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Abstract

For self-regulated learning to be effective, students need to be able to accurately monitor their performance while they are working on a task, use this as input for self-assessment of that performance after the task, and select an appropriate new learning task in response to that assessment. From a cognitive load perspective, monitoring can be seen as a secondary task that may become hard to maintain and may hamper performance on the primary task (i.e., learning) under high load conditions. Therefore, this study investigated the effects of concurrent performance monitoring on cognitive load and performance as a function of task complexity. Task complexity was varied as between-subjects factor and monitoring as within-subjects factor. It was hypothesized that monitoring would significantly increase cognitive load and decrease performance on complex, but not on simple tasks. Results from a pilot study based on data from 31 participants seem to confirm this hypothesis.

Keywords: education; cognitive load; monitoring; task complexity; self-regulated learning.

Cognitive Demands of Self-regulated Learning

A major aim of many contemporary educational programs is to foster students self-regulation skills. It is often assumed that this aim can be achieved in a 'learning by doing' manner (i.e., by providing learners with a high amount of control over their learning process). Unfortunately, however, studies that compared the effects of learner controlled vs. system controlled instruction, often show detrimental effects on learning outcomes of providing learners with control over what tasks they work on, in what order, and for how long (e.g., Niemic, Sikorski, & Walberg, 1996). So even if learners would acquire self-regulation skills this way (which can also be questioned, considering the findings on learning by doing in acquiring problem solving skills; cf. Kirschner, Sweller, & Clark, 2006; Sweller, Van Merriënboer, & Paas, 1998), giving learners a high degree of control may have unwanted effects when it comes to learning outcomes. These effects, however, are not entirely surprising if we look at the cognitive demands imposed by self-regulated learning.

For self-regulated learning to be effective, students need to be able to accurately monitor their performance while they are working on a task, use this as input for self-assessment of that performance after the task, and select an appropriate new learning task (one that allows them to train the task aspects they do not yet master sufficiently) in response to that assessment (cf., Ertmer & Newby, 1996; Zimmerman, 1990). Research has shown, however, that accurate self-assessment is very difficult for learners. Not only are humans prone to several biases that make accurate self-assessment difficult (see Bjork, 1999), but accuracy of self-assessment also seems to be related to the amount of experience in a domain (Dunning, Johnson, Erlinger, & Kruger, 2003). Presumably, advanced learners are more accurate self-assessors because their experience not only provides them with more task knowledge, but also with more knowledge of the criteria and standards that good performance should meet (Dunning et al., 2003). Interestingly, it is also the case that when positive effects on learning outcomes are reported in studies on learner control, this tends to be for high prior knowledge learners (Lawless & Brown, 1997; Scheiter & Gerjets, 2007; Steinberg, 1989). This suggests that the accuracy of self-assessment indeed plays a very crucial role in the effectiveness of self-regulated learning.

However, as mentioned before, self-assessment of performance after task completion, also relies on accurate performance monitoring *while* working on the task. If learners do not have a good recollection of their performance, for example, of what actions they took and what the results of those actions were, they cannot accurately assess it. So, another possible explanation (which is not mutually exclusive with the other ones mentioned here) for why learners, and especially novice learners, are not accurate self-assessors, is that difficulties may already arise in the performance monitoring stage.

Monitoring and Cognitive Load

Many learning tasks are complex, that is, they impose a high intrinsic cognitive load (Sweller, 1988; Sweller et al., 1998). Intrinsic cognitive load depends on task complexity, because it is determined by the number of interacting information elements that have to be related, controlled, and kept active in working memory during task performance. It also depends on the expertise of the task performer: As a result of learning, elements are combined into cognitive schemata stored in long-term memory that can be retrieved and handled as a single element in working memory, thereby decreasing the intrinsic load of the task (Sweller et al., 1998).

The need to monitor performance during self-regulated learning can be seen as a secondary task. Under dual-task conditions, accurate performance of the secondary task or of both the primary and the secondary task becomes hard to maintain under high load conditions (see e.g., Brünken, Plass, & Leutner, 2003). That is, under conditions of high task complexity, or high intrinsic load, little resources are available for processes that impose additional cognitive demands, such as concurrently monitoring performance. As a result, monitoring, task performance, or both, may be hampered. Under conditions of low task complexity, or low intrinsic cognitive load, on the other hand, additional cognitive demands can be easily accommodated as ample resources are available. In other words, under conditions of high intrinsic load, which is the case with many learning tasks, the need to monitor performance may: a) lead to low quality monitoring (secondary task), and therefore, a poor recollection of performance on which to base self-assessment, and/or b) hamper performance of the learning task (primary task). This cognitive load perspective on the cognitive demands that are imposed by learner control may (at least partially) explain why self-regulated learning is often ineffective for learning compared to teacher- or system-controlled instruction. Moreover, given that intrinsic load is also determined by expertise, this cognitive load perspective would also (again, at least partially) explain why novices might be less able to accurately monitor their performance than individuals who have prior knowledge of the task.

This pilot study seeks to establish the effects of concurrent performance monitoring on cognitive load as a function of task complexity, using Sudoku puzzles of different complexity levels. It is hypothesized that the instruction to monitor performance while working on the task will lead to a significant increase in cognitive load and a significant decrease in performance of the primary task on complex, but not on simple tasks.

Method

Participants and Design

From a larger sample of 85 Dutch secondary education students who volunteered to participate in this study, those participants were selected who knew the rules of Sudoku and sometimes played Sudoku (once a week on average), resulting in 31 participants (11 males; age M = 15.42, SD = .56). Task complexity was used as between-subjects factor (Simple, n = 12; Complex, n = 19), whereas monitoring was applied as within-subjects factor.

Materials

Demographic questionnaire. This short questionnaire asked participants to indicate their age and gender as well as there familiarity with Sudoku rules and their experience with playing Sudoku.

Tasks. The tasks consisted of two Sudoku puzzles at each level of complexity (Simple, Complex). Sudoku puzzles consist of a grid with several regions that has to be filled with numbers so that every row, column, and region contain only one instance of each number. The two simple Sudoku puzzles (low in intrinsic load) consisted of a 4x4 grid with four 2x2 regions (mini-grids). Four cells were already filled in. The complex Sudoku puzzles (high in intrinsic load) consisted of a 9x9 grid with nine 3x3 regions (mini-grids). In the first puzzle, 30 cells were already filled in, in the second puzzle 28 cells. Both were at a medium level of difficulty according to the source from which they were obtained.

Mental effort rating scale. Invested mental effort was measured using the 9-point subjective rating scale developed by Paas (1992). The scale ranged from (1) very, very low mental effort, to (9) very, very high mental effort. This scale is a reliable measure of actual cognitive load (i.e., the cognitive capacity that is actually allocated to accommodate the demands imposed by the task) and is sensitive to variations in task complexity between and within tasks (for details see Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Van Gog & Paas, 2008).

Procedure

In both conditions, participants first filled out the demographic questionnaire. Then, they worked on the two Sudoku puzzles, for maximally 2 minutes per puzzle. This was not enough time to solve the Complex puzzles, but participants were instructed to try and complete as much of the puzzle as possible. Time on task was held constant to cancel out potential interaction of this factor with mental effort measures. Start and stop times were indicated by the experimenter. Immediately after completing each puzzle, participants rated their invested mental effort on the 9-point rating scale. Monitoring was applied as a within-subjects factor, with participants first working on the task without monitoring ("Please try to complete as much of the puzzle as you can within the next two minutes"), then with the instruction to concurrently monitor their performance ("Please try to complete as much of the puzzle as you can within the next two minutes while simultaneously keeping track of what you are doing, in what order, and why"). The order of task performance with and without monitoring was not counterbalanced, as the instruction to monitor on the first task might influence later task performance even when this instruction would not be given with the second task.

Moreover, this order could not affect cognitive load to the advantage of the hypothesis: as mentioned before, experienced cognitive load tends to decline with increasing practice of a task (cf. Van Gog, Paas, & Van Merriënboer, 2005; for a discussion of the relationship between performance and cognitive demands as a result of practice see e.g., Kanfer & Ackerman, 1989; Yeo & Neal, 2004). Here, it is expected to increase on the second task (at least on the complex tasks) as a result of the monitoring instruction.

Data Analysis

Participants' performance was rated by counting the number of cells they correctly filled in. This resulted in a maximum score of 12 on both Simple Sudoku puzzles, and a maximum score of 51 and 53, respectively, on the Complex puzzles.

Results

The manipulation of intrinsic cognitive load (caused by the number of interacting information elements a task contains) was successful: mean mental effort invested in the Simple condition (n = 12) was 1.75 (SD = .81), whereas in the Complex condition (n = 19) this was 6.03 (SD = 1.75). This difference is highly significant $t(29) = -7.90$, $p < .001$.

GLM repeated measures analysis showed that in line with our hypothesis, the instruction to monitor did not affect mental effort ratings in the Simple tasks condition ($M_{without}$ = 1.83, SD = 1.03; M_{with} = 1.67, SD = .89), $F(1,11) < 1$, *ns*. Nor did it affect performance: All participants in the Simple task condition managed to correctly complete the entire puzzle both times (i.e., maximum score of 12 on both tasks).

GLM repeated measures analysis showed that on Complex tasks, instruction to monitor resulted in a trend towards higher mental effort ratings ($M_{without}$ = 5.68, SD = 2.11; M_{with} = 6.37, SD = 1.71), $F(1,18) = 3.63$, $MSE = 1.23$, $p = .073$, $\eta_p^2 = .168$, and had a significant negative effect on performance ($M_{without}$ = 4.89, SD = 2.64; M_{with} = 2.79, SD = 1.51), $F(1,18) = 10.84$, $MSE = 3.88$, $p = .004$, $\eta_p^2 = .376$.

Discussion

Some caution is required in interpreting these data, because of several reasons. First of all, this pilot study had a small number of participants. Secondly, future studies need some adaptations to the design, such as counterbalancing the order of the tasks (even though they are at the same level of difficulty, the possibility that the findings are due to potential differences between the tasks should be ruled out). Follow-up experiments are planned from which data should be available at the time of the conference.

Although definite conclusions cannot yet be drawn, these preliminary results seem to be in line with our hypothesis that monitoring can be seen as a secondary task that increased the total experienced cognitive load and decreased performance on complex tasks. On simple tasks, these effects did not arise, presumably because the task was so simple that any additional cognitive demands could be quite easily accommodated.

These results may provide at least a partial explanation for why high prior knowledge learners seem better able to assess their own performance (cf. Dunning et al., 2003) and seem to do better than novices in learner-controlled instruction (cf. (Lawless & Brown, 1997) when they are working on the same tasks. Because these tasks are lower in intrinsic load for the advanced learners, they may have enough cognitive capacity available for performing the learning task and monitoring their task performance simultaneously.

However, it is important to note that this advantage for high prior knowledge learners probably only arises when they indeed work on the same tasks as novices. In effective learning trajectories (whether self-regulated or regulated by a teacher or system), students ideally work on tasks that are at an appropriate level of difficulty for them, that is, on tasks that are appropriately challenging (cf. Vygotsky's, 1978, concept of 'zone of proximal development'), not ones that they can already perform (unless the goal is to automate and/or speed up performance). In this sense, students at all levels of expertise ideally always work on tasks that are relatively high in intrinsic load for them.

Next to the methodological issues mentioned earlier that need to be addressed in future studies, there are some other interesting questions to be investigated. First of all, in this study, effects on performance on the secondary task, that is, on the quality of monitoring, were not investigated. The data from this study suggests that for complex tasks, monitoring has a negative effect on performance on the primary task, but it would be interesting to investigate whether this negative effect is due to more resources being allocated to monitoring in order to perform that secondary task well, or whether performance on both tasks suffers. Therefore, future studies should also investigate the quality of students' monitoring in relation to cognitive load and task complexity.

In addition, this study used tasks that were either very simple or very complex; another interesting question we intend to address is what would happen with tasks of medium complexity (e.g., 6x6 Sudoku puzzles). It can be hypothesized that these would lead to an increase in cognitive load as evidenced by mental effort ratings, but without the detrimental effect on performance because the additional load might still be manageable.

Finally, in the future, studies such as this one should be replicated with other types of tasks that rely more on conceptual knowledge rather than procedural knowledge and should take into account not only direct effects on task performance, but also effects on learning.

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