JAEPR, 3(*1*),

TRANSFER OF INFORMATION

How do Students Learn and Retain New Information? A Response to the Deans for Impact Report, *The Science of Learning*

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This article explores the second Key Question and provides a review of the 11 pieces of literature the Deans for Impact used to support their second question, "How do students learn and retain information?" in the Science of Learning article. This article determined that literature used to support the Deans for Impact article is appropriate and validates their position. This review does reveal that the bulk of the supporting studies were conducted on students at post-secondary schools which may have influenced the data. A wider range of subject ranges may have made the report more applicable to the intended audience.

Keywords: Cooperative Learning, Mnemonics, Question Generation, Quizzing, Feedback, Deliberate practice

The Deans for Impact: *Science of Learning* (2015) report (DFI) was designed to provide an overview of the existing research from cognitive science on how students learn in order to help colleges of education better instruct future teachers. This article will focus on the second Key Question in the report which asks, "How do students learn and retain new information?" The authors rely on two key cognitive principles to answer this question. The first cognitive principle addresses the impact of remembering information, while the second cognitive principle focuses on practice as a method to learn and master new material. Within this literature review, each cognitive principle will be discussed and the current research regarding the cognitive principles will be analyzed.

COGNITIVE PRINCIPLE 1

Information is often withdrawn from memory just as it went in.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 the meaning when they encounter to-be-remembered material.

The DFI report offers five research studies to support the first cognitive principle addressing Key Question 2. Three of the studies were written before 2000 with the oldest study being written in 1977. There is one current online publication from the University of Michigan. The first study, from Morris, Bransford, and Franks (1977), found that the semantic acquisition model (learning by focusing on the meaning) has a higher level of retention than that of rhyme acquisition (focusing on sound and mouth position). The authors arrived at this conclusion after conducting three experiments with 171 college students in introductory psychology classes. Each experiment consisted of a set of semantic and rhyming tasks followed by either a semantic or rhyming test after task completion. During experiment one, some students were given a standard recognition test and others were given a rhyming recognition test. The second experiment differed slightly as it incorporated a delay of 24 hours between task completion and testing. In experiment three, all subjects received a rhyming acquisition test after task completion. The results of the experiments showed students who participated in the study were able to recall more information by focusing on the meaning not just superficial factors such as phonetic patterns. However, the experiments showed each subject participant performed better when they were given tests that aligned to the way in which they learned the material. This study supports cognitive principle one by demonstrating that the connection between understanding content on a semantic level helps improve memory of that material.

Some research shows that incorporating information within a story can enhance meaning and thus improve retention. McDaniel, Hines, Waddill, & Einstein (1994) developed six experiments to identify the specific attributes of folk tales that cause them to be effective teaching tools. A total of 232 introductory psychology students at Purdue University participated in six experiments. The first three experiments utilized strategies such as sentence unscrambling, letter deletion (letters removed throughout the story), and a reading control group. Participants read a piece of fiction about baseball and were to either unscramble the story sentences, or fill in the missing letters within words in the story. These experiments showed that background knowledge may have helped provide a superstructure for the completion of text representation. In addition, they showed that sentence unscrambling supported free recall of script-based reading. In the next three experiments, a folktale was embedded in a different type of text (newspaper article) and the same unscrambling strategies from the first three experiments were used. Each of the experiments demonstrated that story grammar had little/no effect on free recall of information from folk tales or text with components of folk tales embedded in them. Though these laboratory tales have aspects of hierarchical superstructures such as goals, episodes, and causal links, they seem to be devoid of a core feature of “real” folk tales, a feature that may confer some unique mnemonic benefits (McDaniel, et al, 1994). These results suggest that folk tales are learned and recalled at a semantic level that seems to only work with them, thus supporting the first cognitive principle from the DFI report.

Rosenshine, Meister, and Chapman (1996) conducted a meta-analysis of 26 studies that utilized question generation as a cognitive strategy to improve retention of material. Participants

in the studies were students in grades ranging from third grade to ninth grade. This strategy focused on participants generating their own questions about the material they had read. In the analysis, subjects were given a test to read and instruction on how to generate text-based questions. The experimenters tested the students on the information they had learned through standardized tests and experimenter-created tests. Overall, teaching students to generate questions on the text they have read resulted in gains in comprehension, as measured by tests given at the end of the intervention (Rosenshine et al., 1996). It is also important to note that students performed better on experimenter-created tests instead of standardized tests. When students learn through generating questions, they are able to recall information correctly if asked questions about the information. Teachers want students to remember the information and comprehend what they learn, which supports the first cognitive principle.

Another study used to support the DFI report was done by Graesser and Olde (2003). The authors believed cognitive disequilibrium leads to higher level questioning. They developed an experiment to test the PREG model of questioning (predicts what questions a reader should ask based on what they have read) and Graesser-McMahen model of questioning which are founded on the concept that disequilibrium drives information seeking questions. (Graesser & Olde, 2003, p.524) These models measured question quality and frequency when subjects were confronted with a dilemma. In the study, 108 college students from the University of Memphis who were trying to fulfill a requirement for their Introduction to Psychology course participated. Participants were given a diagram of a lock showing how the moving parts are supposed to function. Next, the subjects read a passage that presented a problem with the mechanism. After reading the passage, the participants were asked to create questions defining what the problem could be. The authors found that the subjects who understood the mechanisms better first were able to ask better quality questions to determine why the mechanisms failed. Overall, the study supported the DFI report because it showed that the subjects were able to ask higher level questions in an effort to better understand and organize the material.

The Teaching Works (n.d.) report by the University of Michigan provides a list of 19 "high-leverage practices" that can improve student learning. Embedded in a few of the directives, practitioners are encouraged to draw out a student's thinking through carefully chosen questions and tasks. These questions can then be used as a launching point for the practitioner to consider and check alternative interpretations of the student's ideas and methods. In doing so, the practitioner is utilizing discussions to build collective knowledge and capability in relation to specific instructional goals. This building also allows the students to practice listening, speaking, and interpreting content. (Teaching Works, n.d.) This report reinforces the first cognitive principle by providing examples of ways in which students can construct meaning. Additionally, this document supports the purpose of the DFI report by providing practical applications for educators to support student learning. There is also mention of the implementation of quizzing and providing feedback which connects to principle two.

The final study used to support the first cognitive principle was by Peters & Levin (1986) focused on the use of mnemonics to assist above and below average readers. The authors sought to find out if students with different reading levels could benefit from mnemonic strategies. Unlike most of the other articles used to support cognitive principle one, this study focused on junior high school students. The 38 subjects were selected randomly out of 638 eighth grade students; they were then split into two groups: the control group and the mnemonics group. The mnemonics group was taught a mnemonic strategy to assist them in remembering important information from a reading passage. The control group was allowed to use any recall strategy

with which they were familiar. The students were then asked to read a passage using the strategy. Then, they had to try to remember the name of the person in the passage and why they were famous. The study showed that mnemonic strategies assist both above average and below average readers. This supports the DFI report statement that, teachers can help students learn to impose meaning on hard-to-remember content. Stories and mnemonics have been shown to be particularly effective at helping students remember difficult information.

COGNITIVE PRINCIPLE 2

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

The DFI report used five articles or texts to support cognitive principle two. This literature was published between 2006 and 2015 and consisted of research articles and one application guide. The first article, by Ericsson, Krampe, & Tesch-Romer (1993), conducted experiments to determine how much deliberate practice impacts a subject's ability or performance in mastering music. The subjects were divided into three groups. There were ten violinists considered good, ten violinists who were considered great, and ten students who were from the music education department but specialized in violin at the Music Academy of West Berlin. The researchers matched the subjects' gender and age in all three groups in an effort to mirror the groups. The researchers conducted a series of interviews with the subjects and after each round, they had the subjects' record the amount of time spent practicing.

The second study of these musicians focused on improvement over a set period of time. The amount of time used for practice was recorded as data. These twelve subjects were pianists taking soloist classes at their university. They were given a piece of music to play and tested on the music again seven days later. Each time the musicians were rated based on how well they played the piece and they were interviewed concerning the amount of practice time spent between sessions. After seven days both studies showed the groups who performed the best, either by outside evaluation by their professors or by an actual rating of their playing, had spent a significant amount of time focused on practice. This study supports cognitive principle two by demonstrating that practice is a key component in learning and acquisition. In addition, it also found that the type and amount of practice influenced the level of success reinforcing the DFI's conclusion that not all practice is equal.

The next article was a meta-analysis by Cepeda, Pashler, Vul, Wixted, and Rohrer (2006) to determine the effect of distributed practice over time. The researchers analyzed 186 different studies which combined for over 300 experiments and over 830 assessments. Their analysis showed students perform better over time when they practice and the interstudy interval (time between study events of the same material) is increased. In short, the brain learns the material and keeps it stored longer when there are intervals of rest between study sessions instead of studying without breaks. This concept of distributed practice supports the DFI cognitive principle two, specifically relating to the statement that refers to teachers' use of practice over time.

The DFI report also referenced a practice guide by Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel (2007) which was published by the US Dept. of Education. The evidence used to support the practice guide was a meta-analysis of scholarly work focusing on

each article. The authors provided practical application examples for professionals in the field of education. This practice guide was used within the DFI report to support three different concepts:

- Spacing practice over time helps students remember.
- The use of quizzes can help students make information more permanent.
- Interleaving (alternating) different concepts helps students learn.

The practice guide evaluated each strategy by the level of evidence, and found the spacing of material over time to have moderate supporting evidence. The use of quizzes (testing-effect) was found to have strong support. The interleaving of concepts during practice was determined to have moderate supporting evidence. During the explanation of evidence, the subjects of these works are referenced as students without additional information such as level of school or student's age. Each concept within this report is directly connected to cognitive principle two.

Argwal, Bain, & Chamberlin (2012) performed a review of applied research in the K-12 setting on the effects of quizzing. The researchers conducted a five year study of 1,400 middle school students (grades 6-8). Students were presented material from the textbook and the teacher's lessons. They were quizzed on the textbook material. At the end of the cycle they were given a test on both the textbook material and teacher lessons. Students performed better on the material they had practiced as quizzes than they did from the teacher's lessons. The quizzing strategy also increased long term learning and decreased testing anxiety. Delayed quizzes also showed to improve long-term memory which could be attributed to the interstudy interval effect. Students will retain information longer when there are longer breaks between studying. It should be noted that although quizzing students helps increase retention and memory, teachers must provide accurate and effective feedback to ensure students do not retain incorrect information. The effect of quizzing examined in this article supports the importance of quizzing in relation to student learning.

An additional study by Rohrer, Dedrick, & Stershic (2015) investigated the effects of interleaving (alternating) practice problems with 126 seventh grade students. The study lasted for three months and consisted of students completing the same practice problems with either the interleaved or blocked approach. Students were required to take a pop quiz at a later date. Students who had practiced with the interleaved approach outscored the blocked approach students. This study supported the DFI report not just because it supports the concept of interleaving problems, but also because it provides guidance to educators and those who will one day work with K-12 students. It provides evidence that the methods by which students practice information is important.

ADDITIONAL RESOURCES

Additional literature was reviewed in order to determine if there was more data to support the cognitive principles cited in the DFI report. A total of six additional articles were reviewed. Renkel, Hilbert, and Schworm (2009) conducted a review of studies researching the effect of worked examples on Cognitive Load Theory (CLT) by focusing a subject on the most important aspects of difficult material. The research reviewed included studies on the effects of worked examples on CLT, double content examples, self-explanation prompts, instructional explanations as a support, prior knowledge, and the focus of learning. The reviewed studies spanned a wide

range of subjects including K-12 and postsecondary students. The review found the following: worked examples diminish the stress of cognitive load and support the learning of new materials. Double content examples, which teach both concept and skill acquisition, help students gain skills in a variety of content domains. Self-explanation can promote learning if it does not contain any related to the content that would cause a negative effect on learning. A student's explanation could be misguided if they are missing important information from the content. Instructional explanations did not help beginning learners master content better than having students self-explain. Prior knowledge can negatively affect the acquisition of skills if there are gaps in the content domain in which learning is desired. Learning is not positively impacted by focusing on multiple types of examples. Focusing on one domain is beneficial to learning. The use of worked examples and student self-explanation aligns with the DFI report's principles of attaching meaning to learning and improving the quality of practice to increase student learning.

Wittwer and Renkel, (2010) performed a meta-analytic review of 21 studies focused on the use of instructional explanations with worked examples as well as reviewing other meta-analyses on the use of instructional explanations and example based learning. The search for studies to include in this review stretched from the 1970's to the 2000's and was conducted utilizing several different databases. This review found three important themes. First, the use of instructional explanation has a minimal positive effect on example based learning. Second, conceptual knowledge is enhanced by instructional explanations more than procedural knowledge. Finally, the use of instructional explanations are not always more impactful than self-explanation. This meta-analysis supports cognitive principle one in that self-explanation is a strategy used to help students construct meaning to retain information.

Additional research shows that repeated testing produces superior retention and transfer to the final test relative to repeated studying (Butler, 2010). In this study, Butler (2010) designed four experiments that examined how repeated testing and repeated studying affected retention and transfer of facts and concepts. There were 48 students in the study, 24 in each group. The participants were enrolled in undergraduate psychology courses. Subjects studied prose passages and then either repeatedly studied or took tests on the material. After a week, the subjects took a final test and were either presented with new inferential questions within the same knowledge domain or with new inferential questions from different knowledge domains. The findings indicate that the mnemonic benefits of test-enhanced learning are not limited to the retention of the specific response tested during initial learning but rather extend to the transfer of knowledge in a variety of contexts (Butler, 2010). This research supports the DFI cognitive principle of providing essential practice.

Additional research by Karpicke and Grimaldi (2012) looked at the importance of retrieval as the key process for understanding and for promoting learning. In this study, undergraduate students were shown to have higher test results when active retrieval methods, or the specific practice of using memory recollection cues, were used in conjunction with studying. Karpicke and Grimaldi (2012) also found that many students currently lack the metacognitive awareness of the benefits of practicing active retrieval. Quizzing and a computer-based learning program that guides students to practice retrieval are suggested as measures correcting this shortcoming (Karpicke and Grimaldi, 2012). In their judgment, retrieval processes must be considered in any analysis of learning. Additionally, incorporating retrieval practice into educational activities represents a powerful way to enhance learning. Supporting principle two, Karpicke and Grimaldi's (2012) findings show that retrieval processes must be considered in any

analysis of learning, and incorporating retrieval practice into educational activities represents a powerful way to enhance and promote student learning.

Additional research shows that quizzing promotes learning and retention of information by exposing students to the material more often. Roediger, Agarwal, McDaniel & McDermott (2011) tested this theory with 142 suburban, 6th grade, middle school students in a social studies classroom. Using three slightly different experiments, the students were quizzed periodically about the information taught prior to the semester test and the final exam. The results showed that students who quizzed themselves frequently or who were quizzed within the classroom frequently did better on the test and exam than students who just read and highlighted the information. This information supports principle two which states practice is essential to learning new facts.

Foos & Goolkasian (2005) conducted four experiments to assess learning by using various cognitive methods such as pictures, spoken words, and written terms to retain information. The work was done to address why some types of presentation formats formulate better recall from working memory than other types. It was determined that printed words receive less processing attention than pictures and spoken words during processing. This contributes to principle two that states all methods of learning are not equal.

Finally, Shore, Ray, and Goolkasian (2015) found that in practice, having seventh grade science students draw pictures of science terminology resulted in improved retention and perhaps more importantly, the students reported that they preferred using a drawing method to copying definitions of terms out of the back of a textbook. They found it more "fun" and less "boring." (Shore, Ray, Goolkasian 2015). An ancillary finding of this study was that if terminology was too similar spelling, confusion ensued regardless of instructional methods (Shore, Ray, & Goolkasian 2013).

CONCLUSION

Key Question 2 of the Deans for Impact report (2015) asked: How do students learn and retain new information? The report answered the question with two cognitive principles:

- 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 the meaning when they encounter to-be-remembered material.
- Practice is essential to learning new facts, but not all practice is equivalent.

These principles were supported by a total of eleven pieces of literature which included research studies spanning from 1977 to 2015. While the second cognitive principle was supported by more recent research almost all of the research for cognitive principle one is pre-2005. This does not mean the research is valid or applicable to today's teaching programs or students; however, it brings to question why the authors of the report did not use anything more recent to help support their work.

In addition, the majority of research used was conducted on subjects who were of college age or older. Many of these students would likely have been performing at an above average level already, having been accepted to a post-secondary institution. The intent of the DFI report is to assist colleges of education and inform teacher preparation courses, research which focused

on subjects in the K-12 spectrum may have made the report more applicable to the audience it seeks to reach. A number of studies can be found to support the cognitive principles presented while making the research applicable to the age range of students who are likely to be taught by members of these programs.

Overall, the Deans for Impact (2015) report authors provide supportive evidence to answer the question: How do students learn and retain new information? For students at any grade level to learn and retain information, it requires they find meaning to associate with the material being studied and engage in quality practice to gain mastery of the material.

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