Metacognition and the Use of Tools

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Abstract

In this chapter the relationship between metacognition and the use of tools is addressed. Being able to determine when the use of a tool would be beneficial for one's learning is seen as a metacognitive skill. Different assumptions are made with respect to this relationship between metacognitive knowledge (including instructional conceptions) and tool usage. A series of studies are addressed in which different instruments were used to measure metacognitive knowledge and metacognitive skills to provide empirical underpinning for these assumptions.

Metacognition is a learner characteristic that enables learners to regulate and make optimal choices with respect to their learning process (Dörner & Wearing, 1995; Frensh & Funke, 1995). Flavell (1976) defines it as:

> metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them (….). It refers to the active monitoring and the consequent regulation and orchestration of these processes in relation to cognitive objects or data on which they bear, usually in the service of some concrete goal or objective. (p. 232)

Flavell (1979) makes a distinction between metacognitive knowledge, metacognitive experiences, and metacognitive strategies (i.e., regulatory skills). Metacognitive knowledge refers to knowledge of cognition. It includes knowledge of what and how factors act and interact to affect learning processes, knowledge of how to use available information to achieve a goal, knowledge of what strategies to use for particular purposes, and knowledge of when and where particular cognitive strategies should be used. The aforementioned knowledge can be declarative, procedural, or conditional knowledge (Schraw, 2001; Schraw & Dennison, 1994; Paris, Lipson, & Wixson, 1983). Metacognitive experiences have to do with the conscious awareness of where one

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stands in a certain cognitive process and what progress one is making to achieving learning goals. These experiences may induce metacognitive strategies that control one's cognitive processes. Metacognitive strategies are "executive" activities—such as planning, monitoring, and evaluation—that one uses to control and regulate one's cognitive processes (Gourgey, 2001; Livingston, 2003).

This chapter focuses on the relationship between metacognitive knowledge and strategies and the use of support devices in computer-based learning environments (CBLEs). Learning environments, and more specifically CLBEs, consist of content, tasks, and different supportive elements (Jonassen, 1999). The supportive elements refer to the devices that foster learning; they support learners to deal with the content and the tasks of the learning environment. These devices can be embedded, meaning that the use is mandatory and out of control of the user, or non-embedded which leaves the use under the learners' control. These non-embedded support devices are referred to as tools (Clarebout & Elen, 2006) and are the focus of this chapter. Depending on the kind of support offered, a distinction is made between information, cognitive, and scaffold tools. Information tools provide the content in a different way, for instance, in a structured or elaborated way. Cognitive tools allow learners to interact with the content and scaffold tools guide the learning efforts. Being able to strategically use tools to learn more efficiently can be considered as a metacognitive strategy (e.g., Greene & Azevedo, 2007; Horz, Winters, & Fries, 2009; Winne & Jamieson-Noel, 2002).

Learner Control, Tools, and Metacognition

In numerous CBLEs, learners have control over the use of tools. When giving learners control over supportive elements, support can be said to be adapted to their needs. Learners receive as much support as they need. This means that possible detrimental effects for learning of either too much or too less support can be avoided. However, giving learners control over the supportive elements assumes that they are good judges of their own learning process and they possess the necessary metacognitive knowledge and skills to determine when and how to use the support. This seems not so evident: Learners often lack the knowledge and skills to regulate their own learning (Butler & Winne, 1995; Clark, 1990; Greene, & Azevedo, 2007; Horz et al., 2009; Winne & Jamieson-Noel, 2002). Indeed, recent reviews and studies indicate that learners often do not use the support offered to them (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Azevedo, 2005; Clarebout & Elen, 2006; Narciss, Proske, & Koerndle, 2007; Winne, 2006). Additionally, a number of studies report overuse in an attempt of learners to "game the system" (Aleven & Koedinger, 2000; Bartholomé, Stahl, Pieschl, & Bromme, 2006; Wood & Wood, 1999). Different studies hypothesized that students may not seek adequate support because they lack the necessary metacognitive knowledge and skills. In these studies metacognition has often been the object of support (Jonassen, Beissner, & Yacci, 1993; Narciss et al., 2007; Winters, Greene, & Costich, 2008), but the relationship between metacognition and the use of tools has seldom been the focus of research.

In the studies presented in this chapter, specific attention was given to one aspect of metacognitive knowledge, namely, learners' instructional conceptions about the different support devices (Elen & Lowyck, 1999). Learners' instructional conceptions are a kind of metacognitive knowledge referring to "all ideas and theories that an individual learner holds about (the components of) the learning environment" (Lowyck, Elen, & Clarebout, 2005). Winne (2006) states that the functionality students ascribe to a tool will determine whether and how they use this tool.

The assumption is that in order to be able to make adequate decisions, learners need to know the functionality of tools in general and more specifically how or when the use of these tools may be helpful for their own learning. This also relates to one of the conditions put forwards by Perkins (1985) with respect to grasping learning opportunities, in this case, using support devices.

Perkins indicates that first the opportunity has to be there and second that learners need to know the functionality of the tools at hand. In line with the above reasoning, some studies also suggest that interventions promoting metacognitive strategies and skills need to include aspects that increase metacognitive knowledge (e.g., Schraw & Dennison, 1994; Schwonke, Berthold, & Renkl, 2009).

Based on this theoretical framework, the following assumptions were made:

- *Learners' instructional conceptions influence tool use*: The better learners know the functionality of a tool and how it can contribute to their learning, the more optimal they will use it (including not using it when not needed). The more knowledgeable learners are about the (functionality of the) tools, the more knowledgeable decisions they can make. The more students perceive a tool as functional, the more they will be inclined to adequately use it.
- *Learners' metacognitive skills influence tool usage*: The extent to which learners are able to detect their own learning problems and are capable of regulating their own learning will determine the extent to which they will be inclined to use support devices to solve these problems (Mercier & Frederiksen, 2007). The more they are capable to do this, the more adequate they will use tools. Given that either too much or too less support can be detrimental for learning (Clark, 1990), a third assumption is that for the learners with limited metacognitive skills, the mandatory use of supportive elements, and hence inducing the learners to use the supportive elements, will be beneficial for their learning. While for learners who possess the necessary metacognitive skills, learner control over the supportive elements will be more beneficial than supplanting this decision for them by obliging them to use these elements.

These assumptions were tested in different studies that will be discussed in the next section of this chapter. First the learning environments used in these studies will be described including the participants they aimed at. Next, the different instruments to measure metacognition will be discussed and the results of their use in different studies on the use of tools. Finally, the assumptions are discussed in relation to the results of the studies.

Overview of Empirical Evidence on Metacognition and the Use of Tools

Context

Different studies were carried out in CBLE's. Three of the four studies were a text-based CBLE. Students were asked to read a text on a computer (on obesities/airplanes) and got access to different tools. In the first obesities study (Clarebout & Elen, 2009), students got access to cognitive and scaffold tools, namely, a dictionary, instructional goals, and example questions, and help with interpreting graphics and text. In one version of the environment, additional explanation was offered on the functionality of the support devices before seeing the actual text (e.g., *By clicking on this tool you receive an explanation of the goals that you should achieve by reading this text. By reading these goals, you will be able to gain more insight into what is expected from you*). This intervention aimed at influencing learners' instructional conceptions and hence to make them more knowledgeable about the functionality of the support devices. In the second obesities study (Clarebout, Horz, Elen, & Schnotz, 2010), a German translation was used of the text in the first obesities study and one cognitive tool. This tool gave additional explanation on a graph, where after, students were asked to give an interpretation of this graph in their own words. Two versions were made of the environment, one in which the use of supportive elements was mandatory and hence where the program took over some metacognitive activity. In the other version, students had themselves control of the use of the supportive elements.

A third study with a text-based CBLE was a text on airplanes. Two versions were created, both with a cognitive tool: one with an advanced organizer and one containing three questions.

A final learning environment that was used was an ill-structured CBLE (Clarebout & Elen, 2004) where students were confronted with an ecological problem. Participants were asked to come up with the most environmental-friendly drinking cup for a music festival by considering ecological, financial, and safety aspects. Different tools were available to the learners: information tools (information list containing official documents, videos with opinions of stakeholders), cognitive tools (calculator), and scaffold tools (problem-solving script, reporting script). Additionally, two conditions received advice on the use of these tools. In one condition this advice was given at fixed moments; in the other condition, the advice was given based on the learner's process.

All the CBLEs discussed here were directed towards higher education students and aimed at gaining insight into learners' tool use and factors influencing this tool use.

In order to grasp learner's support device usage, log files were kept and analyzed. These log files allowed to gain insight into the number of times learners consulted a tool and the duration of their consultation. In the problem-solving environment, it was also possible to gain insight into when students consult a tool in their problem-solving process. Next to quantitative data, the log files also registered some more qualitative data. For instance, when students consulted additional explanations on the graph and were asked to give their own interpretation, these interpretations were logged and gave insight into the depth with which learners used the tool and hence formed a measurement of qualitative tool use.

Measurement of Metacognition

Throughout the different studies, different instruments to measure metacognition were used, and they will be addressed in the following, including some empirical results of their use:

ICON questionnaire. In the problem-solving study, students' metacognitive knowledge, more specifically their instructional conceptions, were measured using the ICON questionnaire (Sarfo, Elen, Clarebout, & Louw, 2010). This questionnaire confronts learners with eight statements for each tool. Learners have to indicate the extent to which they agree (from totally disagree to totally agree) that a specific tool can be functional for their problem-solving process [e.g., *According to me, a problem solving script helps students to better understand the content* (Cronbach's alpha = 0.91)]. Strangely enough, the higher students scored on the ICON questionnaire, meaning the more functional they found a tool prior to being confronted with it, the less they used the tool. In the second obesities study, the ICON questionnaire was also used (Cronbach's alpha = 0.93). In this study, no significant relationship was found between learners' instructional conceptions and their tool usage. Interestingly though, a significant correlation was found between learners' instructional conceptions and their internal regulation (see scale below). The more learners were internally regulating their learning process, the more they conceived the tools as being functional for their learning and vice versa.

Perceived usefulness. Based on the questionnaire from Davis and colleagues (Davis, 1989; Davis, Bagozzi, & Warshaw, 1989), perceived usefulness was measured as an indicator of metacognitive knowledge. In contrast to instructional conceptions, learners were already confronted with the learning environment and its tools. Perceived usefulness refers to the extent to which students believe that using a particular tool will enable efficient learning processes and/or increase performance of present learning tasks. Six statements were used to measure this concept (e.g., *studying an available advance organizer/answering questions will enable me to accomplish this learning task more quickly;* Cronbach's alpha = 0.92). This questionnaire was used in the airplane study and revealed a significant effect of perceived usefulness on tool usage. Students who perceive the tools as less useful spent less time on the tools. Students who perceived the usefulness of a tool at medium level spent the most time on the tools.

Regulation scales of Vermunt (1992). To measure learners' metacognitive skills, part of the learning style inventory of Vermunt (1992) was used, namely, the three regulation scales. These scales are internal regulation (e.g., *After each paragraph I try to formulate the learning content in my own words to test my learning process*), external regulation (e.g., *I study according to the instructions given in the study material or provided by the* teacher), and no regulation (e.g., *I notice that it is difficult for me to determine whether I master the subject matter sufficiently*). This questionnaire has been used in a variety of settings and found to be a valid and reliable instrument (Boyle, Duffy, & Duleavy, 2003; Veenman, Prins, & Verheij, 2003; Schouwenburg, 1996). In the problem-solving study, reliabilities for the internal regulation scale were good (Cronbach's alpha = 0.80) but not for the external regulation (Cronbach's alpha = 0.62) or for the no regulation scale (Cronbach's alpha = 0.68). This was the reason why in the first obesities study, only the internal regulation scale was used (resulting in that study in a Cronbach's alpha = 0.77). The studies could not retrieve a significant relationship between internal regulation and the frequency of tool usage; but it was found that the less learners are inclined to engage in regulation activities, the more time they spent on tools.

Help-seeking behavior measurement. Learners' help-seeking behavior was measured as an indicator of metacognitive skills. Help seeking includes the ability to identify one's own problem and act upon it (Schunk & Zimmerman, 1994). The instrument of Pajares, Cheong, and Oberman (2004) was used. Nine statements measured students' help avoidance behavior (e.g., *I would write down any answer rather than ask for help in class*; Cronbach's alpha = 0.90) and six items measuring students' perceived benefits of help seeking (e.g., *I think asking questions in this class helps me learn;* Cronbach's alpha = 0.86). Results reveal that the more learners avoid help-seeking behavior, the more time they spent on tools. This can be explained by the different nature of help seeking referred to in the instrument of Pajares et al. (2004), and the support learners could request in a CBLE. In the instrument, the help-seeking behaviors are all directed towards humans. One could argue that the less inclined learners are to request help from a teacher, the more they will use the tools in a CBLE.

LIST questionnaire. One of the studies took place in Germany (the second obesities study), which led to the use of a German instrument to measure metacognition to avoid translation issues. The LIST questionnaire (Wild & Schiefele, 1994; Wild, 2000) consists of 48 items that relate to studying learning materials individually (e.g., *I make a list of subject specific expressions and difficult words; the materials I just read are the starting point for my own thoughts.*). Items that were not included related to discussing study materials with others and referring to different contexts (e.g., *I order to study, I remain in the same place*). These statements were not applicable to the task at hand. The scales included in the instruments that were administered were organization, elaboration, critical thinking, memorizing, metacognitive strategies, and effort. These different subscales all showed a good reliability (Cronbach's alphas between 0.73 and 0.84). No relationship was found between metacognitive strategies and the frequency or proportional times spent on tools. However, an interaction effect was found between metacognition and condition on the quality of tool usage. The high metacognitive skilled learners used the tools in significantly less depth in the condition were usage of supportive elements was mandatory as compared to the high metacognitive skilled that had learner control. This difference was not found for the low metacognitive skilled.

Underpinning of the Assumptions

In this part we start with looking at the assumptions that were made and how the different studies can provide empirical evidence for these assumptions.

Assumption 1
Learners' instructional conceptions influence tool usage: the better learners know the functionality of a tool and how it can contribute to their learning, the more optimal they will use it (including not using it when not needed).

In both the problem-solving study and the first obesities study, learners' instructional conceptions were measured. The results are nonconclusive. While in the problem-solving study, the more students conceived of tools as being functional, the less they actually used them; in the first obesities study, no relation was found in terms of tool usage. A possible explanation for these results may be that in the obesities study, the statements did not refer to the specific respondent of the items but to "students" or "learners" in general. Participants may have indicated that indeed tools may be helpful for some learners, but not necessary to themselves. Every item in the questionnaire started with a general explanation on the tool. But it may also be that this explanation was not sufficient for them to imagine the actual tool. Given that in the problem-solving study, the negative effect of instructional conceptions disappeared in the conditions that received fixed advice. The advice provided may have conflicted with students' own conceptions about why they would think the tool would be functional for their own problem-solving process. However, in the first obesities study, this effect was not found, while in one condition, an explanation was given on the functionality of the support devices. It may be that learners need to experience a support device functionality before they can actually express instructional conceptions. In other words, learners may not be able to think about the functionality of a tool before they have actually encountered it. Another argument could be that these instructional conceptions should be measured on a level that connects more to an individual's learning rather than learning in general. This was done in the airplane study. The results of this study revealed that perceived usefulness is related to time spent on tools. However, the relationship is nonlinear. A quadratic trend indicates that students with a medium score on perceived usefulness spent most time on tools. Perceived usefulness was also found to motivate students to optimally use questions. The more students thought questions were useful, the more knowledge students called upon (i.e., activation) and the deeper their understanding (i.e., students were able to give more correct information in their answers).

Assumption 2
Learners' metacognitive skills influence support usage: the extent to which learners are capable of regulating their own learning and are able to detect their own learning problems will determine the extent to which they will be inclined to use tools to solve these problems (Mercier & Frederiksen, 2007).

In the problem-solving study, metacognitive skills were part of a model explaining the variance in frequency of tool use for the fixed advice group. Although this variable did not yield a significant result, removing it from the model reduced the fit of the model significantly. This effect was not found for the time spent on tools. It almost seems that students' metacognitive skills allowed them to compensate for the fixed advice provided in the learning environment. In the first obesities study, no effects were found of metacognitive skills on tool usage. The results of the second obesities study are more in line with the assumptions; learners that possess sufficient metacognitive skills do not use the tools more but use them more in depth if they are given the choice. If the decision when to use a supportive element is taken for them, support provided through these elements is processed in a more superficial way, compared to when learners can decide themselves to use the supportive elements.

Assumption 3
Given that either too much or too less support can be detrimental for learning, a third assumption is that the embeddedness of the supportive elements and the amount of metacognitive skills will interact.

This assumption was mainly tested in the second obesities study, and as already discussed in relation to assumption 2, we could see that embeddedness of supportive elements does matter, especially with respect to the quality of usage. Depending on the presence and kind of advice on tool usage, metacognitive skills seem to play a different role. This was shown in the problem-solving and the first obesities studies. It should be noted though that in these studies, quality of tool usage was not measured.

This third assumption leads to the question whether supportive elements should be mandatory or whether learners should have control. The latter includes the risk that the supportive elements may be less used but to a larger quality if students possess the necessary metacognitive skills.

Conclusion

From a theoretical perspective, it is self-evident that metacognition plays a role in the use of tools. The studies presented here provide some evidence but do also suggest that especially the quality of tool usage seems to be influenced by metacognition, while the quantity expressed by frequency of tool consultation and time spent on the support device have no clear relationship with metacognition. In order to gain more insight into the relationship between metacognition and the quality of tool usage, a clear conceptualization is needed. In these studies, Flavell's definition was used as a starting point. However, when looking at the instruments, it can be questioned whether we actually measured learners' metacognitive knowledge and skills. Metacognitive knowledge was operationalized as students' instructional conceptions or perceived usefulness of the support devices. An extension towards epistemological beliefs and self-efficacy (Bandura, 1997; Moo & Azevedo, 2008) may lead to a more complete profile of a learner's metacognitive knowledge. Additionally, metacognitive skills were measured with self-report questionnaire. It is most likely that learners' answers to these questionnaires provide just an intention of what they will do or measure students' metacognitive knowledge rather than their metacognitive strategies (Winne, 2006). In order to test the relationship between metacognitive skills and support usage, more behavioral data should be collected and examined. For instance, when the learning task is studying a hypertext for which different support devices are available, one could do a pretest in which learners are asked to read a text providing them the normal accessible tools such as highlighting, making notes, taking a summary, and access to a number of links. Using these tools can be seen as an indicator of metacognitive strategies for reading a text (Palincsar & Brown, 1984, 1987). In a next step, the relationship between learners' score on this pretest and their actual tool usage behavior for the learning task could be examined.

In this chapter we focused on the aspect of metacognition, but it may be that not only knowledge about the self, the learning environment, and the relationship between self and learning environments should be considered, but also more motivational "self-related" beliefs should be included. This would refer to Perkins' third condition, namely, that a learner should be motivated to use a learning opportunity. Including motivational variables and considering the interaction with metacognition could probably explain more accurately support usage behavior. Consequently, the term self-regulation may be a more adequate theoretical construct that encompasses more than only metacognitive knowledge and skills to study tool usage (e.g., Pintrich & De Groot, 1990).

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