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PROBLEM SOLVING

How Do Students Solve Problems? In Response to the Deans for Impact Report, *The Science of Learning*

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This article explores the third Key Question presented by the 2015 Deans for Impact (DFI) report, "How do students solve problems?" The DFI authors noted working memory and long-term memory as critical to solving problems cognitively. Additionally, the DFI authors found feedback to be an important part of the problem-solving process. This paper examines the literature used to support the two principles and provides additional information from a review of current literature to further strengthen each of the cognitive principles presented by the DFI report (2015). The literature revealed that a major component of problem solving is the cognitive process. Examining how self-regulated learning and cognitive load theory impact problem solving provides the necessary support to justify the importance and application of the cognitive principles presented in the report.

Keywords: Problem solving, cognitive science, self-regulation, effective feedback, science of learning

The Deans for Impact (DFI) report is a compilation of critical components that contributing authors determined were necessary to ultimately impact student achievement and outcomes through programs in colleges of education. This report is based on a review of cognitive science literature and research gathered by the authors that has been separated into cognitive principles and some suggested practical applications that align with each principle. The report is divided into six key questions for educators or future educators. The third key question, "how do students solve problems?" was explored by looking at various empirical and seminal works and two cognitive principles that address this question were posed. Specifically, working memory and long-term memory were noted as critical to solving problems cognitively. Additionally, the DFI authors found feedback to be an important part of the problem-solving process. This paper will examine the literature used to support the two principles and will provide additional information from a review of current literature to further strengthen each of the cognitive principles presented by the DFI report (2015).

Cognitive Principle: 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.

This first cognitive principle that the DFI (2015) utilized to answer the question, "How do students solve problems?" involved looking at how prior knowledge and working memory impact the problem solving process. To support their argument, the authors from the report referenced the work of Ericsson, Krampe, and Tesch-Romer (1993), which examines the role that deliberate practice plays in expert performance. They posit that expert performance on a particular task requires prolonged and deliberate practice of that task. In addition, they present evidence that counters earlier explanations that becoming an expert is a result of some innate quality. Some innate characteristics may help to explain a part of performance early on, but genetics have been found to have less influence for the long term. This is important for consideration in the teaching of a skill such as reading.

Additionally, Chi, Glaser, and Farr's (1988) research focusing on the importance of domain specific content as it relates to a person's ability to solve problems was used to support this cognitive principle. These researchers suggest that expert problem solvers analyzed content on a deeper level than novice learners who only looked at a problem from a more superficial level. They further suggest that although a person may be considered an expert in a domain specific content area, this does not mean the skills will transfer to a new or unfamiliar area. However, the DFI authors did not address the cognitive processes involved in problem solving that some scholars stress as a key element in problem solving (Chi, Glaser, & Farr, 1988; Mayer, 1998; Jonassen, 1997, 2002, 2005, 2010). (These authors assume that the Glaser & Chi, 1988 reference in the DFI report's reference section is meant to be Chi, Glaser, & Farr, 1988.)

Additional studies not referenced in the DFI report show the complexity of the task of applying the cognitive science principles in classrooms. This literature begins with a focus on the problem solver's previous "domain-specific" content knowledge as it relates to a person's ability to solve problems (Ericsson & Smith, 1991; Mayer, 1992). Mayer (1998) argues that this method only prepares students to solve problems that they have previously encountered. Mayer presented two different types of problems: routine and non-routine. Routine problems resemble those that students have already learned to solve and non-routine problems are problems that are not like any that they have solved in the past.

Mayer, a long respected educational psychologist and researcher, stressed the importance of the cognitive process in problem solving. In one of Mayer's seminal works (1998), research suggests the focus on previous content knowledge in the problem solving stages ignores the complex cognitive functions involved in the problem solving process. Mayer presents the idea that three major components are needed for effective problem solving for non-routine problems: skill – domain specific knowledge relevant to the problem-solving task; metaskill – strategies for how to use the knowledge in problem solving; and will – feelings and beliefs about one's interest and ability to solve the problems. Mayer (1998) argues that, "…instruction and prior content knowledge focuses only on basic skills and is incomplete when applied to the problem solving process" (p.50). The actual processes involved with learning new information is deeply complex, nuanced and somewhat based on differentiation between learners and various tasks.

Jonassen (1997) support Mayer's (1998) findings and distinguishes problem solving techniques between types of problems presented. He presents the concept that two types of problems exist: well-structured and ill-structured problems. Jonassen (1997) describes well -

structured problems as those typically encountered in educational settings such as school classrooms. Well-structured problems are described as problems that present all elements of the problem; engage a limited number of rules and principles that are organized in a predictive and prescriptive arrangement; possess correct, convergent answers; and have a preferred, prescribed solution process (Jonassen, 1997). In other words, they typically have a "right answer" result. Ill- structured problems are the types of problems that are may be more frequently encountered in everyday practice and are more difficult to solve. Jonassen characterizes ill-structured problems as having many alternative solutions to problems; vaguely defined or unclear goals; multiple solution paths; and multiple criteria for evaluating solutions. Jonassen (1997) builds on Newell & Simon's (1972) classic General Problem Solver model and Bransford's (1984) IDEAL problem solving model that highlight even more complex components in explaining the problem solving process.

For ill-structured problems especially, self-regulated learning is critical to the problem solving process. The DFI (2015) report does not appear to specifically address self-regulated learning when exploring how students solve problems to learn and retain new information. For many researchers of the learning process, however, self-regulated learning or the ability of a learner to self-regulate is a large and critical component of the problem solving process (Zimmerman, 2000; Schunk & Ertmer, 2000).

Zimmerman (2000) describes self-regulation as an internal process where the student develops thoughts, feelings, and actions (behaviors) to help reach the desired goal. This is accomplished in conjunction with the student having the ability to recognize personal strengths and weaknesses when faced with a task. Self-regulated learning is a pivotal part of the problem solving process because the student sets goals prior to the task, then reviews and revises those goals during task completion, and reflects on the learning experience associated with the specific task (Schunk & Ertmer, 2000; Zimmerman, 1990). Self-regulated learning can be a conscious, deliberate action or an automatic response to solve problems. Some research in the field suggests that students go through three steps when self-regulating. First, prior to completing the task students do a quick task analysis and reaffirm their self-motivational beliefs in preparation for solving the problem. Next, during the learning or performance students observe themselves and practice self-control. Finally, upon completion of the learning experience, students reflect on how the experience went and whether or not they were successful (Schunk & Ertmer, 2000; Weinstein, Husman, & Dierking, 2000; Zimmerman, 1990). For students who are considered experts as described above, self-regulated learning is a more automatized process for familiar tasks, thus increasing their swiftness and accuracy in response. This helps students considered as experts because they are able to solve problems on a deeper and more abstract level than their novice peers.

Chandler and Sweller (1991) describe cognitive load theory as how cognitive resources are used during learning and problem solving when given a task. They indicate that the goal is to reduce cognitive load in order to increase problem solving ability and accuracy (Chandler & Sweller, 1991). Reducing cognitive load increases the ability to solve problems because students are able to determine steps necessary to solve a problem and gives them the ability to focus on the problem at hand, rather than all of the additional extraneous information. When a task has too many conflicting or extraneous components, learning can be negatively impacted depending on the ability of the student and level of understanding of the topic. For example, a student who is considered a novice will have a much more difficult time identifying and ignoring the extraneous or conflicting components and will struggle to complete the task. Much of the research suggests that a student needs ‘average’ academic aptitude in order to integrate multiple sources of information into a meaningful construct (Chandler & Sweller, 1991). Chandler and Sweller (1991) argue that using worked problems increases problem solving abilities by developing more awareness of comprehension failures. By seeing a worked problem, a novice student would become aware of the conflicting or extraneous information thus increasing their cognitive capacity in the future.

While no mention was made as to the DFI report serving as an exhaustive investigation on the applications of cognitive science research on learning environments, some important research conducted on the process of problem solving and the complexity of the process were not cited within the report. Consequently, answering the question posed by the key question, “How do students solve problems?” could be strengthened by adding some major concepts presented by noted problem solving experts in the field such as Glaser and Chi, Mayer, and Jonassen. The report failed to clearly define problems and include more advanced research on the process of problem solving however, it is an excellent launch pad for further discussion. Specifically, the report did not include some processes intertwined with the complex problem solving process, particularly with specificity to different curricular content areas, thus making it challenging to find support for their overly general cognitive principle presented.

COGNITIVE PRINCIPLE

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

Shute (2008) defines feedback as information communicated to the learner that is intended to modify his or her behavior. Hattie and Timperley (2007) conceptualize feedback as information provided by an agent (e.g., teacher, peer, parent, self, experience) regarding aspects of one’s performance or understanding. Other works not cited by the DFI report, such as Poulos and Mahoney (2008), define feedback as information presented that allows comparison between an actual outcome and a desired outcome. Wiggins (2012) further defines feedback as information about how we are progressing in our efforts to reach a particular goal. One common theme among research on feedback and the effective incorporation thereof is an attempt at defining precisely what feedback entails. While the literature has not established a common definition, feedback can be summarized as involving information acquisition and how that information in turn affects potential outcomes.

If learners are to attain goal accomplishment from learning, then feedback is typically used to direct their efforts toward the prescribed outcomes of the learning activity. Two pathways can be identified toward problem solving: expertise and feedback, both concepts may be broken down and studied further. While the DFI report does not expand on different roles for feedback, it has generally been broken down into two types of information. One is summative feedback which is generally evaluative, assessing the end of some program. Formative feedback, however, typically summarizes a learner’s development along a continuum or process. For addressing learners and learning, formative feedback is of more value in its application and effect. Valerie Shute (2008) produced an exhaustive literature review on formative feedback which studied over 170 articles, books, dissertations, and determined that it is, “one of the more instructionally powerful and least understood features in instructional design” (Shute, 2008, p.153). Further, Shute concluded that formative feedback is "information communicated to the learner that is intended to modify his or her thinking or behavior to improve learning" (p 153).

The DFI report mentions feedback as a cognitive principle with practical implications for the classroom, essential to acquiring new knowledge and skills, but is rather sparse on detail that might be needed to improve effective instruction (Deans for Impact, 2015). To make this principle regarding the importance of feedback applicable in the classroom environment, a clarification of elements of good feedback is needed: specific and clear, focused on the task, and explanatory and focused on improvement rather than verifying performance (Shute, 2008). Researchers (Hattie & Timperley, 2007; Shute, 2008) note the critical importance of understanding precisely what feedback is and how to use it in the classroom to improve teacher and student performance.

Shute (2008) further subdivides formative feedback, describing formative feedback as having two prongs: verification (right, wrong, percentages, etc.) and elaboration ("the work" – why was it right or wrong, how can it be better). Hattie and Timperley (2007) further identified four levels of feedback: acquisition, development, application and emotional. Each of the levels is intended to assist in answering guiding questions about task and performance such as where am I going, how am I going, and where to next. Paulos and Mahoney (2008) add to the already rich structure with the results of their thematic analysis by creating the three key dimensions of feedback: perceptions of feedback, impact of feedback, and credibility of feedback. Wiggins (2012) writes that the essential elements of feedback are goal-referencing, tangible and transparent, actionable, user-friendly, timely, ongoing and consistent.

In *Classroom Instruction that Works*, the practices for developing useful feedback in the classroom are listed and include: correcting and elaborating on what students need to do next, appropriately and in time to meet students' needs, are criterion referenced, and engage students in the feedback process (Dean, Hubbell, Pitler, Stone, & Marzano, 2012). Shute's (2008) work stresses the importance of specific feedback, as to avoid vague direction, while also recognizing that feedback that is too brief narrows the focus, yet too long, may distract from what is to be accomplished. Hattie and Timperley (2007) stress the need to create environments and build cultures that emphasize learning, practicing and improving, therefore, zeroing in on the feedback, and decreasing the punishment and self-esteem factor that is often associated with feedback in schools. This is an important piece of the complex problem of applying cognitive science principles in schools. What the literature suggests is that in order for feedback to be effective, educators must develop cultures that allow students to work and develop approaches to problem solving without fear of punishment, it must be targeting gaps in school performance to drive school improvement, and produce outcomes that meet agreed upon expectations.

Though environments and cultures were addressed in the research, more literature on creating the right environment that will allow feedback to be used successfully should be included. Yeager et al. (2014) provides research on what teachers can do in regard to environments and feedback to improve learning environments. Additionally, the report could focus more on assessing the usefulness of feedback from the student perspective in schools since it is designed to inform educator preparation programs. Also, how do students perceive feedback as being useful toward goal attainment? This question was not directly addressed by the Shute and Hattie and Timperley articles and consequently are missing from the DFI report (2015). Additional scholarship addresses feedback from a student perspective and how the conditions that allowed students to use feedback developed problem solving skills (Lizzio & Wilson, 2008).

In addition, Dean et al. (2012), address feedback from the student perspective by suggesting actively engaging students in meaningful feedback that supports student growth.

CONCLUDING THOUGHTS

The DFI report (2015) analyzed a body of literature to develop the two cognitive principles associated with the Key Question, “How do students solve problems?” While the authors of the report provided a number of references, the report could be strengthened by adequately addressing the question of how students in schools solve problems in their classwork. Many of the articles cited related to feedback or specific content areas for application which, while important, still failed to fully support the cognitive principle presented.

A more comprehensive body of literature might include the cognitive processes associated with problem solving. Examining how self-regulated learning and cognitive load theory impact problem solving would also provide the necessary support to justify the importance and application of the cognitive principles presented in the report. Implementing various forms of formative feedback into classrooms filled with children adds the complexity of climate and culture and all of the additional variables created through group dynamics. The report does, however, provide a springboard from which educators can reflect on the cognitive science findings and explore the implications and potential impact of applying them in classrooms.

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