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APPLICATION OF KNOWLEDGE

The Science of Learning: Transferring Learning to Novel Problems

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The fourth Key Question posed in the Deans for Impact report (2015) asks, "How does learning transfer to new situations in or outside of the classroom?" DFI (2015) propose two cognitive principles addressing the question. This paper dissects each of the cognitive principles to distill the following themes educators should employ in the K-12 and Higher Education classrooms to foster students' ability to transfer learning to novel problems: 1) Students should participate in deep initial learning experiences as described earlier in this review that will enable them to see relevance and meaning both in-context and beyond the context of the problem at hand. 2) Learners should develop the ability to decipher signal, relevant details and perspectives, from the noise. 3) Learners need to develop mental maps that make connections between existing knowledge and new knowledge. 4) Students should also have flexibility in applying knowledge to novel problems using an abstract systems perspective.

Keywords: transfer, prior knowledge, mental maps, novel problems

In the upcoming academic year, schools across the nation will open their doors to the Class of 2030. For many of these children, this will be their first formal educational experience. The next thirteen years of their lives will be devoted to learning everything they can in order to be productive members of American society. Though not altogether unforeseeable, the world in which they will live and operate will likely look very differently from our own. As these graduates venture into the real world of the 2030s, will they be equipped with the skills and understandings necessary to transfer their learning to novel problems with all the nuances of a real-world application?

The fourth question posed in the Deans for Impact report (DFI, 2015) asks, "How does learning transfer to new situations in or outside of the classroom?" DFI (2015) propose two cognitive principles addressing this question:

1. 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.
2. We understand new ideas via examples, but it's often hard to see the unifying underlying concepts in different examples.

This article will examine what current research says about each of these cognitive principles and how educators can apply these principles to learning situations to accomplish the ultimate goal of education -- the transfer of learning.

COGNITIVE PRINCIPLE 1

Knowledge of the Problem's Context

When we learn, we constantly rely on our prior experiences. When learners encounter new problems, they base their thinking on what they have experienced previously. Existing prior knowledge can both facilitate and hinder learning and transfer (Bransford, Brown, & Cocking, 2000). According to Gilbert, Bolte, and Pilot (2011), learning is mediated by what is already known. "Seductive" details trigger perspectives when encountering problems. These details potentially increase with the richness of the initial information. For example, while a stick figure may trigger a general perspective, a diagram or photograph includes many more details that require filtering to distinguish relevant from irrelevant information. While this added information when coupled with prior experience can enhance problem solving, it can also stir "noisy," irrelevant schema that may be counter-productive to problem solving (Son & Goldstone, 2009). For learners, it is imperative to sift through and identify both relevant and irrelevant information as they prioritize what to learn. Specific prior knowledge must serve as a lens for assimilating new content, not the focus. Reducing distractors, seductive details, and noisiness will promote transfer (Day & Goldstone, 2012).

The context in which knowledge is learned affects a student's ability to transfer that knowledge to novel problems. Overly contextualized knowledge can reduce transfer, and transfer across contexts is especially difficult when a subject is taught only in a single context rather than in multiple contexts (Bransford et al., 2000). Students often have difficulty transferring knowledge to situations other than the one in which it was learned (Gilbert et al., 2011), and if all learning is tied to specific contexts, the possibility of transfer across domains and phenomena comes into question (Son & Goldstone, 2009). This is especially true when students struggle to make connections to other contexts or merely memorize steps to solve problems.

Gilbert et al. (2011) addressed the problem of students being overloaded with incoherent and fragmented learning of content through the proposition of four attributes common to an effective context-based education:

1. Specific setting of focal event
2. Behavioral environment in which focal event is addressed (how the learners will interact)
3. Participants' use of specialized and precise language ("talking the talk")
4. Links between new and existing (extra-situational) knowledge

Learners use this contextual framework to construct mental maps that crystallize understanding. These mental maps are meaningful wholes versus collections of isolated facts. Students are then able to use parts of mental maps meaningfully in another focal event. Pellegrino and Hilton (2012) found that students who were able to apply what they had learned to what they were doing were impacted by the degree the environments in which they learned the content and applied the content were similar. The authors found this to be the most important factor influencing transfer and that enhancements such as diagrams, animation, concrete manipulatives, etc., promote transfer (Pellegrino & Hilton, 2012).

Both contextualization and decontextualization can result in transfer and must be balanced so that the learner does not develop a dependency on context or concrete details. Teachers might help students connect everyday knowledge to subjects, tease out conceptions, and reconceptualize faulty conceptions (Bransford et al., 2000). When students develop the ability to see a problem in a specific context as well as similarities in other contexts across domains, the potential for transfer is increased (Son & Goldstone, 2009). Teachers must strive to make students' thinking visible and to help them to see the effects of variable manipulation on outcomes by thinking beyond the problem at hand, tinkering with the variables, and observing the effects of their tinkering (Bransford et al., 2000). Students who develop a system-level meaningfulness enjoy a perspective that is aligned with the abstract principles of the system. They are able to look deeper within the system to discern the structural characteristics and zoom out to a detached view of the entire system. (Son & Goldstone, 2009).

Deep Understanding of the Problem's Underlying Structure

Deep learning results in the ability to perceive the underlying structures in problems. According to Chi and VanLehn (2012), deep initial learning fosters transfer. Deep learning should begin at preschool and continue throughout post-secondary education (Pellegrino & Hilton, 2012). This type of learning requires motivation to learn, an exertion of effort, and cannot be rushed (Bransford et al., 2000; Pellegrino & Hilton, 2012). According to Pellegrino and Hilton (2012) two distinct hallmarks of deep learning are that it:

1. Develops understanding of underlying principles
2. Supports the application of knowledge

A deep understanding of both the surface and structural characteristics of the initial problem must be fostered. According to Chi and VanLehn (2012), this understanding determines the degree of transfer. Day and Goldstone (2012) observed that while novices and experts alike can identify surface characteristics of problems comparably (i.e. objects, concepts, settings, etc.) experts excel in perceiving deeper structural characteristics of problems (i.e. rules, schema, plot, etc.). As students use prior knowledge of similar phenomena to construct mental models, they can more efficiently identify structural characteristics. By simply cuing students to notice structural characteristics, teachers can increase transfer in students.

Chi and VanLehn (2012) propose using the Interactive-Constructive-Active-Passive (ICAP) framework for initial learning design. In this framework, interactive experiences are more rigorous than constructive experiences, constructive experiences are more so than active experiences, and active experiences more than passive experiences. When learners are required to build understanding on more rigorous levels, the learning experience requires more effort. Such deep learning fosters transfer to novel problems.

Chi and VanLehn (2012) found that experts and novices can identify relevant surface features with similar proficiency, but experts understand interactions of surface features individually (first-order cues) and systemically (second-order cues). This insight is what distinguishes experts from novices; they can "see" beyond surface features to understand the structural similarities and interactions in novel problems (Chi & VanLehn, 2012). However, second-order cues can be readily observed with explicit teaching to look for them in addition to first-order cues. This approach can improve transfer (Chi & VanLehn, 2012).

Summary

The first cognitive principle proposes the learner must have a contextual and structural understanding in order to transfer skills or knowledge to a novel problem. Contextual understanding can be accessed via prior knowledge or constructed through learning opportunities that build background knowledge. These experiences must couple a richness of information that enables the learner to isolate relevant details with a strong conceptual vision that allows the learner to apply the information across domains. When students develop conceptually sound mental models through deep initial learning, they are better able to understand the underlying principles of novel problems, and they can more efficiently transfer knowledge or skills to novel problems.

COGNITIVE PRINCIPLE 2

New Ideas via Examples

The second cognitive principle involves the concept of utilizing examples to present new ideas. Researchers (Richland, Zur, & Holyoak, 2007) in the field of analogy discuss that math teachers commonly introduce analogy-based instructions for learning new content, but this does not always encourage active reasoning. Learning through examples is important because children show greater transfer when the source is familiar (Richland et al., 2007). Therefore, augmenting the source and utilizing relational comparison with visual representation, such as diagrams, increases transfer (Richland et al., 2007). However, whenever children have difficulty mapping knowledge between representations and examples, the benefits of using multiple external representations (MERs) or examples may not be evident (Ainsworth, Bibby, & Wood, 2002). Ainsworth et al. (2002) also state that if translation between examples or representation is not required for task performance, then the student's attempt to translate to knowledge can be negatively affected.

Other research discusses using analogies in learning that requires the student be able to align the two analogs (Gentner et al., 2016). Assisting students with aligning concepts of the analogs will require effort on the part of the instructors and the students (Gentner et al., 2016). This structural alignment can reveal key contrasts of the two analogs or examples. Gentner et al. (2016) propose that learning a new idea can occur if the alignable differences are connected to the common system. Contrasting research shows that simply providing multiple examples does not ensure formation of a useful schema, and without relational comparison, learning is limited (Richland, Stigler, & Holyoak, 2012). Analogical transfer is ultimately limited by the reasoner's understanding of the source analog (Richland, Stigler, & Holyoak, 2012).

Seeing the Unifying Underlying Concepts in Different Examples

Gentner and Namy (2006) provide research that shows alignment can strengthen children's ability to generalize common relations to other objects and situations. Evidence is beginning to show that alignment also contributes to the learning of grammatical constructions (Gentner & Namy, 2006). Pinpointing underlying concepts in examples or use of analogs can be difficult for children. Goldstone and Son (2005) proposed the idea of concreteness fading. The combination of concrete and idealized formats is valuable and the most valued sequence was to start with concrete and become more idealized over time (Goldstone & Son, 2005).

In looking at different examples, Day and Goldstone (2012) note that when a new case differs from a previously learned characteristic, spontaneous transfer is typically poor. Their study also showed that in the absence of "hints", recognition of surface similarities is not easily recognized. Therefore, the recognition of the previously learned situation is low and successful transfer is low (Day & Goldstone, 2012). Catrambone (1996) pose that potential effective solutions to assist with low transfer. Effective problem solvers create subgoals and identify necessary steps to achieve the subgoals rather than attempting to solve problems in one long step; they utilize labels that serve as cues or triggers (Catrambone, 1996). Determination of the degree of label meaningfulness is critical. Experts require less information or abstract symbols, while novices are better able to solve problems with more meaningful labels (Catrambone, 1996). Catrambone (1998) defines subgoals as mini-problems versus a set of steps. These subgoals reduce cognitive effort by enabling the learner to access and initiate specific processes to solve each one; this approach requires less filtering. Creating general subgoals leads to more flexibility in problem solving, such as find the frequency versus calculating totals and dividing (Catrambone, 1998).

Utilizing the research of transfer through example, teacher instruction continues to evolve. Bottge, Rueda, Serlin, Hung, and Kwon (2007) introduces enhanced anchored instruction (EAI), which is the concept of students first solving a problem in a multimedia format and then applying this in a related hands-on problem. Within this approach, learners have limited working memory and learning tasks should be structured to not overload.

Summary

The second cognitive principle proposes the learner will understand new knowledge through examples and transfer can occur by understanding underlying concepts within the examples. Utilizing familiar sources for examples and mapping knowledge between examples is critical for learners. Transfer also can occur when the learner can recognize surface similarities between examples and by using cues and triggers to solve problems. Therefore, teachers should be cognizant of using examples with familiar sources and utilizing a combination of concrete and idealized formats to teach new concepts.

CONCLUSION

Overarching Themes for Transferring Learning in or outside the Classroom

The question posed in The Science of Learning and the cognitive principles Deans for Impact proposed is a distillation of decades of research. Through the examination of research on how learning is transferred in or outside the classroom, several themes emerge. Students should participate in deep initial learning experiences as described earlier in this review that will enable them to see relevance and meaning both in-context and beyond the context of the problem at hand. Learners should develop the ability to decipher signal, relevant details and perspectives, from the noise. Learners need to develop mental maps that make connections between existing knowledge and new knowledge. Students should also have flexibility in applying knowledge to novel problems using an abstract systems perspective. If today's educators instill these abilities in learners, the research suggests the Class of 2030 will be well-equipped to live and operate in their world.

REFERENCES

Ainsworth, S., Bibby, P., & Wood, D. (2002). Examining the effects of different multiple representational systems in learning primary mathematics. *Journal of the Learning Sciences*, *11* (1), 25-61.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.

Bottge, B. A., Rueda, E., Serlin, R. C., Hung, Y.-H., & Kwon, J. M. (2007). Shrinking achievement differences with anchored math problems: Challenges and possibilities. *Journal of Special Education*, *41*(1), 31-49.

Catrambone, R. (1996). Generalizing solution procedures learned from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(4), 1020-1031.

Catrambone, R. (1998). The subgoal learning model: Creating better examples so that students can solve novel problems. *Journal of Experimental Psychology: General*, *127*(4), 355-376.

Chi, M. H., VanLehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist*, *47*(3), 177-188.

Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist*, *47*(3), 153-176.

Deans for Impact (2015). *The Science of Learning.* Austin, TX: Deans for Impact.

Gentner, D., Levine, S. C., Ping, R., Isaia, A., Dhillon, S., Bradley, C., & Honke, G. (2016). Rapid learning in a children's museum via analogical comparison. *Cognitive Science*, *40* (1), 224-40.

Gentner, D., & Namy, L. L. (2006). Analogical processes in language learning. *Current Directions in Psychological Science*, *15*(6), 297-301.

Gilbert, J. K., Bulte, A. W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education*, *33*(6), 817-837.

Goldstone, R. L., & Son, J. Y. (2005). The Transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences*, *14*(1), 69-110.

Pellegrino, J. W., & Hilton, M. L. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington, D.C: The National Academies Press.

Richland, L. E., Stigler, J. W., & Holyoak, K. J. (2012). Teaching the conceptual structure of mathematics. *Educational Psychologist*, *47*(3), 189-203.

Richland, L. E., Zur, O., & Holyoak, K. J. (2007). Cognitive supports for analogies in the mathematics classroom. *Science*, *316*(5828), 1128–1129. Retrieved from http://www.jstor.org.librarylink.uncc.edu/stable/20036317.

Son, J. Y., & Goldstone, R. L. (2009). Contextualization in perspective. *Cognition and Instruction*, *27*(1), 51-89. doi: 10.1080/07370000802584539