Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

Strategies for Memory and Recall

Retrieval Practice

There are three stages to learning: **encoding**, **storage**, and **retrieval**. Encoding deals with getting information *in* to student's heads, storage focuses on getting information to "stick", and retrieval focuses on getting information *out*.

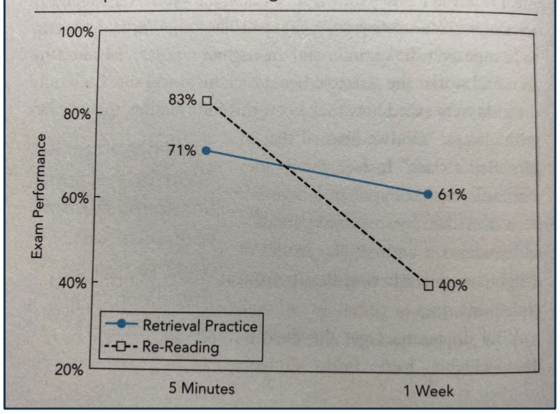
As a profession, we spend a lot of time trying to improve teachers' instructional delivery (encoding). However, a robust body of research identifies the importance of using retrieval to improve students' long-term retention of key material.

Retrieval practice (often referred to as **the testing effect**) is about using assessment *for* learning, instead of just assessment *of* learning.

Retrieval practice (and its variations **spacing** and **interleaving**) are a type of **desirable difficulty**. A desirable difficulty is something that makes learning harder and feels more difficult, but is shown to improve outcomes for learners.

In the graph below from Roediger and Karpicke's (2006) research, students were placed in two conditions to study for a test. The first group re-read their notes while the other practiced testing themselves on the materials. Students in the re-reading condition performed better in the short-term, but students in the retrieval condition saw less learning loss a week later, where they outperformed the re-reading group by 21%.

Figure 2.1 College students remember information after re-reading in the *short term*, but retain significantly more after retrieval practice over the *long term*.



This effect has been replicated countless times. It should also be noted that students tend to think that things like re-reading or highlighting their notes will help them do better, while giving themselves a test will not. This appears to be due to the **"illusion of mastery,"** which is where re-reading makes students *feel* like they've mastered the material, but when it comes time to retrieve it from their memory, they're unable to because they haven't practice it.

Design Considerations

When designing K-5 Integrated materials, retrieval should be leveraged as a learning strategy as frequently as possible. There are many ways to do this before, during and after the lesson. Just a few examples:

- **Low- or no-stakes quizzes:** 3-5 question quizzes that require students to retrieve from long-term memory concepts they have learned recently as well as earlier in the year.
- **Self-testing:** Instead of re-reading or highlighting their notes, students should test themselves on material and evaluate their responses.
- **Brain Dumps:** Giving students brief opportunities to retrieve everything they know about a topic and then discuss it or write about it.
- **"Retrieve-taking":** In this variation on note-taking, the teacher presents information in small chunks, then has students write down key points. This requires them to retrieve information they have briefly started to forget as they add it to their notes.

We should explore as many creative ways as we can to encourage retrieval of previous learned content as the year progresses to strengthen connections in long-term memory.

It will also be important to train teachers on 1) how to explain "desirable difficulties" to students so they persist through challenge and 2) to expect lower performance during short-term practice with retrieval compared to other conditions.

References and Resources

Powerful Teaching: Unleash the Science of Learning (Agarwal & Bain, 2019)

Retrieval Practice and the Maintenance of Knowledge (Bjork, 1988)

The Critical Role of Retrieval Practice in Long-Term Retention (Roediger & Butler, 2011)

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

Test-Enhanced Learning: Taking Memory Tests Improves Long-Term Retention (Roediger & Karpicke, 2006)

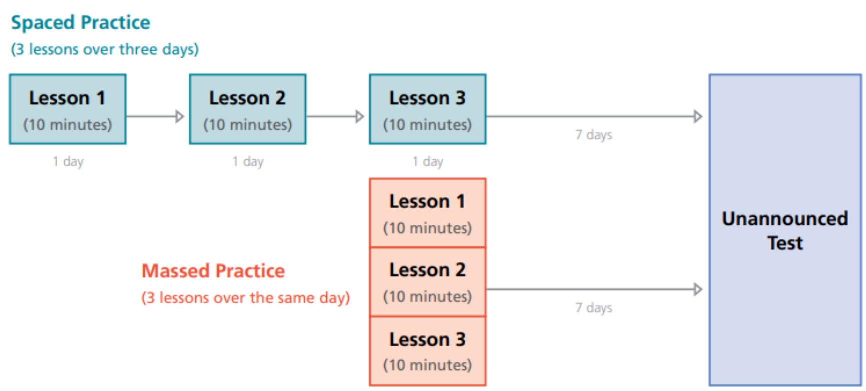
How to Use Retrieval Practice to Improve Learning (Agarwal, et al., 2020)

Make it Stick: The Science of Successful Learning (Brown, Roediger, & McDaniel, 2014)

Spaced Practice

Spaced practice (also known as **spacing**) is related to retrieval practice. Spacing is engaging in retrieval practice over time.

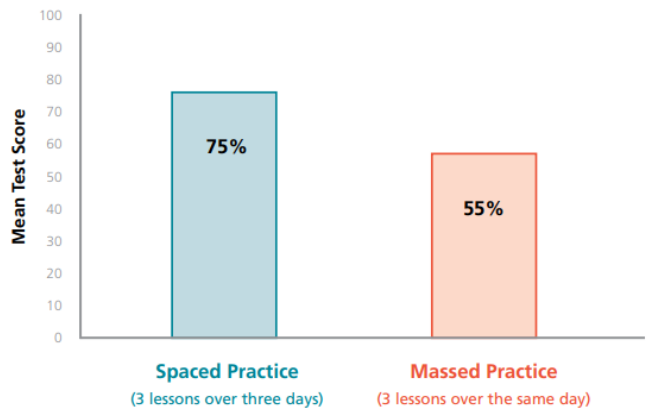
In a 1981 study conducted by Bloom and Shuell, students were split into two groups. Both groups had 30 minutes of instruction on a topic. Group 1 spaced those lessons out over three days, while group 2 experienced massed practice with all three lessons taking place in the same day. Both groups then took an unannounced test a week later.



Students in the spaced practice condition scored 20% higher than students in the massed practice condition on the unannounced test.

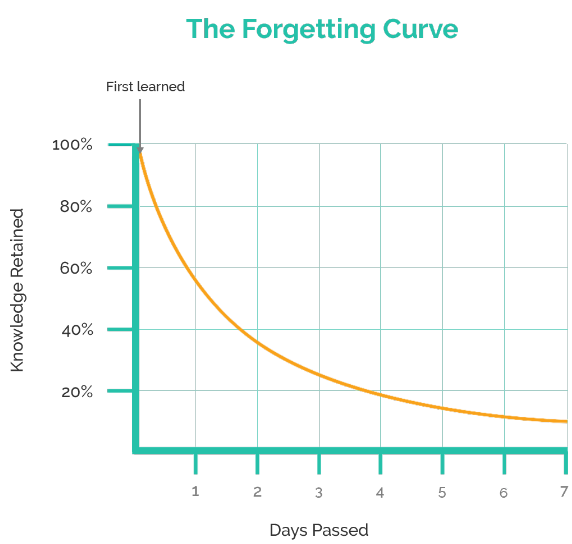
Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series



Ebbinghaus' Forgetting Curve

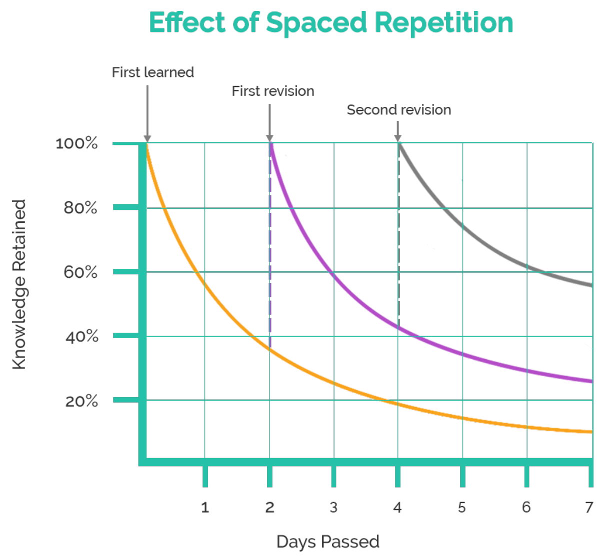
Spaced practice can counteract **Ebbinghaus' Forgetting Curve.** The Forgetting Curve shows a steep, initial decline (in other words, fast forgetting) immediately after learning something, then a gradual slowing over time.



If students engage in spaced retrieval/repetition, the Forgetting Curve is interrupted, the memory is strengthened, and the curve becomes much more gradual.

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series



Design Considerations

In designing K-5 Integrated, students need constant opportunities to interrupt their forgetting curve. This could include retrieval opportunities from material studied days, weeks, or months prior; frequent low-stakes quizzes spaced out over time; and cumulative quizzes and exams.

Tools such as **Power Tickets** are an example of a modified exit ticket that engages students in spaced retrieval practice.

What did we talk about…

	Today?	*Yesterday?*	*Last week?*	*Last month?*	*Last quarter?*	*Last semester?*
	[insert concept 1]	[insert concept 2]	[insert concept 3]	[insert concept 4]	[insert concept 5]	[insert concept 6]
Write **one** fact						
Write a **second** fact						
Write a **third** fact						

Careful consideration also needs to be given to engineering the optimal spacing lag when considering spaced practice opportunities. Kang's 2016 paper references research findings that the optimal lag for spacing depends on the targeted retention interval. Ultimately, for long-term retention, spacing should occur on an **expanding schedule**, with the lag between each success review progressively increasing over time.

We have a unique opportunity with the K-5 Integrated product to offer spaced practice both within and across content areas. We should take advantage of every opportunity for students to retrieve key facts, ideas, concepts or procedures from other content areas.

References and Resources

The Science of Effective Learning with Spacing and Retrieval Practice (Carpenter, Pan & Butler, 2022)

Effects of Massed and Distributed Practice on the Learning and retention of Second-Language Vocabulary (Bloom & Shuell, 1981)

Practice Tests, Spaced Practice, and Successive Relearning (Dunlosky & Rawson, 2015)

Spaced Repetition Promotes Efficient and Effective Learning: Policy Implications for Instruction (2016)

How to Use Spaced Retrieval Practice to Boost Learning (Carpenter & Agarwal, 2020)

Replication and Analysis of Ebbinghaus' Forgetting Curve (Murre & Dros, 2015)

Spaced Effect Learning and Blunting the Forgetfulness Curve (Wollstein & Jabbour, 2022)

Interleaved Practice

Also known as **interleaving**, interleaved practice is a set of problems mixed in a certain way. Key to interleaving is that problem sets are arranged so that consecutive problems cannot be solved by the same strategy. Interleaving is the opposite of **blocked practice**, in which students can solve multiple problems using the same strategy.

Interleaving relies on **discrimination**, which is a student's ability to choose the appropriate strategy to solve similar but different problems.

A 2015 study on interleaving in 7th grade mathematics organized students into two groups. Group 1 was "business as usual" blocked practice: the teacher would teach on Topic A, then students would practice Topic A. The next day, the teacher would teach Topic B, then students would practice Topic B.

Group 2 (the interleaved condition) would learn about Topic A, complete several practice problems on Topic A, but then complete one problem each on eight different previously learned skills.

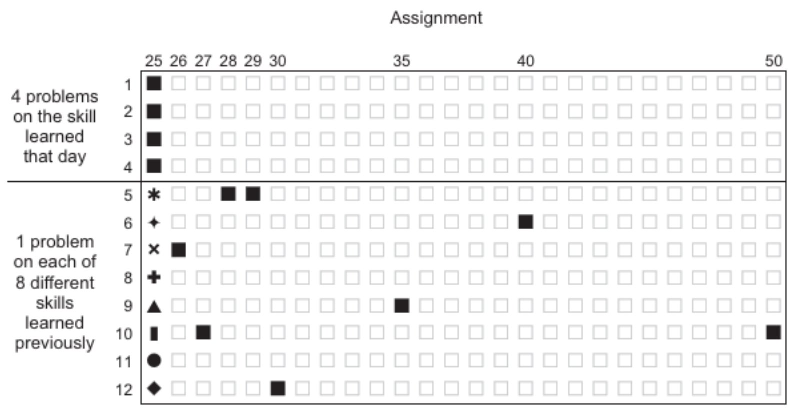


Figure 2. Interleaved mathematics practice. In this hypothetical illustration, Assignment 25 includes a small block of four problems (squares) and eight problems of interleaved practice (non-squares). For example, if Assignment 25 follows a lesson on proportions, it would include four problems on proportions and one problem on each of eight different skills learned earlier in the course or during a prior course. Eight additional proportion problems are distributed across subsequent assignments. The empty squares are placeholders for unidentified kinds of problems.

This went on for about 90 days, then each group completed a review after seven days, then took a test after one day or 30 days. As shown below, students in the interleaved condition outperformed the blocked condition on both tests, with a significant gap between the two groups after 30 days.

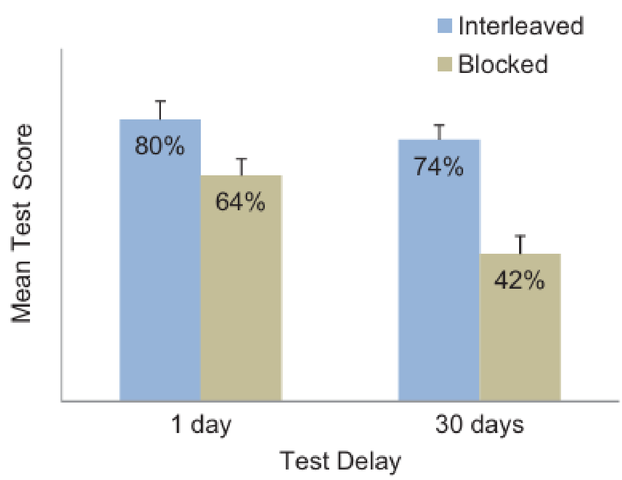


Figure 4. Results: Interleaving produced greater test scores at both test delays. Error bars represent 1 standard error. See the online article for a color version of this figure.

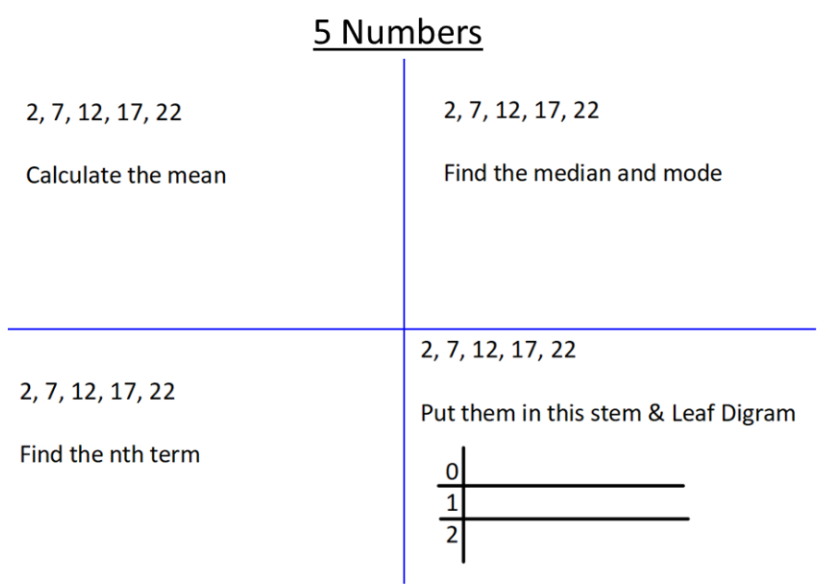
Design Considerations

- We need to conduct a small-scale pilot of current Bluebonnet Learning K-5 Math users to test if interleaved problem sets and/or homework will increase student achievement. Based on those results, we should consider a restructuring of our approach to Problem Sets from a blocked approach to one that is more spaced and interleaved.
- We also need to conduct additional research on interleaving in other content areas such as RLA, Science and Social Studies and incorporate interleaving practices in those areas as well.
- Teachers will need training on the purpose of interleaved practice so they can support students to persevere through more challenging problem sets.

"Same Surface, Different Deep"

There is an interesting approach to interleaved problem sets called "Same Surface, Different Deep." The idea behind these problems is that they require a significant amount of discrimination by students. This is due to their surface features being nearly identical while the underlying structure of the problem is different.

An example called "5 Numbers" is shown below.



Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

We should explore the use of the SSDD structure for use in the math component of K-5 Integrated. This could potentially be used as a cumulative review activity, where students are given one stimulus and asked four problems with different underlying structures

References and Resources

The Effects of Interleaved Practice (Taylor & Rohrer, 2009)

Interleaved Practice Improves Mathematics Learning (Rohrer, Dedrick, & Stershic, 2015)

The Relationship between Interleaving and Variability Effects: A Cognitive Load Theory Perspective (Chen, et al., 2023)

Interleaved practice in multi-dimensional learning tasks: Which dimension should we interleave? (Rau, Aleve, & Rummel, 2011)

Interleaving Retrieval Practice Promotes Science Learning (Sana & Yan, 2022)

Effective Approaches for Scheduling and Formatting Practice (Hughes & Lee, 2019)

How I Wish I'd Taught Maths (Barton, 2017)

Same Surface, Different Deep (ssddproblems.com)

Interleaved Mathematics Practice (Rohrer, Dedrick, & Agarwal, 2017)

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

Pretesting Effect

Research on the **pretesting effect** shows that taking a test on information *before* learning it has a significantly positive impact on learning. It seems counterintuitive to test students on material they haven't learned yet (which will obviously include generating incorrect answers), but extensive research shows that students perform better on posttests when they have taken a related pretest first.

Multiple theories propose that the pretesting effect supports learning in several ways including activating retrieval processes, strengthening memory, and increasing attentional focus on the material to be learned.

In Richland, Kornell, and Kao's 2009 pretesting study, two conditions were compared. Group 1 (extended study) was given extended time to study new material, then took a post test on the material. Group 2 (test and study) took a pre-test, studied, and then took a post test.

The data below shows Group 1's performance in the extended study condition compared to Group 2s performance on the items that were and were not included on the pretest. In the "Test and Study" condition, performance on items *not* on the pretest is represented by the white bar while performance on items that *were* on the pretest is represented by the grey bar.

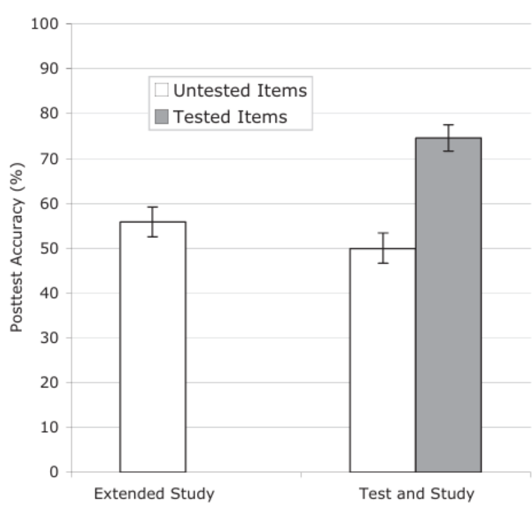


Figure 1. Experiment 1: Performance on a final test across conditions when studying an unmarked text.

Group 2's post test performance on pretested items exceeds that of students in the extended study condition by nearly 20%.

Design Considerations

- Pretests should be a core design component of K-5 Integrated in all content areas.
- Spaced retrieval practice should be combined with pretesting. For example, lessons could begin with a five-question low/no stakes quiz: three of those questions could be retrieval of previous learning while the remaining questions could be pretest questions of untaught material to prepare for the day's lesson.
- Pretesting could also be used at the unit level to both serve a diagnostic function for teachers and to prepare students for the most important information in the unit.
- *Where* pretested information is located in a lesson appears to be key to supporting acquisition of *non-pretested* information. From Sana and Carpenter's 2023 study, information not included on the pretest gets a "bump" in posttest performance if included *before* the pretested information is presented. The authors theorize that the "curiosity window" opened by the pretest closes once the pretested information has been identified in the lesson.
- The pretesting effect is counterintuitive, so teacher training on the importance and role of pretests is key. For pretests to be considered valuable by teachers, they need to understand the research behind the pretesting effect and its impact on student outcomes.

References and Resources

The Pretesting Effect: Do Unsuccessful Retrieval Attempts Enhance Learning? (Richland, Kornell, & Kao, 2009)

Prequestioning and Pretesting Effects: a Review of Empirical Research, Theoretical Perspectives, and Implications for Educational Practice (Pan & Carpenter, 2023)

Metacognitive Awareness of the Pretesting Effect Improves with Self-Regulation Support (Pan & Rivers, 2023)

Broader Benefits of the Pretesting Effect: Placement Matters (Sana & Carpenter, 2023)

The Pretesting Effect Thrives in the Presence of Competing Information (Kliegl, Bartl, & Bauml, 2023)

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

Metacognition

Metacognition is the ability to "think about one's thinking" and evaluate one's knowledge. Generally, mistakes in thinking occur at two levels: one is at the **cognitive** level (where a student's memory was incorrect), the other is at the **metacognitive** level (where a student's *confidence* in the correctness of their memory was incorrect).

Researchers evaluate metacognition by asking students to make two types of ratings: **"judgments of learning"**, which predict *future* learning or memory or **confidence judgments**, which is a student's confidence in *recent* or *past* learning.

Metacognition is important because providing students with a clear understanding of their knowledge drives behavior and decisions, both for teachers and for student study habits.

In one study, students who completed "Metacognition Sheets" and reflection questions at the end of lectures showed an increase in exam performance nearly a letter grade higher than lectures alone.

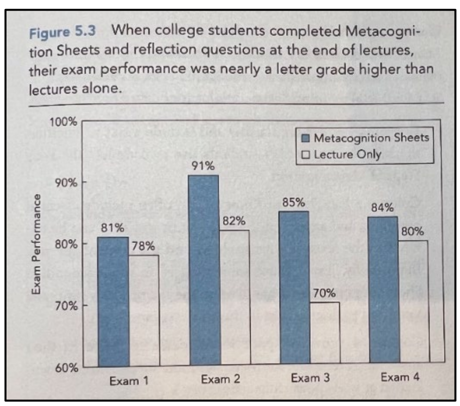
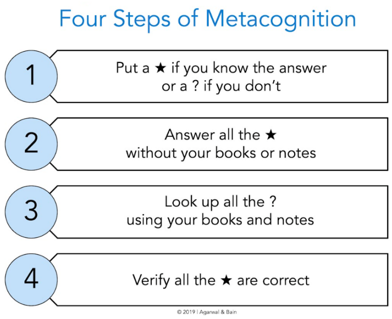


Figure 5.3 When college students completed Metacognition Sheets and reflection questions at the end of lectures, their exam performance was nearly a letter grade higher than lectures alone.

Tools like "Metacognition Sheets" (shown below on right) require students to answer factual questions (cognitive level) *and* evaluate their confidence in the accuracy of their response (metacognitive level). Students engage in this process using Agarwal and Bain's (2019) "Four Steps of Metacognition."

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series



Four Steps of Metacognition: Example Concepts from World History

☆	?	Items to Know	Answer
		Maximilien Robespierre	
		Definition of "revolution"	
		How did each revolution change the lives of working people?	
		How did the social pyramids change as a result of the revolutions?	

Design Considerations

- Opportunities for metacognition and reflection on understanding should be built in to all content areas in K-5 Integrated.
- Tools and processes like "Metacognition Sheets" are simple approaches that engage students in spaced retrieval practice as well as metacognition.
- Retrieval opportunities should also include confidence judgments, where students evaluate their confidence in the accuracy of their answer. These judgments can then direct teachers on providing feedback on low-confidence correct answers to ensure correct answers are reinforced. (Butler, Roediger, & Karpicke, 2008)
- All opportunities for retrieval must be coupled with feedback so students can reflect on their understanding and the accuracy of their knowledge.
- We need to build support for teachers to teach students how to study based on the results of their own metacognitive evaluation.
- Teachers will need training on how to support students with evaluating their knowledge and engaging in metacognitive practices.

References and Resources

Correcting a Metacognitive Error: Feedback Increases Retention of Low-Confidence Correct Responses (Butler, Roediger, & Karpicke, 2008)

Developing a Reflective Mind: From Core Metacognition to Explicit Self-Reflection (Goupil & Kouider, 2019)

Improving Metacognition in the Classroom through Instruction, Training, and Feedback (Callender, Franco-Watkins, & Roberts, 2015)

Improving Self-Regulated Learning with a Retrieval Practice Intervention (Ariel & Karpicke, 2018)

When People's Judgments of Learning (JOLs) Are Extremely Accurate at Predicting Subsequent Recall: The "Delayed-JOL Effect" (Nelson & Dunlosky, 1991)

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series

Metacognition: How to Improve Students' Reflections on Learning (Son, Furlonge, & Agarwal, 2020)

Science of Learning Concepts

Classroom Teacher Pedagogy Standards EC–12 Learning Series