THE ROLE OF METACOGNITION IN LEARNING AND TEACHING OF PHYSICS

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This article provides a brief overview of the theory of metacognition and its role in learning and teaching. The metacognitive knowledge of strategy, task and personal variables enables students to perform better and learn more. The instructional strategies that facilitate the construction of knowledge are discussed. Metacognitive strategies for physics learning and teaching are given.

Introduction

Metacognitive knowledge involves knowledge about cognition in general, as well as awareness of and knowledge about one's own cognition. The research on learning emphasis on helping students become more knowledgeable of and responsible for their own cognition and thinking [Flavell, J.1979 , DeJager *et al.* 2005]. Students become more aware of their own thinking as well as more knowledgeable about cognition in general. Furthermore, as they act on this awareness they tend to learn better [Eylon, B. S. and Reif, F.1984]. The labels for this general developmental trend vary from theory to theory, but they include the development of metacognitive knowledge, metacognitive awareness, self-awareness, self-reflection, and self-regulation. Although there are many definitions and models of metacognition, an important distinction is one between (a) knowledge of cognition (Metacognitive knowledge) and (b) the processes involving the monitoring, control, and regulation of cognition.

Metacognitive knowledge includes knowledge of general strategies that might be used for different tasks, knowledge of the conditions under which these strategies might be used, knowledge of the extent to which the strategies are effective, and knowledge of the self. Metacognitive control and self regulatory processes are cognitive processes that learners use to monitor, control, and regulate their cognition and learning. The metacognitive and self-regulatory processes are well represented in tasks such as checking, planning, and generating. Accordingly, on the knowledge dimension, 'metacognitive knowledge' categories refer only to knowledge of cognitive strategies, not the actual use of those strategies.

Three Types of Metacognitive Knowledge

In a classic article on metacognition, Flavell (1979) suggested that metacognition include knowledge of strategy, task, and person variables. Flavell's model encourages students to consider how each variable affects their own learning processes. Metacognitive knowledge could be categorized under three heads - Strategic Knowledge, Knowledge about cognitive task and Self-knowledge.

Strategic Knowledge

Strategic knowledge includes knowledge of the various strategies students might use to memorise material, to extract meaning from text, and to comprehend what they hear in classrooms or what they read in books and other course materials. Although there are a large number of different learning strategies, they can be grouped into three general categories: rehearsal, elaboration, and organisational [Isaacson and Fujita 2006]. Rehearsal strategies refer to the strategy of repeating words or terms to be remembered over and over to oneself, generally not the most effective strategy for learning more complex cognitive processes. In contrast, elaboration strategies include various mnemonics for memory tasks, as well strategies such as summarising, paraphrasing, and selecting main ideas from texts. The elaboration strategies result in deeper processing of the material to be learned and lead to better comprehension and learning than the rehearsal strategies. Finally, organisational strategies include various forms of outlining, concept mapping, and note taking, where the student makes connections between and among content elements. Like elaboration strategies, these organisational strategies usually result in better comprehension and learning than rehearsal strategies.

Students can have knowledge of various metacognitive strategies that will be useful to them in planning, monitoring, and regulating their learning and thinking. These strategies include the ways in which individuals plan their cognition (e.g., set subgoals), monitor their cognition (e.g., ask themselves questions as they read a piece of text; check their answer to a problem in mathematics), and regulate their cognition.

Knowledge about cognitive task

In addition to knowledge about various strategies, individuals also accumulate knowledge about different cognitive tasks. In recall task, the individual must actively search memory and retrieve the relevant information; while in the recognition task, the emphasis is on discriminating among alternatives and selecting the appropriate answer. As students develop their knowledge of different learning and thinking strategies and their use; this knowledge reflects the "what" and "how" of the different strategies. However, this knowledge may not be enough for developing expertise in learning. Students also must develop some knowledge about the "when" and "why" of using these strategies appropriately [Rajkumar 200], Shulman 1986]. Because not all strategies are appropriate for every situation, the learner must develop some knowledge of the different conditions and tasks where the different strategies could be used most appropriately.

Self-knowledge

Along with knowledge of different strategies and knowledge of cognitive tasks, Flavell (1979) proposed that self-knowledge was an important component of metacognition. Self-knowledge includes knowledge of one's strengths and weaknesses. This self-awareness of the breadth and depth of one's own knowledge base is an important aspect of self-knowledge. Finally, individuals need to be aware of the different types of strategies they are likely to rely on in different situations. An awareness that one relies more on a particular strategy when there may be better alternative adaptive strategies for the task, could lead to the possibility of a change in strategy use.

Implications for learning and teaching

Metacognitive knowledge can play an important role in student learning and, by implication, in the ways students are taught and assessed in the classroom [Nuthall, G.1999]. First, as previously noted, metacognitive knowledge of strategies and tasks, as well as self-knowledge, is linked to how students will learn and perform in the classroom. Students who know about the different kinds of strategies for learning, thinking, and problem solving are more likely be using them. After all, if students do not know of a strategy, they will not be able to use it. Students who do know about different strategies for memory tasks, for example, are more likely to use them to recall relevant information. Similarly, students who know about different learning strategies are more likely to use them while studying. And, students who know about general strategies for thinking and problem solving are more likely to use them when confronting different classroom tasks. Metacognitive knowledge of all these different strategies enables students to perform better and learn more. Many teachers assume that some students will be able to acquire metacognitive knowledge on their own, while others lack the ability to do so. Of course, some students do acquire metacognitive knowledge through experience and with age, but many more fail to do so. It is not expected that teachers would teach for metacognitive knowledge in separate courses or separate units.

It is more important that metacognitive knowledge is embedded within the usual content-driven lessons in different subject areas. General strategies for thinking and problem solving can be taught in the context of English, mathematics, science, social studies, arts, music, and physical education courses. Science teachers, for example, can teach general scientific methods and procedures, but learning will likely be more effective when it is tied to specific science content, not as an abstract idea. The key is that teachers plan to include some goals for teaching metacognitive knowledge in their regular unit planning, and then actually try to teach and assess for the use of this type of knowledge as they teach other content knowledge. One of the most important aspects of teaching for metacognitive knowledge is the explicit labelling of it for students.

Implication of physics learning

Metacognitive strategies refer to strategies for helping learners become more aware of themselves as learners, and include ability to monitor one's understanding through self-regulation; ability to plan, monitor success and correct errors when desirable; and ability to assess one's readiness for high level performance in the field one is studying [Mestre and Touger 1989]. Reflecting about one's own learning is a major component of metacognition, and does not occur naturally in the physics classroom, due to lack of opportunity and also because instructors often do not emphasize its importance. It is common to hear physics students comment, 'I am stuck on this problem', but when asked for more specificity about this condition of 'stuckness', students are at a loss to describe what we are sticking on this problem that has them stuck, and often just repeat that they are just stuck and can't proceed. If during instruction, we were to take the time to suggest why, and how, students should reflect about their learning, there would be fewer incidents of the 'stuck' condition, since students would be able to identify what they are missing that would allow them to proceed. The contemporary view of learning is that individuals actively construct the knowledge they possess.

Constructing knowledge is a lifelong, effortful process requiring significant mental engagement from the learner. In contrast to the 'absorbing knowledge in ready-to-use form from a teacher or textbook' view of learning, the 'constructing knowledge' view has two important implications for teaching. One is that the knowledge that individuals already possess affects their ability to learn new knowledge. When new knowledge conflicts with resident knowledge, the new knowledge will not make any sense to the learner, and is often constructed (or accommodated) in ways that are not optimal for long-term recall or for application in problem-solving contexts [Redish 2000].

The second implication is that instructional strategies that facilitate the construction of knowledge should be favoured over those that do not. Sometimes this statement is interpreted to mean that we should abandon all lecturing and adopt instructional strategies where students are actively engaged in their learning. Lecturing could be a very effective method for helping students learn, but wholesale lecturing is not an effective means of getting the majority of students engaged in constructing knowledge during class-room instruction. Hence, instructional approaches where students are discussing physics, doing physics, teaching each other physics and offering problem solution strategies for evaluation by peers will facilitate the construction of physics knowledge.

Implication of physics teaching

Largely missing from science classrooms, especially large lecture courses, is formative assessment intended to provide feedback to both students and instructors, so that students have an opportunity to revise and improve the quality of their thinking and instructors can tailor instruction appropriately. The age-old technique of asking a question to the class, and asking for a show of hands has been tried by most, but does not work well since few students participate in the hand-raising largely due to lack of anonymity. In classes having fewer number of students it is not difficult to shape teaching so that two-way communication takes place between the teacher and the student. For example, one very effective method of teaching physics to having classes with fewer number of students, perfected by Resnick (1983) involves class-wise discussions led by the teacher. Students offer their reasoning for evaluation by the other classmates and by the teacher, with the instructional format taking somewhat the form of a debate among students, with the instructor moderating the discussion and leading it to desired certain direction by posing carefully crafted questions. In classes with large enrollment, the advent of classroom communication systems allows the incorporation of a workshop atmosphere, with students working collaboratively on conceptual or quantitative problems, entering answers electronically via calculators, and viewing the response of entire class's in the form of histogram form for discussion [Mestre *et.al.* 1989, Redish 2000]. With this approach, the histogram serves as a springboard for a class-wise discussion in which students volunteer the reasoning that led to particular answers and the rest of the class evaluates the arguments. The teacher moderates, making sure that the discussion leads to appropriate understanding.

Metacognitive strategies in Physics teaching

The research reviewed above carries important implications for how instruction for teachers should be structured. In this section I provide a list of desirable attributes for physics courses suggested by research on learning.

- Construction, and sense-making, of physics knowledge should be encouraged.
- The teaching of content should be a central focus.
- Ample opportunities should be available for learning 'the process of doing science'.
- Ample opportunities should be provided for students to apply their knowledge flexibly across multiple contexts.
- Helping students organise content knowledge according to some hierarchy should be a priority.
- Qualitative reasoning based on physics concepts should be encouraged.
- Metacognitive strategies should be taught to students.
- Formative assessment should be used frequently to monitor students understanding and to help tailor instruction to meet students' needs.
- Teachers must provide students with opportunities to practice strategies they have been taught.

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