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How Do Students Understand New Ideas?
In Response to the Deans for Impact Report (DFI)

Jacob Boula, Kristina Morgan, CarieAnn Morrissey, and Rebecca Shore
University of North Carolina at Charlotte

The first Key Question posed in the Deans for Impact report (2015) asks “How do students understand new ideas?" This question emerged from research that produced 3 cognitive principles regarding learning, particularly learning new information. Those principles are: 1) students learn new ideas by reference to ideas they already know. 2) To learn, students must transfer information from working memory to long-term memory. 3) The mastery of new concepts occurs in “fits” and “starts”. Sequencing the curriculum in order to ensure that students have the necessary prior knowledge to connect to new concepts, scaffolding by modeling and using worked examples to support problem solving, and integrating multiple modalities that complement each other into instructional presentations, can increase the effectiveness of teaching and learning in the educational environment.

Keywords: cognitive science principles, cognitive load, working memory, multiple modalities, long-term memory, transfer

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. The Deans for Impact report (DFI) posed six guiding questions and outlined their underlying cognitive principles, supported by current research about cognition.

By working through the six questions and related cognitive principles, teacher candidates and educational professionals can gain deeper understanding of the science of learning by connecting current research to their existing understanding of how students learn, apply, and transfer new knowledge. Although the mission of the DFI organization focuses on teacher preparation programs and teacher candidates, the questions can also be used for authentic professional development to help teachers and administrators build a better understanding of how learning takes place, and connect that work to their practice in order to improve the quality of teaching and learning in the educational environment. The following literature review focuses on the cognitive principles addressed by Key Question number one in DFI Report, “How do students understand new ideas?” (Deans for Impact, 2015).

COGNITIVE PRINCIPLE 1

Students learn new ideas by reference to ideas they already know.

To consider this cognitive principle, instructional leaders must consider content on both the micro and macro levels. Teachers must consider prior learning for each single classroom lesson, while administrators and teacher leaders carefully consider the curriculum from year to year. According to Bransford, Brown, and Cocking (2000), referencing a relationship between new ideas and what students already know is a key to enhancing learning in schools. Extensive learning opportunities for teachers are required in order to enable teachers to better meet these needs. In order to teach in a manner consistent with new theories of learning and connecting students' prior knowledge to new concepts different professional development for teachers is required. Their research gave examples of quality lessons showing that expert teachers have a deep understanding of the structure and epistemologies of their disciplines, combined with knowledge of the kinds of teaching activities that will help students come to understand the discipline for themselves. Furthermore, Bransford, et al. (2000) stated that incorporating students' prior knowledge creates an opportunity for "organizing information into a conceptual framework [which] allows for greater 'transfer'; that is, it allows the student to apply what was learned in new situations and to learn related information more quickly" (Bransford, et al., 2000, p.17).

Agodini, Harris, Atkins-Burnett, Heaviside, Novak, and Murphy (2009) developed an extensive study to measure different math curricula and its impact on the learning of students. This study examined whether some early elementary school math curricula are more effective than others at improving student math achievement in schools that serve students from economically disadvantaged homes. The authors cited national achievement data from the 2009 National Assessment of Educational Progress to show that elementary school students in the United States, particularly those from low socioeconomic backgrounds, had weak math skills (Agodini, et al., 2009). The data also showed substantial differences in average math scores between students from different socioeconomic backgrounds: ethnic minority students and those eligible for free or reduced-price meals had an average math scale score about 20 points (0.69 standard deviations) lower than their peers (Agodini, et al., 2009). The study focused on integral parts of the content knowledge of teachers and program training. Researchers found that small group instruction, teacher preparation, and hands on learning showed greatest impact on the degree to which students mastered and retained the math skills (Agodini, et al., 2009).

Richland, Zur, and Holyoak (2007) investigated how certain mathematics classroom activities differed between the United States and nations in which students score higher on international tests. This study focused on factors of cognition and memory, which can be distinguished from cultural differences in instruction. Mathematical reasoning involves understanding abstract relations (such as equality, proportion, and integers) that can appear in different contexts. Such abstract relations may be best taught by drawing parallels to similar examples. National differences emerged in adherence to sound cognitive principles for teaching by relational comparisons. For all six principles that were coded, the U.S. sample yielded lower scores, indicating less promotion of relational learning (Richland, et. al., 2007).

In addition to the research cited by DFI, Baxter, Woodward, and Olson (2001) further supported that opening discussions facilitate conjecture and argumentation in an environment where students create and develop ideas that "matter mathematically" (Baxter, et al., 2001, p.

535). The reform-based curriculum highly recommended using open-ended discussions where the intent was to validate student-derived solutions to problems, including algorithmic procedures. This was additional support for the cognate that instructors facilitate learning by using students' previous knowledge of topics (Baxter, et al., 2001). Implementing these discussions promotes synergy within the learning environment, further activating the use of prior learning within groups of students in classrooms.

In another article not cited by DFI, Kilpatrick, Swafford and Findell (2001) described how children begin learning mathematics well before they enter elementary school. They observed that preschoolers' mathematical thinking rested on a combination of conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick, et al., 2001). The research suggested that students learn more from guided discovery than pure discovery in the area of agent-based multimedia learning environments (Moreno, 2004). Unguided instructional strategies impose heavy cognitive demands on novice learners. Worked examples reduce the extraneous cognitive load imposed by means-ends problem solving, and explanatory feedback increases a student's understanding.

COGNITIVE PRINCIPLE 2

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.

The DFI report states that in order to learn new ideas, students must transfer information from working memory to long-term memory, and that one effective way teachers can make this happen is by using "worked examples" as part of their instruction (DFI, 2015). In using worked examples, the cognitive load on the working memory is reduced. According to Sweller (1988), the depth of knowledge of schemas determines the proficiency level of a problem solver. Conventional problem solving creates a heavy cognitive load, which impedes schema acquisition. Therefore, it might be beneficial if some conventional problems were replaced by worked examples. Atkinson, Derry, Renkl, and Wortham (2000) supported Sweller's findings when they concluded that pairing practice problems with worked examples increased problem-solving performance. It appeared that using worked examples proved most successful in the beginning stages of developing cognitive skills, and showed minimal success in the latter stages. In further research, Sweller (2006) found that worked examples may produce greater amounts of learning for beginner problem solvers due to the limited use of working memory. This is due to worked examples requiring less cognitive processing of random informational factors involved in problem solving. The less complex the problem, the fewer random factors the problem contains. The use of worked examples reduces the extraneous cognitive load imposed by means-ends problem solving, and explanatory feedback increases a student's understanding (Moreno, 2004).

Kalyuga and Sweller (2015) found that when students are learning complex material, high levels of guidance are likely to result in enhanced performance over lower levels of guidance. When learning simple material that is easy for students to understand, learners should practice generating responses. Active participation in the learning process produces better retention than passive observations when learning simple material. For example, worked examples can increase problem-solving success by using analogy: the connection of new information to concepts already learned. Analogies are very successful when the teacher explains the parts of an analogy, demonstrates how to "read" and interpret an analogy from left to right, and when students learn to recognize the different relationships that can exist in different analogies, such as compare/contrast, number, time, and opposites (Morgan, 2016). Students can make connections between known concepts and new information through the various relationships used in analogies.

The DFI (2015) report explained that the guidance given to students when learning through worked examples should slowly be decreased to allow students to become more proficient at solving problems independently. Teachers can make this happen by incorporating appropriately paced explanations, modeling, and worked and/or modeled examples. Von Gog and Rummel (2010) showed that using worked examples to give learners specific steps to work out a problem works well in applied math, such as algebra, geometry, and statistics. Students using worked examples are not necessarily focused on learning the solutions to the problems, but on learning the steps to solve problems (Von Gog et al., 2010). Modeling examples may be a more effective way to teach less structured skills such as writing, collaboration, and metacognitive skills such as self-regulation and self-assessment. The researchers demonstrated that the same neural circuits that are involved in executing a motor action oneself also respond to observing someone else executing that action. The neural circuits that are active when executing and observing motor actions also respond when hearing sentences that describe such actions (Von Gog et al., 2010). In light of this study, modeling may help classrooms of students move more uniformly through the curriculum.

Intrinsic cognitive load is the natural complexity of information that is to be learned (Sweller 2010). Information to be learned has high or low levels of element interactivity. Inefficient instructional procedures impose an extraneous cognitive load, whereas germane cognitive load varies because it is determined in part by the learner’s characteristics. A cognitive load can be imposed by instructional material and by element interactivity associated with either intrinsic or extraneous cognitive load. Working memory resources must be dispersed to deal with those interacting elements. So when planning instructional procedures, the three loads must be taken into account and decisions made on how to lower the extraneous load for learners.

To increase retention, learning should be spaced over time of weeks or months, and students should be exposed to material at least twice (Pashler, Bain, Bottge, Graesser, Koedinger, & McDaniel, 2007). Problem solving and worked examples should be interleaved to increase student learning. Illustrations and graphics should be used in conjunction with verbal explanations. When presenting a concept, both concrete and abstract representations should be used. When introducing new material, pre-tests should be given to assess prior knowledge and to identify concepts that need to be learned. Closed book tests and quizzes repeatedly expose students to material, thus increasing retention. It would also be beneficial to allow students to reflect on their learning and evaluate how well they are retaining information. Teachers should use quizzes and tests to identify material that needs to be studied again. Teachers need to provide specific feedback and correct answers for tests and quizzes as soon as possible.

The DFI report concluded that using multiple modalities to present an idea increases learning (2015). The report also stated that if different sources of information are presented at the same time, the student's attention is divided and as a result, learning may be impeded. Chandler and Sweller (1992) found that worked examples require less of a cognitive load. Worked examples that are made up of two or more sources of information, such as diagrams, tables, and text, require cognitive combination of information, and a student's attention is divided. If a problem solver must search for information and match it within a problem, his/her cognitive effort is not directed towards learning. Therefore, attention is split, or divided, so understanding and learning is impaired (Chandler & Sweller, 1992).

Furthering Chandler and Sweller's research, Moreno and Mayer (1999) concluded that mixed modality presentations increase learning. More information is retained when verbal narration is paired with visual graphics than when text and visual graphics are paired together. More information is retained in the visual and auditory working memory when they are paired together in mixed modality presentations (Moreno & Mayer, 1999). Goolkasian and Foos (2002) further examined the ability to retrieve information from working memory. They had subjects compare three types of presentation formats (pictures, printed words, and spoken words), to determine influence of format on the processing task and for item recall. They found that stimulus items presented as spoken words and as pictures were recalled and recognized equally well or better than printed words. For example, if students saw a picture of a ball or spoke the word, "ball," their ability to retrieve the word was better than if they read the word, "ball." In follow-up studies, Foos and Goolkasian (2005) found that a recall disadvantage for printed words may lie in the fact that learners were not able to give their full conscious attention to printed words, supporting earlier studies that found that less cognitive load was beneficial to learning. This research shows how deeply educators must understand cognitive science research to carefully plan lessons to maximize learning for all students.

Kirschner, Sweller, and Clark (2006) found that long-term memory is the central component of human cognition. Problem solvers draw on the wide experience stored in their long-term memory. Direct instruction, involving much guidance, results in a much higher level of learning than unguided instruction, also known as discovery learning. Unguided exploration of the learning environment creates a heavy cognitive load as problem solvers build a loaded working memory, which is less conducive to learning. Therefore, unguided learning may lead students to learn misconceptions, incorrect, incomplete, or erroneous information and concepts. Students who received instructional explanations and no explanations showed a higher level of learning than those who relied on self-explanations of conceptual learning (Kirschner, et al., 2006).

Attempting to apply some cognitive science principles into classrooms can also impact learning, perhaps by inadvertently increasing cognitive load or through the additional inevitable distractions of having peers nearby. Many cognitive science principles are established by testing one student at a time (oftentimes college Psychology students) in a laboratory. This more structured testing environment produces a result that may differ when the strategy is implemented in a classroom full of students.

In one study, researchers did just that; applied cognitive science principles in middle school science classrooms to test for retention of complex science terminology (Shore, Ray, Goolkasian, 2015). In this study, researchers worked with teachers to develop two active learning strategies, having students draw pictures of what the terms meant to them, and having students engage in conversations with their shoulder neighbors about the meanings of the science terms. These two more active strategies were compared to a strategy whereby students simply copy the definitions of the terms from the back of a textbook. Three units of science terms were used and an iterative development process was implemented resulting in data collected from every student using every strategy across the 3 units.

Researchers expected the two more active strategies to result in better retention of the science terms. However, results showed significantly higher retention of the terms using the drawing or copying strategies, over the conversation strategies (Shore, Ray, Goolkasian, 2015). Upon reflection, the researchers discovered that when the conversation strategy was employed, teachers were not walking around the classroom monitoring the conversations to help enforce that the conversations were, in fact, about the science terms. The researchers also surveyed the students and found that while they thought that the copying strategy would be the most effective (they were "used to it"), they liked participating in the drawing and conversation strategies best (Shore, Ray, Goolkasian, 2013). So perhaps opting for the drawing strategy, since it was enjoyed by the students and proved to be effective, might be the best choice for teachers. However, teachers reflected that the drawing strategy took the most time to implement. Discussions following this research resulted in a teacher decision to assign the drawing of the term meanings for homework instead of using class time to implement the strategy. This scenario is an example of the difficulty of translating some cognitive science principles into classrooms. The group dynamic introduces a vastly more complex environment with many additional variables that can affect learning outcomes. It also, however, reveals the importance of the group learning potential by teachers and researchers when working together to explore implementing the science of learning into classrooms.

COGNITIVE PRINCIPLE 3

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

Current theories of cognitive development are general, global, and universal, describing the types of cognitive behavior one might generally expect from a person based on their chronological age. Weinert and Helmke (1998) referred to theories of cognitive development as "structural", which they defined as focused on information processing structures and cognitive competencies rather than changes in specific knowledge, skills and performance. The authors further defined the naturalistic-descriptive nature of cognitive development theories: developmental occurrences are inherent to human nature and cannot be impacted by external conditions (Weinert, et al., 1998). However, in a longitudinal study of children between the ages of 4 and 12 years, although there was a linear increase in performance related to age, within the general developmental patterns there were "extremely large intraindividual and interindividual differences underlying the overall mean changes" (Weinert, et al, 1998, p. 321). The authors urged for the integration of a differential perspective, not to replace but to rather to complement the current general and structural focus.

Some research suggests that following a strict sequence of instruction that is aligned to cognitive stage theory may not be appropriate. When teachers intentionally activate prior knowledge to scaffold the acquisition of new understanding this approach can have a greater impact on learning. Flynn, O'Malley, and Wood (2004) demonstrated that it is not necessary for children to have a theory of mind in order to be successful with executive inhibition tasks. Children develop inhibition skills gradually, not through a sudden shift, and at first the development is unstable. There appears to be a period during development when children are unsuccessful at tasks that they were previously successful with (Flynn, et al., 2004).

Gray and Reeve (2016) examined how different cognitive markers are associated with math ability profiles in preschoolers. The research indicated that domain-specific cognitive markers are more strongly related than general cognitive markers to differences in mathematical performance among young children. Gray and Reeve assessed preschoolers using number-specific markers, general cognitive markers, and math ability measures. The researchers used number-specific markers and math ability measures to classify the children into math profiles: excellent math, good arithmetic, good math/poor count sequence, average math, and poor math. Age, magnitude comparison efficiency, working memory, response inhibition, and attention were not significantly associated with math profiles. Children in the "Good Math, Poor Count Sequence" group performed poorly on basic skills like count sequence, but did well on the more complex ordinal relations tasks (Gray & Reeve, 2016). The findings of Gray and Reeve (2016) supported the position of Holmes and Dowker (2013) that children have different growth profiles and that one skill is not necessarily a required prerequisite for another skill.

Daniel Willingham (2008) argued that developmentally appropriate practice, linked to cognitive development theory, is not an effective tool for instruction because development does not occur in "discrete, pervasive stages" (Willingham, 2008, p.36), but rather is more continuous and depends on "…the details of what they are asked to understand and how they are asked to show that they understand it" (Willingham, 2008, p.37). Willingham recommends that educators use general information about cognitive principles, but realize that they are not absolute. Content may not be developmentally inappropriate, if scaffolding occurs so that students can access the content at a level that makes sense to them. Instead of assuming that a task is not developmentally appropriate because most students were not successful, educators might instead think about whether students have the necessary background knowledge to understand the new content, or whether a different way of presenting the information would be more effective.

Because children's performance varies, teachers might consider using different methods of presenting and solving problems. Introducing complex ideas by making them concrete and helping children connect the new information to their experiences, or providing experiences to help them gain background knowledge, helps children scaffold the new information by connecting it to existing knowledge. Understanding of new concepts will be incomplete for children, but this does not mean they are not ready to be introduced to those concepts (Willingham, 2008).

CONCLUSION

By working through the DFI report and other current research related to the question, "How do students learn new ideas?" (Deans for Impact, 2015), teachers and teacher candidates develop an understanding of the cognitive principles related to the question, and develop the ability to consider and apply those principles when planning and reflecting upon instructional presentations. Sequencing the curriculum in order to ensure that students have the necessary prior knowledge to connect to new concepts, scaffolding by modeling and using worked examples to support problem solving, and integrating multiple modalities that complement each other into instructional presentations, can increase the effectiveness of teaching and learning in the educational environment.

These are all suggestions based on cognitive science research that aim to help facilitate the understanding of new ideas by students. Far from being prescriptive or comprehensive, the questions and cognitive principles are a jumping-off point to encourage research and reflection, so that teacher candidates and current educators will continue to develop a deeper understanding of cognitive science principles and how they can be applied in different educational contexts to increase the quality of teaching and learning. The next article offers more strategies for applying these cognitive science principles into classrooms.

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