DEANS FOR IMPACT

WHAT YOU WON'T FIND IN THIS DOCUMENT:
"Technology"
"Critical thinking"
Learner-centered classrooms
Personalized learning
Project-based learning
Teachers being a "guide on the side, not a sage on the stage"
Students “taking ownership” of their learning
“Action research”
Peer editing
Grammar being "caught not taught"
Whole language
Balanced literacy
Reading workshop
Writing workshop
Constructivism
Google as the curriculum
Tony Wagner
21st century skills
Teachers “taking risks”

THE SCIENCE OF LEARNING

* **The primary task of the school is to move knowledge inside students’ long-term memory.**

* Knowledge = facts and other information organized and connected by a “schema,” all stored inside long-term memory. Knowledge includes understanding; it's very difficult to memorize material you don't understand.

* However, the understanding of a novice is inflexible and shallow, *and that is normal and appropriate.* Beginners need only beginner-level understanding.

* The schema is modified and refined as students gain sophistication in a subject; as more facts are committed to memory; and as new connections among remembered facts are forged.

* Moving knowledge inside students’ long-term memory requires **an explicit, sequenced, and coherent curriculum**; an **effective practice regimen**; and **a knowledgeable teacher who assigns and oversees learning activities and assesses student learning and comprehension**.

* Students are novices. Novices think differently from experts.

* Experts can teach themselves (though experts also benefit from expert teaching). Novices can't.

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About
THE SCIENCE OF LEARNING

The purpose of *The Science of Learning* is to summarize the existing research from cognitive science related to how students learn, and connect this research to its practical implications for teaching and learning. This document is intended to serve as a resource to teacher-educators, new teachers, and anyone in the education profession who is interested in our best scientific understanding of how learning takes place.

This document identifies six key questions about learning that should be relevant to nearly 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 Science of Learning was developed by member deans of Deans for Impact in close collaboration with Dan Willingham, a cognitive scientist at the University of Virginia, and Paul Bruno, a former middle-school science teacher. We are greatly indebted to the reviewers who provided thoughtful feedback and comments on early drafts, including cognitive scientists, teacher-educators, practicing teachers, and many others.

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. Because our scientific understanding is ever evolving, we expect to periodically revise *The Science of Learning* to reflect new insights into cognition and learning. We hope that teachers, teacher-educators, and others will conduct additional research and gather evidence related to the translation of these scientific principles to practice.

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About
DEANS FOR IMPACT

Founded in 2015, Deans for Impact is a national nonprofit organization representing leaders in educator preparation who are committed to transforming educator preparation and elevating the teaching profession. The organization is guided by four key principles:

- Data-informed improvement;
- Common outcome measures;
- Empirical validation of effectiveness; and
- Transparency and accountability for results.

More information on the organization and its members can be found on the Deans for Impact website.

www.deansforimpact.org

DEANS FOR IMPACT

1 HOW DO STUDENTS UNDERSTAND NEW IDEAS?

The core mission of a K-12 school is to move knowledge from teacher and textbook inside students' long-term memory. To do that, schools need a coherent, sequenced, field-tested curriculum. Using Google to find lessons and worksheets does nto produce a coherent curriculum.

COGNITIVE PRINCIPLES

PRACTICAL IMPLICATIONS FOR THE CLASSROOM

Prior knowledge stored inside long-term memory, not on Google

Students learn new ideas by reference to ideas they already know.[1]

Students can't "discover" these relationships for themselves.

- A well-sequenced curriculum is important to ensure that students have the prior knowledge they need to master new ideas.[2]
- Teachers use analogies because they map a new idea onto one that students already know. But analogies are effective only if teachers elaborate on them, and direct student attention to the crucial similarities between existing knowledge and what is to be learned.[3]

I do/we do/you do
Classic direct instruction

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). Students have limited working memory capacities that can be overwhelmed by tasks that are cognitively too demanding. Understanding new ideas can be impeded if students are confronted with too much information at once.[4]

- Teachers can use "worked examples" as one method of reducing students' cognitive burdens.[5] A worked example is a step-by-step demonstration of how to perform a task or solve a problem. This guidance – or "scaffolding" – can be gradually removed in subsequent problems so that students are required to complete more problem steps independently.
- Teachers often use multiple modalities to convey an idea; for example, they will speak while showing a graphic. If teachers take care to ensure that the two types of information complement one another – such as showing an animation while describing it aloud – learning is enhanced. But if the two sources of information are split – such as speaking aloud with different text displayed visually – attention is divided and learning is impaired.[6]
- Making content explicit through carefully paced explanation, modeling, and examples can help ensure that students are not overwhelmed.[7] *(Note: "explanation" does not mean teachers must do all the talking.)*

Research: the most effective teachers speak in short 5 to 7-minute bursts.

Cognitive development does not progress through a fixed sequence of age-related stages. The mastery of new concepts happens in fits and starts.[8]

- Content should not be kept from students because it is "developmentally inappropriate." The 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?"[9]

Effective charter schools use homogeneous grouping.

[1] Bransford, Brown, & Cocking, 2000
[2] Agodini, Harris, Atkins-Burnett, Heaviside, Novak, & Murphy, 2009; TeachingWorks
[3] Richland, Zur, & Holyoak, 2007
[4] Sweller, 1988
[5] Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007; Kirschner, Sweller, & Clark, 2006; Atkinson, Derry, Renkl, & Wortham, 2000; Sweller, 2006
[6] Chandler & Sweller, 1992; Moreno & Mayer, 1999; Moreno, 2006
[7] Kirschner, Sweller, & Clark, 2006; TeachingWorks
[8] Flynn, O'Malley, & Wood, 2004; Siegler, 1995
[9] Willingham, 2008

Morningside Academy, in Seattle, uses homogeneous grouping for all subjects during all periods of the day. The school guarantees that students (all of whom are having learning difficulties in their public schools) will make 2 years' progress in 1 year's time, in their subject of greatest difficulty, or tuition is refunded. Homogeneous grouping is critical to their success.

2 HOW DO STUDENTS LEARN AND RETAIN NEW INFORMATION?

COGNITIVE PRINCIPLES

PRACTICAL IMPLICATIONS FOR THE CLASSROOM

Teacher-guided, not peer-guided

Information is often withdrawn from memory just as it went in. We usually want students to remember what information means and why it is important, so they should think about meaning when they encounter to-be-remembered material.[10]

- Teachers can assign students tasks that require explanation (e.g., answering questions about how or why something happened) or that require students to meaningfully organize material. These tasks focus students' attention on the meaning of course content.[11]
- Teachers can help students learn to impose meaning on hard-to-remember content. Stories and mnemonics are particularly effective at helping students do this.[12]

Mnemonics are a memorization aid
Memorization is a good thing, not a bad thing

Practice is essential to learning new facts, but not all practice is equivalent.[13]

* The teacher--not the student, the parent, or the tutor--structures the practice regimen and assesses its effectiveness

* Telling 6th-grade students to "brush up" on their math skills over the summer isn't teaching

* Sending an email to a parent warning that her child is likely to fail Regents isn't teaching

- Teachers can space practice over time, with content being reviewed across weeks or months, to help students remember that content over the long-term.[14]
- Teachers can explain to students that trying to remember something makes memory more long-lasting than other forms of studying. Teachers can use low- or no-stakes quizzes in class to do this, and students can use self-tests.[15]
- Teachers can interleave (i.e., alternate) practice of different types of content. For example, if students are learning four mathematical operations, it's more effective to interleave practice of different problem types, rather than practice just one type of problem, then another type of problem, and so on.[16]

Daily quizzes w/ immediate feedback are effective

Again: students need coherent, carefully sequenced instruction, which includes a coherent, carefully sequenced practice regimen

* The responsibility for *learning* can't be outsourced to after-school hours, leaving students to explore and discover during the school day. Teachers must provide effective practice regimens & oversee students as they practice.

* All "basal ganglia" learning (skill learning) requires immediate and unambiguous feedback.

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[10] Morris, Bransford, & Franks, 1977

[11] McDaniel, Hines, Waddill, & Einstein, 1994; Rosenshine, Meister, & Chapman, 1996; Graesser & Olde, 2003; TeachingWorks

[12] Peters & Levin, 1986

[13] Ericsson, Krampe, & Tesch-Römer, 1993

[14] Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007

[15] Agarwal, Bain, & Chamberlain, 2012; Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007

[16] Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007; Rohrer, Dedrick, & Stershic, 2015

3 HOW DO STUDENTS SOLVE PROBLEMS?

COGNITIVE PRINCIPLES

PRACTICAL IMPLICATIONS FOR THE CLASSROOM

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. The size and content of this set varies by subject matter.[17]

- Teachers will need to teach different sets of facts at different ages. For example, the most obvious (and most 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. Math facts (e.g., 8 x 6 = ?) are embedded in other topics (e.g., long division). A child who stops to calculate may make an error or lose track of the larger problem.[18] The advantages of learning to read by phonics are well established.[19]

* The fundamentals must be committed to long-term memory, not looked up on cell phones.

* Facts stored inside long-term memory are different from facts stored on Google: different usability, different meaning, & different connectedness to other facts.

Effective feedback is often essential to acquiring new knowledge and skills.[20]

- Good feedback is:
  - Specific and clear;
  - Focused on the task rather than the student; and
  - Explanatory and focused on improvement rather than merely verifying performance.[21]

* Research supports the existence of two learning systems inside the brain: declarative memory (facts, dates, persons, places, things, etc.) and nondeclarative or implicit memory (bicycle riding, paper-and-pencil arithmetic, perceptual learning, category learning, intuition).
* No one knows, yet, how the two systems are related.
* Implicit memory requires *immediate* feedback, which means worksheets must be done in class – or the answer sheet must go home with students so they can check their answers.
* For implicit memory, immediate "right-wrong" feedback is all that's required. Explanations may actually be counterproductive (though this is still being researched).
* Clear explanations are *vitally* important to declarative memory.
* "All memories for events and facts depend on skill memories, because the abilities to speak, write, and gesture to convey information are learned abilities that improve over time with practice." (*Learning and Behavior* by Gluck, Mercado, & Myers)

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[17] Glaser & Chi, 1988; TeachingWorks

[18] National Mathematics Advisory Panel, 2008

[19] National Reading Panel, 2000; EU High Level Group of Experts on Literacy, 2012

[20] Ericsson, Krampe, & Tesch-Römer, 1993

[21] Ericsson, Krampe, & Tesch-Römer, 1993; Shute, 2008; TeachingWorks; Butler & Winne, 1995; Hattie & Timperley, 2007

4 HOW DOES LEARNING TRANSFER TO NEW SITUATIONS IN OR OUTSIDE OF THE CLASSROOM?

Solving novel problems depends upon knowledge stored inside long-term memory, and getting knowledge into students' long-term memory is the school's job.

COGNITIVE PRINCIPLES

PRACTICAL IMPLICATIONS FOR THE CLASSROOM

The transfer of knowledge or skills to a novel problem requires both knowledge of the problem's context and a deep understanding of the problem's underlying structure.[22]

- Teachers can ensure that students have sufficient background knowledge to appreciate the context of a problem.[23]

We understand new ideas via examples, but it's often hard to see the unifying underlying concepts in different examples.[24]

The teacher is a "sage on the stage"

- Teachers can have students compare problems with different surface structures that share the same underlying structure. For example, a student may learn to calculate the area of a rectangle via an example of word problem using a table top. This student may not immediately recognize this knowledge is relevant in a word problem that asks a student to calculate the area of a soccer field. By comparing the problems, this practice helps students perceive and remember the underlying structure.[25]
- 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.[26]
- Teachers can alternate concrete examples (e.g., word problems) and abstract representations (e.g., mathematical formulas) to help students recognize the underlying structure of problems. [27]

[22] Bransford, Brown, & Cocking, 2000; Pellegrino & Hilton, 2012

[23] Pellegrino & Hilton, 2012; Day & Goldstone, 2012

[24] Richland, Zur, & Holyoak, 2007; Ainsworth, Bibby, & Wood, 2002

[25] Richland, Zur, & Holyoak, 2007; Gentner, et al., 2015

[26] Catrambone, 1996; Catrambone, 1998

[27] Goldstone & Son, 2005; Botge, Rueda, Serlin, Hung, & Kwon, 2007

5 WHAT MOTIVATES STUDENTS TO LEARN?

COGNITIVE PRINCIPLES	PRACTICAL IMPLICATIONS FOR THE CLASSROOM
Beliefs about intelligence are important predictors of student behavior in school. [28]	• Teachers should know that students are more motivated if they believe that intelligence and ability can be improved through hard work.[29] • Teachers can contribute to students' beliefs about their ability to improve their intelligence by praising productive student effort and strategies (and other processes under student control) rather than their ability.[30] • Teachers can prompt students to feel more in control of their learning by encouraging them to set learning goals (i.e., goals for improvement) rather than performance goals (i.e., goals for competence or approval).[31]
Self-determined motivation (a consequence of values or pure interest) leads to better long-term outcomes than controlled motivation (a consequence of reward/punishment or perceptions of self-worth).[32]	• Teachers control a number of factors related to reward or praise that influence student motivation, such as: ▪ whether a task is one the student is already motivated to perform; ▪ whether a reward offered for a task is verbal or tangible; ▪ whether a reward offered for a task is expected or unexpected; ▪ whether praise is offered for effort, completion, or quality of performance; and ▪ whether praise or a reward occurs immediately or after a delay.[33]
The ability to monitor their own thinking can help students identify what they do and do not know, but people are often unable to accurately judge their own learning and understanding.[34]	• Teachers can engage students in tasks that will allow them to reliably monitor their own learning (e.g., testing, self-testing, and explanation).[35] If not encouraged to use these tasks as a guide, students are likely to make judgments about their own knowledge based on how familiar their situation feels and whether they have partial – or related – information. These cues can be misleading.[36]
Students will be more motivated and successful in academic environments when they believe that they belong and are accepted in those environments.[37]	• Teachers can reassure students that doubts about belonging are common and will diminish over time.[38] • Teachers can encourage students to see critical feedback as a sign of others' beliefs that they are able to meet high standards.[39]

[28] Burnette, O'Boyle, VanEpps, Pollack, & Finkel, 2013
[29] Burnette, O'Boyle, VanEpps, Pollack, & Finkel, 2013; Yeager, Johnson, Spitzer, Trzesniewski, Powers, & Dweck, 2014
[30] Mueller & Dweck, 1998; Blackwell, Trzesniewski, & Dweck, 2007; Kamins & Dweck, 1999
[31] Elliott & Dweck, 1988; Smiley & Dweck, 1994
[32] Davis, Winsler, & Middleton, 2006
[33] Deci, Koestner, & Ryan, 1999; Levitt, List, & Neckermann, 2012
[34] Koriat, 1993
[35] Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007; Karpicke, Butler, & Roediger, 2009
[36] Koriat & Levy-Sadot, 2001
[37] Yeager, Walton, & Cohen, Addressing achievement gaps with psychological interventions, 2013
[38] Walton & Cohen, 2011; Yeager, Walton, & Cohen, Addressing achievement gaps with psychological interventions, 2013
[39] Yeager, et al., 2014; Cohen, Steele, & Ross, 1999

Students can't be left alone to assess their own learning. They must be explicitly taught how to study and how to determine whether they've learned or must carry on working.

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

COGNITIVE PRINCIPLES

- Students do not have different "learning styles."[40]
- Humans do not use only 10% of their brains.[41]
- People are not preferentially "right-brained" or "left-brained" in the use of their brains.[42]
- Novices and experts cannot think in all the same ways.[43]
- Cognitive development does not progress via a fixed progression of age-related stages.[44]

PRACTICAL IMPLICATIONS FOR THE CLASSROOM

- Teachers should be able to recognize common misconceptions of cognitive science that relate to teaching and learning.

The notion that "all children learn differently" is false.
We all have the same brain biology. Children differ most notably in speed of learning and in motivation to learn.

Very important. K-12 students should not be seated in pods and expected to behave like "leadership teams" or graduate students. They are novices; they need teachers.

[40] Pashler, McDaniel, Rohrer, & Bjork, 2008
[41] Boyd, 2008
[42] Nielson, Zielinski, Ferguson, Lainhart, & Anderson, 2013
[43] Glaser & Chi, 1988
[44] Willingham, 2008

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