying structure.<sup>74,75,80,81,82,83,84,85</sup>

- 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.<sup>86</sup>
- 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.<sup>87,88</sup>
- 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.<sup>89,90,91,92,93</sup>
- Teachers can provide structured worked examples for beginners and then shift toward more independent problem-solving as students become more proficient.<sup>94,95</sup>

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 is rarely 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.**<sup>96,97</sup>

- 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.<sup>98</sup>
- 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).<sup>96</sup>

- 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.<sup>99</sup>

## 4

## WHAT MOTIVATES STUDENTS TO LEARN?



## PRINCIPLE

Students engage more deeply when they are focused on mastery and feel that they can succeed in their learning environments.<sup>100,101</sup>



## 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 constructive), focused on individual progress.<sup>102,103,104,105</sup>
- 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).<sup>105,106</sup>
- 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.<sup>108,109</sup>



## 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).<sup>110</sup> 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.<sup>111,112</sup>
- 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.<sup>113,114</sup>

Intrinsic motivation driven by a sense of autonomy and interest leads to better long-term outcomes than motivation controlled by rewards/punishments.<sup>115</sup>

- 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, and minimizing controlling practices, such as being overly directive, or harshly punishing them).<sup>100</sup>

- 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.<sup>122</sup>

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## 4

## WHAT MOTIVATES STUDENTS TO LEARN?



## PRINCIPLE



## PRACTICAL IMPLICATIONS FOR THE CLASSROOM



## PITFALLS TO BE WARY OF

- 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).<sup>116,117,118,119</sup>
  - Create situational interest in the task or content (e.g., meaningful projects, group competitions).<sup>120</sup>
  - Provide extrinsic rewards (e.g., bonus points for participation).<sup>121</sup>
- Providing extrinsic rewards, especially for things that students are already interested in, can undermine their intrinsic motivation (e.g., asking a student who is intrinsically motivated to read to do a competitive “reading challenge” might cause them to feel that it’s a “chore” and thus, undermine their motivation).<sup>123,124</sup> Teachers can provide extrinsic rewards for activities where students are not already intrinsically motivated.

**Students are more motivated when they believe that they belong and are accepted in their environments.**<sup>125</sup>

- 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).<sup>126,127,128</sup>
- Teachers can reassure students that doubts about belonging are common and will diminish over time.<sup>108,129</sup>
- Group work intended to encourage collaboration in the learning environment can backfire if not structured well (e.g., one person doing all the work).<sup>130</sup> 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, and roles are clear).

**Motivation does not always have to precede learning: building up knowledge and skill can build motivation.**<sup>131,132</sup>

- 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.<sup>105</sup>
- 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 SELF-REGULATE THEIR LEARNING?



## PRINCIPLE

Self-regulated learners actively manage their own learning, enabling them to learn more effectively and independently over time. 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).<sup>133</sup>



## PRACTICAL IMPLICATIONS FOR THE CLASSROOM

- 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.<sup>134,135</sup>
- Teachers can take on a dual role, not just teaching content but also teaching students how to take control of their own learning.<sup>135</sup> 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.<sup>137,138</sup>



## PITFALLS TO BE WARY OF

- 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.<sup>139</sup>

Students should understand that they learn by putting in effort and challenging themselves. Learning should not feel easy.<sup>140,141</sup>

- 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.<sup>142,143,144,145</sup>
- 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.<sup>143</sup>

- 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 supportive of learning progress.<sup>112,146</sup>

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## 5

## HOW DO STUDENTS SELF-REGULATE THEIR 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).<sup>139,147,148</sup>

**Establishing effective habits can sustain self-regulated learning even in the absence of motivation.**<sup>149,150</sup>

- 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” or “teach this concept to a classmate”) to help students both strengthen and monitor their learning.<sup>151,152</sup>
- Teachers can model for students how to use effective strategies in their own study time and set assignments focused on building good habits.<sup>153,154</sup>
- 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?



## COMMON MISCONCEPTION

Humans only use 10% of their brains.<sup>155</sup>



## WHAT THE EVIDENCE TELLS US

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.<sup>142,155,156</sup>

Students have different “learning styles,” and people are preferentially “right-brained” or “left-brained” in the use of their brains.<sup>157,158</sup>

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.<sup>157,158,159</sup>

Novices and experts think in all the same ways.<sup>160,161</sup>

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.<sup>161</sup> 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.<sup>38,146,160,161</sup>

Memorization is just rote regurgitation that does not support new learning and deeper conceptual understanding.<sup>163</sup>

“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.<sup>112,163</sup>

Productivity is the same as competence; performance is the same as learning.<sup>164</sup>

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.”<sup>139,164</sup>

## REFERENCES

- 1 Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11). Washington, DC: National Academy Press.
- 2 Agodini, R., Harris, B., Atkins-Burnett, S., Heavside, S., Novak, T., & Murphy, R. (2009). *Achievement Effects of Four Early Elementary School Math Curricula: Findings from First Graders in 39 Schools*. NCEE 2009-4052. National Center for Education Evaluation and Regional Assistance
- 3 Grissmer, D., Buddin, R., Berends, M., White, T. G., Willingham, D. T., DeCoster, J., ... & Evans, T. (2024). How Building Knowledge Boosts Literacy and Learning. *Education Next*, 24(2), 8-12.
- 4 Ritter, S., Yudelson, M., Fancsali, S. E., & Berman, S. R. (2016). How mastery learning works at scale. In J. Haywood, V. Alevan, J. Kay, & I. Roll(Eds.), *Proceedings of the third (2016) ACM conference on learning @ scale (L@S '16)* (pp. 71-79). Association for Computing Machinery. <https://doi.org/10.1145/2876034.2876039>
- 5 Pan, S. C., & Carpenter, S. K. (2023). Prequestioning and pretesting effects: A review of empirical research, theoretical perspectives, and implications for educational practice. *Educational Psychology Review*, 35(4), 97. <https://doi.org/10.1007/s10648-023-09814-5>
- 6 Braasch, J. L. G., & Goldman, S. R. (2010). The Role of Prior Knowledge in Learning From Analogies in Science Texts. *Discourse Processes*, 47(6), 447-479. <https://doi.org/10.1080/01638530903420960>
- 7 Eriksson, S., Gericke, N., & Thörne, K. (2026). Analogy competence for science teachers. *Studies in Science Education*, 62(1), 41-69. <https://doi.org/10.1080/03057267.2024.2434797>
- 8 Gray, M.E. and Holyoak, K.J. (2021), Teaching by Analogy: From Theory to Practice. *Mind, Brain, and Education*, 15: 250-263. <https://doi.org/10.1111/mbe.12288>
- 9 Richland, L. E., & Simms, N. (2015). Analogy, higher order thinking, and education. *WIREs Cognitive Science*, 6(2), 177-192. <https://doi.org/10.1002/wcs.1336>
- 10 Brand, C., Loibl, K. & Rummel, N. (2025). Prior knowledge activation as preparation prior to instruction: does the coverage of relevant prior knowledge affect learning?. *Instructional Science* 53, 1633-1661. <https://doi.org/10.1007/s11251-025-09727-6>
- 11 Sweller, J. (2024). Cognitive load theory and individual differences. *Learning and Individual Differences*, 110, 102423. <https://doi.org/10.1016/j.lindif.2024.102423>
- 12 Vaughn, S., & Fletcher, J. (2021). Explicit Instruction as the Essential Tool for Executing the Science of Reading. *The Reading League Journal*, 2(2), 4-11.
- 13 Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review*, 36(1), 8. <https://doi.org/10.1007/s10648-023-09842-1>
- 14 Mayer, R. E., & Pilegard, C. (2014). Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pre-training, and Modality Principles. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 316-344). Chapter 13, Cambridge: Cambridge University Press. <https://doi.org/10.1017/CBO9781139547369.016>
- 15 Renkl, A. (2014). Learning from worked examples: How to prepare students for meaningful problem solving. In V. A. Benassi, C. E. Overson, & C. M. Hakala (Eds.), *Applying science of learning in education: Infusing psychological science into the curriculum* (pp. 118-130). Society for the Teaching of Psychology. ISBN: 978-1-941804-29-2.
- 16 Chen, O., Retnowati, E., Chan, B. K. Y., & Kalyuga, S. (2023). The effect of worked examples on learning solution steps and knowledge transfer. *Educational Psychology*, 43(8), 914-928. <https://doi.org/10.1080/01443410.2023.2273762>
- 17 Cuevas, J., & Dawson, B. L. (2018). A test of two alternative cognitive processing models: Learning styles and dual coding. *Theory and Research in Education*, 16(1), 40-64. <https://journals.sagepub.com/doi/pdf/10.1177/1477878517731450>
- 18 Kienitz, A., Krebs, M. C., & Eitel, A. (2023). Seductive details hamper learning even when they do not disrupt. *Instructional science*, 1-22. Advance online publication. <https://doi.org/10.1007/s11251-023-09632-w>
- 19 Noetel, M., Griffith, S., Delaney, O., Harris, N. R., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2022). Multimedia Design for Learning: An Overview of Reviews With Meta-Analysis. *Review of Educational Research*, 92(3), 413-454. <https://doi.org/10.3102/00346543211052329>
- 20 Norman, G., Dore, K., & Grierson, L. (2012). The minimal relationship between simulation fidelity and transfer of learning. *Medical Education*, 46(7), 636-647
- 21 Flynn, E., O'Malley, C., & Wood, D. (2004). A longitudinal, microgenetic study of the emergence of false belief understanding and inhibition skills. *Developmental Science*, 7(1), 103-115. <https://doi.org/10.1111/j.1467-7687.2004.00326.x>
- 22 Siegler, R. S. (1995). How does change occur: A microgenetic study of number conservation. *Cognitive Psychology*, 28(3), 225-273. <https://doi.org/10.1006/cogp.1995.1006>
- 23 Willingham, D. T. (2008, Summer). What is Developmentally Appropriate Practice? *American Educator*, pp. 34-39.
- 24 Dunlosky, J., & Rawson, K. A. (2015). Practice tests, spaced practice, and successive relearning: Tips for classroom use and for guiding students' learning. *Scholarship of Teaching and Learning in Psychology*, 1(1), 72.
- 25 Grissmer, D., Buddin, R., Berends, M., White, T. G., Willingham, D. T., DeCoster, J., ... & Evans, T. (2024). How Building Knowledge Boosts Literacy and Learning. *Education Next*, 24(2), 8-12.
- 26 Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge University Press.
- 27 Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, 16(5), 519-533. [https://doi.org/10.1016/S0022-5371\(77\)80016-9](https://doi.org/10.1016/S0022-5371(77)80016-9)
- 28 Fiorella, L. (2023). Making sense of generative learning. *Educational Psychology Review*, 35(2), 50. <https://doi.org/10.1007/s10648-023-09769-7>
- 29 Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review*, 28(4), 717-741. <https://doi.org/10.1007/s10648-015-9348-9>
- 30 Rau, M.A., Matthews, P.G. How to make 'more' better? Principles for effective use of multiple representations to enhance students' learning about fractions. *ZDM Mathematics Education* 49, 531-544 (2017). <https://doi.org/10.1007/s11858-017-0846-8>
- 31 Putnam, A. L. (2015). Mnemonics in education: Current research and applications. *Translational Issues in Psychological Science*, 1(2), 130-139. <https://doi.org/10.1037/tps0000023>
- 32 Hattie, J. A., & Donoghue, G. M. (2016). Learning strategies: A synthesis and conceptual model. *npj Science of Learning*, 1(1), 16013. <https://doi.org/10.1038/npjscilearn.2016.13>
- 33 Carpenter, S.K., Pan, S.C. & Butler, A.C. (2022). The science of effective learning with spacing and retrieval practice. *Nature Review Psychology*, 1, 496-511. <https://doi.org/10.1038/s44159-022-00089-1>
- 34 Kang, S. H. (2016). Spaced repetition promotes efficient and effective learning: Policy implications for instruction. *Policy Insights from the Behavioral and Brain Sciences*, 3(1), 12-19. <https://doi.org/10.1177/2372732215624708>
- 35 McDermott, K. B. (2021). Practicing Retrieval Facilitates Learning. *Annual Review Psychology*. 72:609-633. <https://doi.org/10.1146/annurev-psych-010419-051019>
- 36 Yang, C., Luo, L., Vadillo, M. A., Yu, R., & Shanks, D. R. (2021). Testing (quizzing) boosts classroom

- learning: A systematic and meta-analytic review. *Psychological Bulletin*, 147(4), 399–435. <https://doi.org/10.1037/bul0000309>
- <sup>37</sup> Kang, S. H., Lindsey, R. V., Mozer, M. C., & Pashler, H. (2014). Retrieval practice over the long term: Should spacing be expanding or equal-interval?. *Psychonomic Bulletin & Review*, 21(6), 1544–1550. <https://doi.org/10.3758/s13423-014-0636-z>
- <sup>38</sup> Yan, V. X., Sana, F., & Carvalho, P. F. (2024). No simple solutions to Complex problems: Cognitive science principles can guide but not prescribe educational decisions. *Policy Insights from the Behavioral and Brain Sciences*, 11(1), 59–66. <https://doi.org/10.1177/23727322231218906>
- <sup>39</sup> Agarwal, P. K., Nunes, L. D., & Blunt, J. R. (2021). Retrieval practice consistently benefits student learning: A systematic review of applied research in schools and classrooms. *Educational Psychology Review*, 33(4), 1409–1453. <https://doi.org/10.1007/s10648-021-09595-9>
- <sup>40</sup> Koh, A. W. L., Lee, S. C., & Lim, S. W. H. (2018). The learning benefits of teaching: A retrieval practice hypothesis. *Applied Cognitive Psychology*, 32(3), 401–410. <https://doi.org/10.1002/acp.3410>
- <sup>41</sup> Kornell, N., Bjork, R. A., & Garcia, M. A. (2011). Why tests appear to prevent forgetting: A distribution-based bifurcation model. *Journal of Memory and Language*, 65(2), 85–97. <https://doi.org/10.1016/j.jml.2011.04.002>
- <sup>42</sup> Kornell, N., & Vaughn, K. E. (2016). How retrieval attempts affect learning: A review and synthesis. In B. H. Ross (Ed.), *The psychology of learning and motivation* (pp. 183–215). Elsevier Academic Press.
- <sup>43</sup> Brunmair, M., & Richter, T. (2019). Similarity matters: A meta-analysis of interleaved learning and its moderators. *Psychological Bulletin*, 145(11), 1029–1052. <https://doi.org/10.1037/bul0000209>
- <sup>44</sup> Sana, F., & Yan, V. X. (2022). Interleaving retrieval practice promotes science learning. *Psychological Science*, 33(5), 782–788. <https://doi.org/10.1177/09567976211057507>
- <sup>45</sup> Firth, J., Rivers, I., & Boyle, J. (2021). A systematic review of interleaving as a concept learning strategy. *Review of Education*, 9(2), 642–684. <https://doi.org/10.1002/rev3.3266>
- <sup>46</sup> Yan, V. X., & Schuetz, B. A. (2022). Not just stimuli structure: Sequencing effects in category learning vary by task demands. *Journal of Applied Research in Memory and Cognition*, 11(2), 218–228. <https://doi.org/10.1016/j.jarmac.2021.09.004>
- <sup>47</sup> Kellman, P. J., Jacoby, V., Massey, C., Krasne, S. (2022). Perceptual Learning, Adaptive Learning, and Gamification: Educational Technologies for Pattern Recognition, Problem Solving, and Knowledge Retention in Medical Learning. In: Witchel, H. J., Lee, M. W. (eds) *Technologies in Biomedical and Life Sciences Education. Methods in Physiology*. Springer, Cham. [https://doi.org/10.1007/978-3-030-95633-2\\_5](https://doi.org/10.1007/978-3-030-95633-2_5)
- <sup>48</sup> Abel, M., & Roediger, H. L. (2018). The testing effect in a social setting: Does retrieval practice benefit a listener? *Journal of Experimental Psychology: Applied*, 24, 347–359. <https://doi.org/10.1037/xap0000148>
- <sup>49</sup> Agarwal, P. K. (2019). Retrieval practice & Bloom's taxonomy: Do students need fact knowledge before higher order learning? *Journal of Educational Psychology*, 111(2), 189–209. <https://doi.org/10.1037/edu0000282>
- <sup>50</sup> Hinze, S. R., & Rapp, D. N. (2014). Retrieval (sometimes) enhances learning: Performance pressure reduces the benefits of retrieval practice. *Applied Cognitive Psychology*, 28(4), 597–606. <https://doi.org/10.1002/acp.3032>
- <sup>51</sup> Winstone, N. E., & Nash, R. A. (2023). Toward a cohesive psychological science of effective feedback. *Educational Psychologist*, 58(3), 111–129. <https://doi.org/10.1080/00461520.2023.2224444>
- <sup>52</sup> Wisniewski, B., Zierer, K., & Hattie, J. (2020). The power of feedback revisited: A meta-analysis of educational feedback research. *Frontiers in psychology*, 10, 487662. <https://doi.org/10.3389/fpsyg.2019.03087>
- <sup>53</sup> Fyfe, E. R., & Rittle-Johnson, B. (2015). Feedback both helps and hinders learning: The causal role of prior knowledge. *Journal of Educational Psychology*, 108(1), 82–97. <https://doi.org/10.1037/edu0000053>
- <sup>54</sup> Mertens, U., Finn, B., & Lindner, M. A. (2022). Effects of computer-based feedback on lower- and higher-order learning outcomes: A network meta-analysis. *Journal of Educational Psychology*, 114(8), 1743–1772. <https://doi.org/10.1037/edu0000764>
- <sup>55</sup> Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, 77(1), 81–112. <https://doi.org/10.3102/003465430298487>
- <sup>56</sup> Fong, C. J., & Schallert, D. L. (2023). "Feedback to the future": Advancing motivational and emotional perspectives in feedback research. *Educational Psychologist*, 58(3), 146–161. <https://doi.org/10.1080/00461520.2022.2134135>
- <sup>57</sup> Butler, A. C., & Woodward, N. R. (2018). Toward consilience in the use of task-level feedback to promote learning. In K. D. Federmeier (Ed.), *The psychology of learning and motivation* (pp. 1–38). Elsevier Academic Press.
- <sup>58</sup> Fyfe, E. R., de Leeuw, J. R., Carvalho, P. F., et al. (2021). ManyClasses 1: Assessing the generalizable effect of immediate versus delayed feedback across many college classes. *Advances in Methods and Practices in Psychological Science*, 4(3), 1–24. <https://doi.org/10.1177/25152459211027575>
- <sup>59</sup> Mullet, H. G., Butler, A. C., Verdin, B., von Borries, R., & Marsh, E. J. (2014). Delaying feedback promotes transfer of knowledge despite student preferences to receive feedback immediately. *Journal of Applied Research in Memory and Cognition*, 3(3), 222–229. <https://doi.org/10.1016/j.jarmac.2014.05.001>
- <sup>60</sup> Eskreis-Winkler, L., & Fishbach, A. (2019). Not learning from failure—The greatest failure of all. *Psychological Science*, 30(12), 1733–1744. <https://doi.org/10.1177/0956797619881133>
- <sup>61</sup> Fong, C. J., Schallert, D. L., Williams, K. M., Williamson, Z. H., Warner, J. R., Lin, S., & Kim, Y. W. (2018). When feedback signals failure but offers hope for improvement: A process model of constructive criticism. *Thinking Skills and Creativity*, 30, 42–53. <https://doi.org/10.1016/j.tsc.2018.02.014>
- <sup>62</sup> Fulham, N. M., Krueger, K. L., & Cohen, T. R. (2022). Honest feedback: Barriers to receptivity and discerning the truth in feedback. *Current Opinion in Psychology*, 46, 101405. <https://doi.org/10.1016/j.copsyc.2022.101405>
- <sup>63</sup> Glaser, R., & Chi, M. T. (1988). Overview. In *The Nature of Expertise* (pp. xv–xxviii). Hillsdale: Erlbaum.
- <sup>64</sup> Datchuk, S. M., & Hier, B. O. (2019). Fluency practice: Techniques for building automaticity in foundational knowledge and skills. *Teaching Exceptional Children*, 51(6), 424–435. <https://doi.org/10.1177/0040059919847213>
- <sup>65</sup> McNeil, N. M., Jordan, N. C., Viegut, A. A., & Ansari, D. (2025). What the Science of Learning Teaches Us About Arithmetic Fluency. *Psychological Science in the Public Interest*, 26(1), 10–57. <https://doi.org/10.1177/15291006241287726>
- <sup>66</sup> Castles, A., Rastle, K., & Nation, K. (2018). Ending the Reading Wars: Reading Acquisition From Novice to Expert. *Psychological Science in the Public Interest*, 19(1), 5–51. <https://doi.org/10.1177/1529100618772271>
- <sup>67</sup> Ehri, L. C. (2020). The science of learning to read words: A case for systematic phonics instruction. *Reading Research Quarterly*, 55(Suppl 1), S45–S60. <https://doi.org/10.1002/rrq.334>
- <sup>68</sup> Ritchie, S. J., Bates, T. C., & Deary, I. J. (2015). Is education associated with improvements in general cognitive ability, or in specific skills?. *Developmental psychology*, 51(5), 573–582. <https://doi.org/10.1037/a003898>
- <sup>69</sup> Willingham, D. T. (2019). *How to teach critical thinking*. NSW Department of Education. [http://www.danielwillingham.com/uploads/5/0/0/7/5007325/willingham\\_2019\\_nsw\\_critical\\_thinking2.pdf](http://www.danielwillingham.com/uploads/5/0/0/7/5007325/willingham_2019_nsw_critical_thinking2.pdf)

- <sup>70</sup> Cook, S. C., Collins, L. W., Morin, L. L., & Riccomini, P. J. (2020). Schema-Based Instruction for Mathematical Word Problem Solving: An Evidence-Based Review for Students With Learning Disabilities. *Learning Disability Quarterly*, 43(2), 75–87. <https://doi.org/10.1177/0731948718823080>
- <sup>71</sup> Jitendra, A. K., Harwell, M. R., Karl, S. R., Dupuis, D. N., Simonson, G. R., Slater, S. C., & Lein, A. E. (2016). Schema-based instruction: Effects of experienced and novice teacher implementers on seventh grade students' proportional problem solving. *Learning and Instruction*, 44, 53–64. <https://doi.org/10.1016/j.learninstruc.2016.03.001>
- <sup>72</sup> Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people learn (Vol. 1). Washington, DC: National Academy Press.
- <sup>73</sup> Hilton, M. L., & Pellegrino, J. W. (Eds.). (2012). Education for life and work: Developing transferable knowledge and skills in the 21st century. National Academies Press.
- <sup>74</sup> Chi, M. T., & VanLehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist*, 47(3), 177–188. <https://doi.org/10.1080/00461520.2012.695709>
- <sup>75</sup> Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist*, 47(3), 153–176. <https://doi.org/10.1080/00461520.2012.696438>
- <sup>76</sup> Nokes-Malach, T. J., & Mestre, J. P. (2013). Toward a model of transfer as sense-making. *Educational Psychologist*, 48(3), 184–207. <https://doi.org/10.1080/00461520.2013.807556>
- <sup>77</sup> Tricot, A., & Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. *Educational Psychology Review*, 26(2), 265–283. <https://psycnet.apa.org/doi/10.1007/s10648-013-9243-1>
- <sup>78</sup> Lewandowsky, S., Little, D., & Kalish, M. L. (2007). Knowledge and expertise. In FT Durso, RS Nickerson, ST Dumais, S Lewandowsky, and TJ Perfect (Eds). *Handbook of Applied Cognition*, (pp 83-109). Wiley & Sons.
- <sup>79</sup> Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and instruction*, 16(3), 183–198. <https://doi.org/10.1016/j.learninstruc.2006.03.001>
- <sup>80</sup> Mix, K.S., Gentner, D. How structure-mapping can improve K-12 education. *Discov Educ* 5, 288 (2026). <https://doi.org/10.1007/s44217-026-01248-9>
- <sup>81</sup> Rau, M.A. (2017). Conditions for the Effectiveness of Multiple Visual Representations in Enhancing STEM Learning. *Educational Psychology Review*, 29, 717–761. <https://doi.org/10.1007/s10648-016-9365-3>
- <sup>82</sup> Rau, M. A., & Matthews, P. G. (2017). How to make 'more' better? Principles for effective use of multiple representations to enhance students' learning about fractions. *ZDM*, 49(4), 531–544. <https://doi.org/10.1007/s11858-017-0846-8>
- <sup>83</sup> Kellman, P. J., & Massey, C. M. (2013). Perceptual learning, cognition, and expertise. In B. H. Ross (Ed.), *The psychology of learning and motivation* (pp. 117–165). Elsevier Academic Press.
- <sup>84</sup> Mayer, R. E. (1996). Learning strategies for making sense out of expository text: The SOI model for guiding three cognitive processes in knowledge construction. *Educational Psychology Review*, 8(4), 357–371. <https://doi.org/10.1007/BF01463939>
- <sup>85</sup> Stoel, G. L., van Drie, J. P., & van Boxtel, C. A. M. (2017). The effects of explicit teaching of strategies, second-order concepts, and epistemological underpinnings on students' ability to reason causally in history. *Journal of Educational Psychology*, 109(3), 321–337. <https://doi.org/10.1037/edu0000143>
- <sup>86</sup> Fyfe, E. R., & Nathan, M. J. (2019). Making "concreteness fading" more concrete as a theory of instruction for promoting transfer. *Educational Review*, 71(4), 403–422. <https://doi.org/10.1080/00131911.2018.1424116>
- <sup>87</sup> Catrambone, R. (1996). Generalizing solution procedures learned from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22(4), 1020–1031.
- <sup>88</sup> Catrambone, R. (1998). The subgoal learning model: Creating better examples so that students can solve novel problems. *Journal of Experimental Psychology: General*, 127(4), 355–376.
- <sup>89</sup> Adams, D.M., McLaren, B.M., Mayer, R.E., Goguadze, G., Isotani, S. (2013). Erroneous Examples as Desirable Difficulty. In: Lane, H.C., Yacef, K., Mostow, J., Pavlik, P. (eds) *Artificial Intelligence in Education. AIED 2013. Lecture Notes in Computer Science*, vol 7926. Springer, Berlin, Heidelberg. [https://doi.org/10.1007/978-3-642-39112-5\\_117](https://doi.org/10.1007/978-3-642-39112-5_117)
- <sup>90</sup> Barbieri, C. A., Booth, J. L., Begolli, K. N., & McCann, N. (2021). The effect of worked examples on student learning and error anticipation in algebra. *Instructional Science*, 49(4), 419–439. <https://doi.org/10.1007/s11251-021-09545-6>
- <sup>91</sup> Barbieri, C., & Booth, J. L. (2016). Support for struggling students in algebra: Contributions of incorrect worked examples. *Learning and Individual Differences*, 48, 36–44. <https://doi.org/10.1016/j.lindif.2016.04.001>
- <sup>92</sup> Chen, O., Retnowati, E., Chan, B. K. Y., & Kalyuga, S. (2023). The effect of worked examples on learning solution steps and knowledge transfer. *Educational Psychology*, 43(8), 914–928. <https://doi.org/10.1080/014434410.2023.2273762>
- <sup>93</sup> Große, C. S., & Renkl, A. (2007). Finding and fixing errors in worked examples: Can this foster learning outcomes?. *Learning and instruction*, 17(6), 612–634. <https://doi.org/10.1016/j.learninstruc.2007.09.008>
- <sup>94</sup> Chen, O., Kalyuga, S., & Sweller, J. (2017). The expertise reversal effect is a variant of the more general element interactivity effect. *Educational Psychology Review*, 29(2), 393–405. <https://doi.org/10.1007/s10648-016-9359-1>
- <sup>95</sup> Salden, R. J., Alevyn, V., Schwonke, R., & Renkl, A. (2010). The expertise reversal effect and worked examples in tutored problem solving. *Instructional Science*, 38(3), 289–307. <https://doi.org/10.1007/s11251-009-9107-8>
- <sup>96</sup> Hong, W., Star, J. R., Liu, R. D., Jiang, R., & Fu, X. (2023). A systematic review of mathematical flexibility: Concepts, measurements, and related research. *Educational Psychology Review*, 35(4), 104. <https://doi.org/10.1007/s10648-023-09825-2>
- <sup>97</sup> Siegler, R. S. (2015). Variation, selection, and cognitive change. In R. S. Siegler (Ed.) *Developing cognitive competence* (pp. 31–76). Psychology Press.
- <sup>98</sup> Nemeth, L., Werker, K., Arend, J., & Lipowsky, F. (2021). Fostering the acquisition of subtraction strategies with interleaved practice: An intervention study with German third graders. *Learning and Instruction*, 71, 101354. <https://doi.org/10.1016/j.learninstruc.2020.101354>
- <sup>99</sup> Rittle-Johnson, B., Schneider, M., & Star, J.R. Not a One-Way Street: Bidirectional Relations Between Procedural and Conceptual Knowledge of Mathematics. *Educ Psychol Rev* 27, 587–597 (2015). <https://doi.org/10.1007/s10648-015-9302-x>
- <sup>100</sup> Linnenbrink-Garcia, L., Patall, E. A., & Pekrun, R. (2016). Adaptive Motivation and Emotion in Education: Research and Principles for Instructional Design: Research and Principles for Instructional Design. *Policy Insights from the Behavioral and Brain Sciences*, 3(2), 228–236. <https://doi.org/10.1177/2372732216644450>
- <sup>101</sup> Schunk, D. H., & DiBenedetto, M. K. (2022). Academic self-efficacy. In K-A Allen, M. J. Furlong, D. Vella-Brodrick and S. Suldo (Eds.) *Handbook of positive psychology in schools* (pp. 268–282). Routledge.
- <sup>102</sup> Koenka, A. C., Berry, D. N., & Nicolai, K. D. (2025). Leveraging the power and potential of feedback: Conceptual contributions and areas for expansion. *Contemporary Educational Psychology*, 102427. <https://doi.org/10.1016/j.cedpsych.2025.102427>

- <sup>103</sup> Lüftenecker, M., Van de Schoot, R., Schober, B., Finsterwald, M., & Spiel, C. (2014). Promotion of students' mastery goal orientations: Does TARGET work?. *Educational Psychology, 34*(4), 451-469. <https://doi.org/10.1080/01443410.2013.814189>
- <sup>104</sup> Lüftenecker, M., Tran, U. S., Bardach, L., Schober, B., & Spiel, C. (2017). Measuring a mastery goal structure using the TARGET framework. *Zeitschrift für Psychologie, 225*(1), 64-75. <https://doi.org/10.1027/2151-2604/a000277>
- <sup>105</sup> Margolis, H., & McCabe, P. P. (2006). Improving Self-Efficacy and Motivation: What to Do, What to Say. *Intervention in School and Clinic, 41*(4), 218-227. <https://doi.org/10.1177/10534512060410040401>
- <sup>106</sup> Hecht, C. A., Murphy, M. C., Dweck, C. S., Bryan, C. J., Trzesniewski, K. H., Medrano, F. N., ... & Yeager, D. S. (2023). Shifting the mindset culture to address global educational disparities. *npj Science of Learning, 8*(1), 29. <https://doi.org/10.1038/s41539-023-00181-y>
- <sup>107</sup> Kroeper, K. M., Muenks, K., Canning, E. A., & Murphy, M. C. (2022). An exploratory study of the behaviors that communicate perceived instructor mindset beliefs in college STEM classrooms. *Teaching and Teacher Education, 114*, 103717. <https://doi.org/10.1016/j.tate.2022.103717>
- <sup>108</sup> Yeager, D. S., Purdie-Vaughns, V., Garcia, J., Apfel, N., Brzustoski, P., Master, A., Hesser, W. T., Williams, M. E., & Cohen, G. L. (2014). Breaking the cycle of mistrust: Wise interventions to provide critical feedback across the racial divide. *Journal of Experimental Psychology: General, 143*(2), 804-824. <https://doi.org/10.1037/a0033906>
- <sup>109</sup> Cohen, G., Steele, C., & Ross, L. (1999). The Mentor's Dilemma: Providing Critical Feedback Across the Racial Divide. *Personality and Social Psychology Bulletin, 25*(10), 1302-1318.
- <sup>110</sup> Hecht, C. A., Dweck, C. S., Murphy, M. C., Kroeper, K. M., & Yeager, D. S. (2023). Efficiently exploring the causal role of contextual moderators in behavioral science. *Proceedings of the National Academy of Sciences, 120*(1), e2216315120. <https://doi.org/10.1073/pnas.2216315120>
- <sup>111</sup> Barger, M. M., Xiong, Y., & Ferster, A. E. (2022). Identifying false growth mindsets in adults and implications for mathematics motivation. *Contemporary Educational Psychology, 70*, 102079. <https://doi.org/10.1016/j.cedpsych.2022.102079>
- <sup>112</sup> Yan, V. X., & Schuetz, B. A. (2023). What is meant by "growth mindset"? Current theory, measurement practices, and empirical results leave much open to interpretation: Commentary on Macnamara and Burgoyne (2023) and Burnette et al. (2023). *Psychological Bulletin, 149*(3-4), 206-219. <https://doi.org/10.1037/bul0000370>
- <sup>113</sup> Meyer, W.-U. (1992). Paradoxical effects of praise and criticism on perceived ability. In W. Stroebe & M. Hewstone (Eds.), *European review of social psychology*, Vol. 3, (pp. 259-283). John Wiley & Sons.
- <sup>114</sup> Henderlong, J., & Lepper, M. R. (2002). The effects of praise on children's intrinsic motivation: A review and synthesis. *Psychological Bulletin, 128*(5), 774-795. <https://doi.org/10.1037/0033-2909.128.5.774>
- <sup>115</sup> Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, 101860. <https://doi.org/10.1016/j.cedpsych.2020.101860>
- <sup>116</sup> Hulleman, C. S., Kosovich, J. J., Barron, K. E., & Daniel, D. B. (2017). Making connections: Replicating and extending the utility value intervention in the classroom. *Journal of Educational Psychology, 109*(3), 387-404. <https://doi.org/10.1037/edu0000146>
- <sup>117</sup> Priniski, S. J., Rosenzweig, E. Q., Canning, E. A., Hecht, C. A., Tibbetts, Y., Hyde, J. S., & Harackiewicz, J. M. (2019). The benefits of combining value for the self and others in utility-value interventions. *Journal of Educational Psychology, 111*(8), 1478-1497. <https://dx.doi.org/10.1037/edu0000343>
- <sup>118</sup> Rosenzweig, E. Q., Hulleman, C. S., Barron, K. E., Kosovich, J. J., Priniski, S. J., & Wigfield, A. (2019). Promises and pitfalls of adapting utility value interventions for online math courses. *The Journal of Experimental Education, 87*(2), 332-352. <https://doi.org/10.1080/00220973.2018.1496059>
- <sup>119</sup> Silverman, D. M., Hulleman, C. S., & Tibbetts, Y. (2023). Identifying the psychological mechanisms of utility-value activities to inform educational research and practice. *British Journal of Educational Psychology, 93*(4), 960-977. <https://doi.org/10.1111/bjep.12614>
- <sup>120</sup> Renninger, K. A., & Hidi, S. E. (2022). Interest development, self-related information processing, and practice. *Theory into practice, 61*(1), 23-34. <https://doi.org/10.1080/0040584.1.2021.1932159>
- <sup>121</sup> Bear, G. G., Slaughter, J. C., Mantz, L. S., & Farley-Ripple, E. (2017). Rewards, praise, and punitive consequences: Relations with intrinsic and extrinsic motivation. *Teaching and Teacher Education, 65*, 10-20. <https://doi.org/10.1016/j.tate.2017.03.001>
- <sup>122</sup> Patall, E. A. (2019). The complex role of choice in human motivation and functioning. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (2nd ed., pp. 135-155). Oxford University Press.
- <sup>123</sup> Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*(6), 627-668. <https://doi.org/10.1037/0033-2909.125.6.627>
- <sup>124</sup> Murayama, K., Matsumoto, M., Izuma, K., & Matsumoto, K. (2010). Neural basis of the undermining effect of monetary reward on intrinsic motivation. *Proceedings of the National Academy of Sciences, 107*(49), 20911-20916. <https://doi.org/10.1073/pnas.1013305107>
- <sup>125</sup> Osterman, K. F. (2000). Students' Need for Belonging in the School Community. *Review of Educational Research, 70*(3), 323-367. <https://doi.org/10.3102/00346543070003323>
- <sup>126</sup> Allen, K., Kern, M. L., Vella-Brodick, D., Hattie, J., & Waters, L. (2018). What schools need to know about fostering school belonging: A meta-analysis. *Educational Psychology Review, 30*(1), 1-34. <https://doi.org/10.1007/s10648-016-9389-8>
- <sup>127</sup> Allen, K. A., Jamshidi, N., Berger, E., Reupert, A., Wurf, G., & May, F. (2022). Impact of school-based interventions for building school belonging in adolescence: A systematic review. *Educational Psychology Review, 34*(1), 229-257. <https://doi.org/10.1007/s10648-021-09621-w>
- <sup>128</sup> Anderman, L. H. (2003). Academic and social perceptions as predictors of change in middle school students' sense of school belonging. *The Journal of Experimental Education, 72*(1), 5-22. <https://doi.org/10.1080/00220970309600877>
- <sup>129</sup> Walton, G. M., & Brady, S. T. (2021). The social-belonging intervention. In G. M. Walton & A. J. Crum (Eds.), *Handbook of wise interventions: How social psychology can help people change* (pp. 36-62). The Guilford Press.
- <sup>130</sup> Shimazoe, J., & Aldrich, H. (2010). Group work can be gratifying: Understanding & overcoming resistance to cooperative learning. *College Teaching, 58*, 52-57. <https://doi.org/10.1080/87567550903418594>
- <sup>131</sup> Ditta, A. S., Strickland-Hughes, C. M., Cheung, C., & Wu, R. (2020). Exposure to information increases motivation to learn more. *Learning and Motivation, 72*, 101668. <https://doi.org/10.1016/j.lmot.2020.101668>
- <sup>132</sup> Senko, C., Perry, A. H., & Greiser, M. (2022). Does triggering learners' interest make them overconfident?. *Journal of Educational Psychology, 114*(3), 482-497. <https://doi.org/10.1037/edu0000649>
- <sup>133</sup> Zimmerman, B. J. (2013). From cognitive modeling to self-regulation: A social cognitive career path. *Educational Psychologist, 48*(3), 135-147. <https://doi.org/10.1080/00461520.2013.794676>

- <sup>134</sup> Chen, P., Powers, J. T., Katragadda, K. R., Cohen, G. L., & Dweck, C. S. (2020). A strategic mindset: An orientation toward strategic behavior during goal pursuit. *Proceedings of the National Academy of Sciences*, *117*(25), 14066–14072. <https://doi.org/10.1073/pnas.2002529117>
- <sup>135</sup> Chen, P., Teo, Q. K., Foo, D. X., Jiang, Y., Sun, L., Ong, X. L., ... & Ong, D. C. (2025). A strategic mindset predicts and promotes effective learning and academic performance. *npj Science of Learning*, *10*(1), 74. <https://doi.org/10.1038/s41539-025-00367-6>
- <sup>136</sup> Kramarski, B. (2017). Teachers as agents in promoting students' SRL and performance: Applications for teachers' dual-role training program. In: *Handbook of self-regulation of learning and performance* (pp. 223–239). Routledge.
- <sup>137</sup> Bell, C. V., & Pape, S. J. (2014). Scaffolding the development of self-regulated learning in mathematics classrooms: results from an action research study examine the development of self-regulated learning behaviors in a seventh grade mathematics class. *Middle School Journal*, *45*(4), 23–32. <https://doi.org/10.1080/00940771.2014.11461893>
- <sup>138</sup> Panadero, E., Jonsson, A., & Botella, J. (2017). Effects of self-assessment on self-regulated learning and self-efficacy: Four meta-analyses. *Educational Research Review*, *22*, 74–98. <https://doi.org/10.1016/j.edurev.2017.08.004>
- <sup>139</sup> Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*(1), 417–444. <https://doi.org/10.1146/annurev-psych-113011-143823>
- <sup>140</sup> Zepeda, C. D., Martin, R. S., & Butler, A. C. (2020). Motivational strategies to engage learners in desirable difficulties. *Journal of Applied Research in Memory and Cognition*, *9*(4), 468–474. <https://doi.org/10.1016/j.jarmac.2020.08.007>
- <sup>141</sup> Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. In M. A. Gernsbacher, R. W. Pew, L. M. Hough, & J. R. Pomerantz (Eds.), *Psychology and the real world: Essays illustrating fundamental contributions to society* (pp. 56–64). Worth Publishers.
- <sup>142</sup> Fries, L., Son, J.Y., Givvin, K.B. et al. Practicing Connections: A Framework to Guide Instructional Design for Developing Understanding in Complex Domains. (2021). *Educational Psychology Review*, *33*, 739–762. <https://doi.org/10.1007/s10648-020-09561-x>
- <sup>143</sup> Yan, V. X., Schuetze, B. A., & Rea, S. D. (2023). Becoming better learners, becoming better teachers: Augmenting learning via cognitive and motivational theories. *Human Arenas*, *7*, 451–469. <https://doi.org/10.1007/s42087-023-00383-1>
- <sup>144</sup> Chi, M. T. H., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., Levy, R., Li, N., McDlood, K. L., Stump, G. S., Wylie, R., Xu, D., & Yaghmourian, D. L. (2018). Translating the ICAP theory of cognitive engagement into practice. *Cognitive Science*, *42*(6), 1777–1832. <https://doi.org/10.1111/cogs.12626>
- <sup>145</sup> Oyserman, D., Elmore, K., Novin, S., Fisher, O., & Smith, G. C. (2018). Guiding people to interpret their experienced difficulty as importance highlights their academic possibilities and improves their academic performance. *Frontiers in Psychology*, *9*, 781. <https://doi.org/10.3389/fpsyg.2018.00781>
- <sup>146</sup> Yan, V. X., Guadagnoli, M., & Haycocks, N. (2019). Appropriate failure to create stress-resistant learning: Lessons from cognitive psychology. In N. J. Hodges & A. M. Williams (Eds.), *Skill Acquisition in Sport: Research, Theory, and Practice* (3rd ed, pp. 313–339). Routledge. <https://doi.org/10.4324/9781351189750>
- <sup>147</sup> Barenberg, J., & Dutke, S. (2019). Testing and metacognition: retrieval practise effects on metacognitive monitoring in learning from text. *Memory*, *27*(3), 269–279. <https://doi.org/10.1080/09658211.2018.1506481>
- <sup>148</sup> Endres, T., Carpenter, S., & Renkl, A. (2024). Constructive retrieval: Benefits for learning, motivation, and metacognitive monitoring. *Learning and Instruction*, *94*, 101974. <https://doi.org/10.1016/j.learninstruc.2024.101974>
- <sup>149</sup> Fiorella, L. (2020). The science of habit and its implications for student learning and well-being. *Educational Psychology Review*, *32*(3), 603–625. <https://doi.org/10.1007/s10648-020-09525-1>
- <sup>150</sup> Wood, W., & R niger, D. (2016). Psychology of habit. *Annual Review of Psychology*, *67*(1), 289–314. <https://doi.org/10.1146/annurev-psych-122414-033417>
- <sup>151</sup> Coglian, M., Bernacki, M. L., & Kardash, C. M. (2021). A metacognitive retrieval practice intervention to improve undergraduates' monitoring and control processes and use of performance feedback for classroom learning. *Journal of Educational Psychology*, *113*(7), 1421–1440. <https://doi.org/10.1037/edu0000624>
- <sup>152</sup> Littrell-Baez, M.K., Friend, A., Caccamise, D. & Okochi, C. (2015). Using Retrieval Practice and Metacognitive Skills to Improve Content Learning. *Journal of Adolescent & Adult Literacy*, *58*(8), 682–689. <https://doi.org/10.1002/jaal.420>
- <sup>153</sup> de Bruin, A. B., Biefer, F., Hui, L., Onan, E., David, L., & Wiradhyani, W. (2023). Worth the effort: The start and stick to desirable difficulties (S2D2) framework. *Educational Psychology Review*, *35*(2), 41. <https://doi.org/10.1007/s10648-023-09766-w>
- <sup>154</sup> Fiorella, L. (2026). Applying the Psychology of Habit: Using Daily Tracking to Support Beneficial Habits. *Teaching of Psychology*, <https://doi.org/10.1177/00986283261425248>
- <sup>155</sup> Boyd, R. (2008, February 7). Do People Only Use 10 Percent of Their Brains? *Scientific American*, <http://www.scientificamerican.com/article/dopepeople-only-use-10-percent-of-theirbrains/>
- <sup>156</sup> Barnett, A. J., & Ranganath, C. (2023). Learning and memory. In G. G. Brown, B. Crosson, K. Y. Haaland, & T. Z. King (Eds.), *APA handbook of neuropsychology: Neuroscience and neuromethods* (pp. 77–95). American Psychological Association. <https://doi.org/10.1037/0000308-004>
- <sup>157</sup> Nielsen, J. A., Zielinski, B. A., Ferguson, M. A., Lainhart, J. E., & Anderson, J. S. (2013). An evaluation of the left-brain vs. right-brain hypothesis with resting state functional connectivity magnetic resonance imaging. *PloS one*, *8*(8), e71275. <https://doi.org/10.1371/journal.pone.0071275>
- <sup>158</sup> D. H. Robinson, V. X. Yan, & J. A. Kim (Eds.). (2022). *Monographs in the Psychology of Education: Learning Styles, Classroom Instruction, and Student Achievement*. Springer. <https://doi.org/10.1007/978-3-030-90792-1>
- <sup>159</sup> Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review*, *36*(1), 8. <https://doi.org/10.1007/s10648-023-09842-1>
- <sup>160</sup> Chi, M.T.H. (2011). Theoretical Perspectives, Methodological Approaches, and Trends in the Study of Expertise. In Li, Y., Kaiser, G. (Eds.) *Expertise in Mathematics Instruction*. Springer. [https://doi.org/10.1007/978-1-4419-7707-6\\_2](https://doi.org/10.1007/978-1-4419-7707-6_2)
- <sup>161</sup> Hagen, S., & Tanaka, J. (2015). Perceptual learning and expertise. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge handbook of applied perception research*, Vol. 2, (pp. 733–748). Cambridge University Press. <https://doi.org/10.1017/CBO9780511973017.045>
- <sup>162</sup> Froyd, J., & Layne, J. (2008, October). Faculty development strategies for overcoming the "Curse of knowledge". In 2008 *38th Annual Frontiers in Education Conference* (pp. S4D-13). IEEE. <https://doi.org/10.1109/FIE.2008.4720529>
- <sup>163</sup> Willingham, D. T. (2009). *Why Don't Students Like School?* Jossey-Bass.
- <sup>164</sup> Soderstrom, N. C., & Bjork, R. A. (2015). Learning versus performance: An integrative review. *Perspectives on Psychological Science*, *10*(2), 176–199. <https://doi.org/10.1177/1745691615569000>