Metacognitive Tutoring Systems (MTS)

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INTRODUCTION

Intelligent Tutoring Systems (ITSs) are computational learning support systems based on the use of artificial intelligence. They incorporate computational models from the cognitive sciences, learning sciences, computational linguistics, artificial intelligence, and mathematics (Graesser et al. 2012). The term ITS was first used by Sleeman and Brown (1982) as the title of an overview on Intelligent Computer-Aided Instruction (ICAI), which at the beginning were focused mainly on the subject matter (Barr and Feigenbaum, 1982). Shute and Psotka (1994) stated that an ITS must possess knowledge of a domain, knowledge of the learner, and knowledge of teaching strategies, and that they should have accurately diagnose students' structures, skills and/or styles and then adapt instruction accordingly. ITSs were more recently defined by Graesser et al. (2018) as "computer learning environments that help students master knowledge and skills by implementing intelligent algorithms that adapt to students at a fine-grained level and that instantiate complex principles of learning" (p. 246).

According to Corbett et al. (1997) ITSs are modeled on human tutors, but the analogy should not be taken literally due to the high standard that it implies, as well as the need for students to think ITSs as tools they are employing, rather than as taskmasters, and the need for teachers to think ITSs as tools that can free their time to interact individually with students.

Cognition, affect, and metacognition are the domains on which ITSs are usually focused. The first refers to information processing, the second to emotions and feelings during the learning process, and the third to the knowledge and regulation of cognition. It is common for ITS to focus on only one of these domains, although there are systems such as Wayang Outpost that focus on all three domains (Arroyo et al., 2014).

Intelligent Tutoring Systems (ITSs) for cognitive support, i.e., support with information processing, have been notable since the 1980s under the name Cognitive Tutors (Anderson et al., 1995). Affect-oriented ITSs, i.e., emotional, and sentimental support, have gained great importance since the beginning of the 21st century under the name Affective Tutoring Systems (Sarrafzadeh et al., 2008). On the other hand, there have been studies on ITSs that focus on metacognition since the 1980s as the work of Kawamura et al. (1986), Conati (2009) referred to these systems as "intelligent tutors that scaffold metacognition". The term Metacognitive Tutoring Systems (MTS) has been used in the work of Joyner and Goel (2015), and Pelta (2015), however, this term is less popular than Cognitive Tutors or Affective Tutoring Systems.

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Since the term ITSs was coined, it was stated that control should be balanced between the student and the system (Sleeman and Brown (1982). This is analyzed from the paradigms of adaptivity and adaptability in which the former gives more control to the ITS, while the latter gives more control to the learner (Dascalu et al., 2017).

In this chapter, we introduce and discuss the meaning of metacognition, the architecture of ITSs, and how the ITSs could support metacognition, then we mention some journals and conferences about these systems, describe four successful application examples, and present some recommendations and future research directions. We also propose those systems to be grouped under the term Metacognitive Tutoring Systems (MTS).

BACKGROUND

Literature Review: Beyond Cognition, Metacognition

The term metacognition was proposed by Flavell (1976) and has a double meaning: first, it is both the knowledge we have about our own cognitive processes and, second, the active monitoring and regulation of those processes.

A cognitive process is a process of information transfer that typically takes place to connect multiple informational inputs related to perception, memory, learning, emotion, intentionality, self-representation, rationality, and decision-making (Newen, 2015). Being aware of these processes means knowing how this information is processed and which conditions and strategies are favorable or unfavorable. In this way, we can use this knowledge to our advantage, making these processes more effective. Supporting and fostering metacognition skills is important within the educational context because it allows students to become autonomous learners, to take an active role in its learning process. It also fosters their critical thinking and helps them to expand what has been learned into other contexts and different tasks.

Paris et al. (1984) highlighted the importance of two fundamental aspects of metacognition that follow the same line as Flavell (1976): knowledge about cognition and self-directed thinking. The first aspect includes declarative knowledge (propositional knowledge that refers to "knowing what"), procedural knowledge (refers to knowing how to carry out various actions) and conditional knowledge (involves knowing when and why different strategies can be used to achieve different purposes). The second aspect was also called executive function, which is made tangible through the activities of evaluation (measured against a standard such as effort or ease), planning (allocation of time and effort to optimize the solution of the task), and regulation (follow one's chosen plan and to monitor its effectiveness).

Two major metacognitive components were then distinguished, in accordance with the two aspects pointed out by Paris et al. (1984). The first one was knowledge about cognition and the second one was regulation of cognition (Brown, 1987; Jacobs & Paris, 1987). Schraw (1994) described the first component as stable information about the learner's strengths and weaknesses, knowledge about strategies and about when and where to use them, which goes hand in hand with the declarative, procedural, and conditional knowledge of Paris et al. (1984). The second component was linked to the actions of planning, monitoring, and correcting one's own performance.

Subsequently, Schraw and Moshman (1995) took up the model of declarative knowledge (knowledge about oneself as a learner and about what factors influence one's performance), procedural knowledge (knowledge about the execution of procedural skills) and conditional knowledge (knowing when and why to apply various cognitive actions) as subprocesses of cognition knowledge. However, with respect to