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Creativity and Metacognition in Education

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ABSTRACT: Creative thinking skills are essential key competencies for the twenty-first century. They enable flexibility and help us navigate the opportunities and challenges of our complex, rapidly changing world. The growing emphasis on innovation, alongside reports of declining creative performance, highlights the importance of cultivating these skills in education. In recent years, there has been a growing emphasis on nurturing and teaching creativity early in schools. While creativity is an integral part of arts education, it is less frequently emphasized in science, technology, engineering, and mathematics subjects. Ultimately, what truly matters is the manner in which these subjects are being taught. Implementing creativity training could enhance creative thinking and hold significant benefits for educational institutions. Similar cognitive techniques that can be employed for this purpose are, i.e, metacognitive strategies that involve self-reflective thinking. Metacognition plays a central role in many areas of education and learning, such as reading, writing, language acquisition, attention, memory, and problem-solving, among others. In this study, we explore the mental functions of metacognition and creativity and the different ways they can be used to improve students' academic performance, with a particular focus on mathematical performance. Overall, the current review study may have theoretical and practical implications for educational institutions.

INTRODUCTION

Metacognition is an area of study that initially came to the surface during research in the fields of psychology of subjective memory and educational development (Wells & Capobianco, 2020). Cognition is responsible for the resolution of problems whereas metacognition is responsible for the adjustment of cognitive effort expended in the resolution of a problem (Vos, 2001). In the extensive literature on metacognition in psychology and philosophy, some specific types of metacognition are rarely touched upon. These include cases of meta-representation of a set of psychological states or processes within that are explicitly stated, as opposed to only implicit or procedural ones (Carruthers, 2021). There is a claim that the most plausible examples of this type of metacognition are included in estimates of cognitive effort (Carruthers, 2021).

Metacognition and creativity are distinct cognitive skills that can assist students in various ways within educational environments. One key aspect of creative thinking is imagination. Imagination is a mental process that creates representations of current and potential future states, which can guide decision-making and behavior (Moore & Milkoreit, 2020). Actively involving oneself in transformation processes naturally depends on imagination. It is generally linked to the capacity to conceive ideas mentally about things beyond sensory perception, such as alternative or fictional worlds (Moore & Milkoreit, 2020). Imagination has been a key driver in enabling Homo sapiens to become the dominant species on Earth (Carroll, 2020). It has significantly contributed to the development of the complex behaviors that define neurologically modern humans. As a neurological phenomenon, imagination resides in specific brain regions. The default mode network of the brain is believed to be the primary area associated with imagination (Carroll, 2020). The three main processes involved in constructing imaginative verbal artifacts are considered to be simulation, mental time travel, and perspective taking—also known as "Theory of Mind" and "mentalizing."

Imaginative thought can lead to the development of new ideas during creative problem-solving. A "matching theory" of creative problem-solving suggests that problems with creative solutions differ in complexity, required knowledge, and the mix of divergent and convergent thinking (Brophy, 1998). It also predicts that individuals with different preferences, abilities, knowledge,

and work strategies will be most effective at solving specific types of problems. The traditional view of insight problem solving holds that working memory plays a significant role, similar to its function in non-insight (incrementally solvable) problems (Gilhooly & Webb, 2018). The alternative 'special process' perspective suggests a lesser role for working memory, emphasizing the importance of unconscious processes that are not restricted by working memory capacity (Gilhooly & Webb, 2018). Working memory plays a somewhat smaller role in insight problems than in non-insight problems, supporting the idea of the involvement of specialized processes in insight solving; however, this effect is minor, indicating considerable overlap between the processes involved in both types of problems (Gilhooly & Webb, 2018). An integrated perspective suggests that solving typical insight problems involves both conventional and special processes, and the extent to which each process is engaged varies among problems—some may rely mostly on special processes with little conventional effort, while others involve significant conventional strategies (such as reaching an impasse) before briefly engaging special processes at the end (Gilhooly & Webb, 2018).

Self-reflective, critical, and creative thinking for enhanced mathematical performance

According to metacognition research, students use memory functions to create a mental model of their understanding, which helps them control their learning, however, when assessing their understanding, students draw conclusions based on traits such as perceived mental load and level of effort in the learning process (Schnaubert & Schneider, 2022). Through continual practice, students can heighten their metacognitive self-awareness to identify strengths and weaknesses, facilitate the conversion of declarative to procedural knowledge, boost top-down processing, and ultimately adjust the equilibrium of their metacognitive self-regulation strategies (Cera et al., 2014). Findings of a study involving 130 students revealed that metacognitive skills, including planning, monitoring, evaluation, and concentration, are significantly linked to self-regulated learning, while metacognitive knowledge and metacognitive attitudes lead to both autonomy in learning and increased self-efficacy (Cera et al., 2014). A recent study (Ocak et al., 2025) suggests that computational thinking particularly fosters self-monitoring and evaluation strategies, such as ongoing performance assessment, adopting new strategies, and exploring alternatives when solutions fail.

Both metacognition and critical thinking notably forecasted problem-solving abilities, indicating that they serve as a dual mediating chain between self-efficacy and problem-solving (Wang, 2024). Critical thinking allows people to reflect on how they are using their mathematical abilities (thinking about their ways of thinking (Su et al., 2016). Math problem solving has been used to investigate individual differences in metacognition by exploring how individuals perceive their own math performance (Legg & Locker Jr, 2009). One study, combined teachers and researchers to trial creative problem solving as a method of teaching mathematics, aiming to boost students' creative thinking and problem-solving abilities (Khalid et al., 2020). The results demonstrated statistically significant improvements in most categories of creativity and problem-solving assessments. In another study, undergraduate university students took part in a creativity training program that used a cognitive approach (Ritter & Mostert, 2017). After the training, enhancements were seen in various measures of creative performance. The study also suggests that cognitive flexibility may be a key underlying factor for these creativity improvements. Besides boosting divergent thinking skills, the training enhanced convergent thinking and showed marginal gains in creative problem-solving abilities.

Metacognitive and creative thinking may facilitate a better understanding of mathematical concepts and definitions, as well as assist in finding solutions to mathematical problems. Being able to provide a concrete definition of a mathematical concept plays a critical role on an individual's problem-solving ability surrounding the concept (Panaoura et al., 2017). Inability to provide an accurate definition for a mathematical concept, such as i.e. the concept of function, was found to be linked with student's insufficient problem-solving skills in the relevant mathematical domain (Elia et al., 2007). Students often feel more comfortable providing examples of a mathematical concept i.e. for functions instead of providing an actual definition of the concept (Elia et al., 2008). A model, based on the unification of several theories in the domain of mathematical representations, has been proposed for fraction and decimal number addition (Deliyianni et al., 2016). Geometrical figures are simultaneously concepts and spatial representations; therefore, the double status of external representation in geometry often causes difficulties to students when dealing with geometrical problems due to the interactions between concepts and images in geometrical reasoning (Deliyianni et al., 2009). In a study investigating high school student's approaches in solving complex number tasks, a mental mechanism of separating of conflicting thoughts was observed in students who chose to solve the tasks using a geometric approach, whereas in students who chose to solve the tasks using an algebraic approach this mechanism was absent (Panaoura et al., 2006). Furthermore, it has been shown that students who used a geometric approach for solving mathematical problems on limits were more efficient in solving non-conventional/complex tasks, than those who used an algebraic approach (Elia et al., 2009).

Perhaps the most renowned example of insight and creativity in the history of science is the well-known "eureka" uttered by Archimedes while he was in his bathtub, contemplating the physical phenomenon of buoyancy. In Figure 1 this exact moment is depicted. Typically, these moments of great insight occur after extended periods of meditative thought on a particular problem. Recent cognitive neuroscience research suggests that these 'aha' moments result from cumulative metacognitive processes stored in the brain as discrete packets, rather than arising from instantaneous bursts of creativity of unknown origin (Kounios & Beeman, 2009). Archimedes' discovery in the 3rd century BC is a fundamental principle of hydrostatics in modern physics.

Figure 1: Illustration of the ancient Greek scientist Archimedes at the moment he realized that the volume of water displaced from his bathtub was equal to the volume of the part of his body submerged in the water.

CONCLUSION

It is widely accepted that metacognition plays a significant role in the acquisition and application of academic skills. Metacognitive skill training has been shown to improve performance in mathematical problem-solving. Individuals who use the "know" ability of their cognition and the "plan" ability of their metacognition seem to be better performers than those who do not. Self-monitoring and self-evaluation skills are especially evident when students decompose problems and develop step-by-step solutions to meet evolving challenges. Research indicates that metacognition contributes to enhanced creative thinking, particularly in tasks that require insightful resources. Courses in mathematics at pedagogical institutions are often characterized by conventional educational practices, with less emphasis placed on creative thinking in mathematics. This study underscores the importance of instructing mathematics courses in a manner that fosters creative and critical thinking among students. One approach for aspiring educators to achieve this is through instructing mathematics in a manner that encourages the cultivation of creativity and insight among students.

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