https://doi.org/10.36315/2022v1end097
Education and New Developments 2022

COGNITIVE LOAD AND QUESTION ASKING – THE CASE OF PROSPECTIVE MATHEMATICS TEACHERS COPING WITH HISTORICAL TEXTS

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Abstract

In this study, we examined aspects relating to the impact of integrating question-asking activities and providing answers to these questions while reading historical mathematical texts on prospective mathematics teachers' self-reported cognitive load. The research group included two classes of 20 students each (experimental and control groups). The experimental group was instructed to ask questions while coping with the texts, whereas the control group received no special instructions. The experimental group participants were asked to think aloud while coping with the texts and audio record themselves. These recordings were transcribed into written protocols. In addition, both groups had to respond to a self-esteem index questionnaire in which they had to report the level of difficulty they experienced as an indicator of their cognitive load. The data was analyzed using quantitative and qualitative methods. Two main observations were obtained: the first is that question-asking reduces cognitive load, and the second is that question-asking supports the assimilation of new information up to a specific limit, depending on the gap between existing knowledge and new information.

Keywords: *Cognitive load, historic mathematical texts, prospective mathematics teachers, question-asking.*

1. Introduction

Developing self-regulated learning skills involves, among other things, helping students to develop their capability for self-reading of professional texts. Specifically, in the case of mathematics, the reading of mathematical texts is critical for establishing mathematical knowledge and it includes interpreting and understanding these texts (Österholm & Bergqvist, 2013). Nonetheless, generally, little attention is paid to nurturing such capabilities (Lavy & Shriki, 2020). The present study explores the effect of question asking (QA) by prospective middle and high school mathematics teachers (PMTs) on the cognitive load created while engaging with mathematical texts, as reported by them. Cognitive load refers to the state of memory storage and processing of information while coping with a particular task (Sweller, 1988), where overloaded working memory impedes reading and learning (e.g., Clark, Nguyen, & Sweller, 2005). The created cognitive load indicates the difficulties learners experience while engaging in a task, and can be measured directly using learner self-reports (Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Paas, Van Merriënboer, & Adam, 1994).

Asking mathematical questions is recognized as fostering active learning, knowledge acquisition, mathematical thinking, and metacognition. Thus, focusing on QA stems from its merits and role in acquiring mathematical knowledge and nurturing mathematical thinking. Answering these questions often leads to the emergence of new mathematical insights (Wong, 2015). The current study sought to examine the effect of QA by PMTs on reducing cognitive load while reading historical mathematical texts. The study was conducted within a course focusing on reading mathematical texts, ancient solution methods and algorithms, and their application for solving problems. The solution methods and algorithms were presented to the PMTs in their Hebrew translation version using the currently accepted mathematical language, keeping their original content and format.

2. Theoretical background

2.1. Reading mathematical texts and question asking

Reading and comprehending texts are among the main modes of individual learning in various settings. Readers apply various strategies for dealing with texts, including encoding information and building a mental representation of the text content, making inferences for connecting different parts of the text, and employing prior knowledge to make sense of the textual information. In general, three factors affect the reading and comprehending of a text: text properties (e.g., content, structure), instructional context (e.g., the reading goals - educational purposes vs. entertainment), and reader characteristics (e.g., working memory - the personal capacity to manipulate information in memory) (Bohn-Gettler & Kendeou, 2014). Students' comprehension of professional texts often affects their ability to solve the problems and constitutes a potential obstacle to learning (Foxman,1999). Mathematical texts differ from texts in other subjects as they contain complicated concepts; they are written in brief format; and consist of a mixture of different representations, which adds to their complexity.

Asking mathematical questions is acknowledged to foster active learning, knowledge acquisition, mathematical thinking, and metacognition (Wong, 2015). Hence, when the learners are the ones who ask the questions, their mathematics knowledge is enhanced because asking a valid question necessitates exploring the relations embedded in the particular situation. In addition, learning to ask questions also supports students' ability to identify their difficulties and formulate appropriate questions for their instructor (Wong, 2015).

2.2. Cognitive load

The concept of 'cognitive load' was coined by Sweller (1988) to describe the state of memory storage and processing of information in a human's mind while coping with a particular task or complex situation, and it can serve as an indicator of the degree of difficulty learners experience while engaging in the task (Paas et al., 2003; Paas et al., 1994). Sweller, et al. (1998) distinguished between intrinsic, extraneous, and germane cognitive load. The intrinsic cognitive load refers to the mental effort one invests in dealing with a task, which varies from person to person according to expertise in the field related to the task. The extraneous cognitive load refers to how the task is formulated or presented and hence can be controlled by modifying the task formulation. The germane cognitive load refers to schemas processing, construction, and automation (García et al., 2011).

Cognitive load can be measured, among others, by employing learner self-reports (Paas et al., 2003). These reports can be done using real-time reporting, retrospective reporting, and a self-esteem index. Real-time reporting refers to the learner documenting all the thoughts that cross his mind while engaging with a given task. In retrospective reporting, the learner reports his thoughts right after the task completion to avoid forgetting. The self-esteem index is based on measurement scales and the assumption that learners can examine themselves and report on the level of mental effort they have put into performing a particular task (Sweller, 2018). The self-esteem index is commonly used in questionnaires that contain measurement scales, which are relatively sensitive to small changes in cognitive load and are valid, reliable, and non-invasive (Paas et al., 2003). Considering both readings of texts and cognitive load, research indicates that readers with high working memory are more successful in adjusting their processing to their general reading goals (Bohn-Gettler & Kendeou, 2014), while overloaded working memory impedes reading and learning (Clark et al., 2005). Thus, in designing the learning environment, one of our primary goals was to find a way to reduce the PMTs' cognitive load to support the process of independent reading of the texts and understanding the mathematical contents. Therefore, we sought to examine the effect of QA by the PMTs while reading the mathematical texts and then answer the questions on the reduction of cognitive load, as reported by the PSTs.

3. The Study

3.1. The research goal

Given the issues related to reading mathematical texts, reducing cognitive load, and QA, the present study sought to examine the effect of QA by PMTs while reading historical mathematical texts on reducing the self-reported cognitive load.

3.2. The study participants

Forty PMTs participated in the study. They were all in the third year of their undergraduate studies in middle and high school mathematics. The research took place within an annual mandatory course dealing with selected topics from the history of mathematics until the beginning of the Christian era. The forty participants were assigned into two groups of 20 PMTs each (experimental and control) following the matching control technique (Johnson & Christensen, 2014). The experimental group was instructed to ask questions related to the texts and record themselves while coping with the texts.

3.3. The learning environment

The course in which the research took place was a two-semester course dealing with selected topics from the history of mathematics until the beginning of the Christian era and is divided into eleven chapters: Egyptian mathematics (arithmetic, algebra, and geometry); Babylonian mathematics (arithmetic and geometry); the mathematics of prominent Greek mathematicians (Thales, Pythagoras, and Euclid); and ancient Indian mathematics (three sections of Vedic arithmetic). The course is based on reading the background of the discussed period, mathematical texts that include ancient solution methods and algorithms, and their application for solving problems. All solution methods and algorithms were presented to the study participants in Hebrew as a verbatim translation of the English version of the original texts, using the currently accepted mathematical language and notations. However, it should be noted that the term 'algorithm' did not exist in ancient times, and it is unclear whether the ancient mathematicians were even aware of its existence. To examine the effect of asking questions and answering them while reading the texts, and since the PMTs had no prior experience in QA, the experimental group members were instructed to formulate questions beginning with 'What'/'How'/ 'Whether' or 'Why', and provide answers. The control group was instructed to cope with the historical texts using any appropriate method.

3.4. Research method and tools, and data analysis

The research design was quasi-experimental (Maciejewski, 2020), employing both qualitative and quantitative approaches and research tools. Four main tools were used: (i) A self-esteem index cognitive load questionnaire (Paas et al., 2003). The statements in the questionnaire were of two types. Statements 'a' to 'f' concern extraneous cognitive load, as they refer to the way the task is presented to the PMTs, while statements 'g' to 'j' concern intrinsic cognitive load as they refer to aspects relating to the mental effort the PMTs invest while engaging with the historical texts. The statements are: (a) Absence of explicit rationale of the algorithm; (b) Transition from step to step in the algorithm; (c) The verbal formulation of the algorithm; (d) The numerical examples presented throughout the algorithm; (e) The mathematical concepts appear in the algorithm; (f) Absence of proof for the algorithm; (g) Applying the algorithm - solving computational problems based on it; (h) Applying the algorithm - solving problems that require high order levels of thinking; (i) The need to generalize the algorithm; and (j) Adapting the algorithm into new situations. These statements reflect the nature of the information the PMTs had to deal with or the mathematical operations they had to perform. The PMTs were asked to report on the level of difficulty they experienced regarding each statement according to a symmetrical scale, ranging from 1 (very very low level of difficulty) to 9 (very very high level of difficulty). Due to the small sample size, the data were analyzed using basic tools of descriptive statistics; (ii) An open-ended questionnaire in which the PMTs were asked to justify their ranking of self-esteem index of cognitive load; (iii) Transcripts of group interviews that were conducted four times throughout the academic year. The group interviews were intended to elicit the PMTs' thinking about issues related to the research questions to allow us to deepen our understanding of their thoughts, opinions, and feelings; and (iv) Think-aloud protocols (Veenman et al., 2004) in which the PMTs were asked to audio record their thoughts while engaging with the mathematical texts. These recordings were transcribed into written protocols. The data received from tools (ii)-(iv) was analyzed using three stages of coding (Creswell, 2012): (1) Open coding, aimed at constructing the initial categories based on prominent words or phrases in PMTs' protocols; (2) Axial coding, in which the initial categories were grouped under more general categories based on their causal conditions; (3) Selective coding, in which we triangulated, refined, and defined the relationships among the categories that surfaced in the axial coding stage.

4. Results and discussion

In this study, we examined the effect of QA on reducing cognitive load. Based on Paas et al. (1994), we distinguished between intrinsic cognitive load (the mental effort one invests in dealing with a task) and extraneous cognitive load (related to the design of the task). The results obtained from the self-reported cognitive load index questionnaire indicate that while the cognitive load reported by the control group remains almost the same for the three texts, the cognitive load reported by the experimental group showed a moderate decrease. In addition, on average, the intrinsic cognitive load was found higher than the extraneous one along with the three texts. Recall that the control and experimental groups differed in the QA engagement and the think-aloud recording while coping with the historical texts. Therefore, it might be inferred that the act of think-aloud also affected the observed decrease in cognitive load among the experimental group. However, a review of 94 studies (involving almost 3,500 participants) comparing the performance in cognitive activities with or without think-aloud indicated little or no reliable difference in performance with or without think-aloud (Fox, Ericsson & Best, 2011). To gain insights into the process of QA and its effect on the reading of the texts and the deciphering of the algorithms, the researchers transcribed the records of the think-aloud processes, representing real-time reporting (Paas et al., 2003).

In what follows, we present the analysis of Rina's protocols produced during her coping with three texts: the Egyptian algorithm for multiplying two numbers; the Babylonian algorithm dealing with the solution of two equations with two unknown variables using geometrical considerations; and the Vedic algorithm for finding the square of a two-digit number. Rina was chosen as her protocols were detailed and reflected the prevalent modes of thinking of the other participants. The analysis of Rina's protocols reveals the existence of two of the reading strategies addressed by Bohn-Gettler & Kendeou (2014): making inferences and employing prior knowledge. As uncovered from the analysis of the three protocols, this was done by asking two types of questions, indicating a two-tier gradual process: The first type of question is related to trying to understand the rationale of the algorithm by examining other numerical examples substituting numbers in the algorithms. From Rina's protocols, it is evident that she relates to this operation as an intuitive action done casually, not involving any cognitive effort. However, this type of question did not lead Rina to comprehend the rationale underlying the algorithms. The second type of question is related to her desire to find compatibility between familiar methods (existing schemas) and the new methods appearing in the texts. That is done through a consistent comparison between the methods. As evident from Rina's protocols, this comparison is made by making inferences and employing prior knowledge (Bohn-Gettler & Kendeou, 2014). From the analysis of Rina's recordings, one can learn about the high intrinsic cognitive effort that was invested to that end. This can be supported by the results indicating that the intrinsic cognitive load is higher than the extraneous one along with the three texts.

The activity of QA (both types of questions) served as an engine of the whole process. Through the process of QA from the first type, Rina progressed in her attempts to understand the texts and not give up right from the beginning. However, realizing it was not enough, she asked the second-type questions during her attempts to assimilate new information into existing knowledge (schema). In case the assimilation was problematic, she experienced difficulties which were reflected by her self-report of high cognitive load. In the last group interview, Rina said: "*The questions I had to ask prevented me from giving up right after the first reading of the texts. Since I was unfamiliar with this technique [QA], I started with questions that helped me repeat the algorithms without necessarily understanding them. Then it occurred to me that I have to cope with different questions that will lead to a breakthrough in my attempts to make sense of the algorithms*". Thus, it can be concluded that the first type of question neither adds to the cognitive load nor promotes understanding of the texts. Whereas the second type of question promotes understanding but at the same time, adds to the cognitive load. In other words, an increase in cognitive load and the development of insights seem to be interwoven. Nonetheless, questions of the first type help preserve coping with the task and not giving up right away. Although it is evident that QA, and in particular questions of the second type, helps reduce the cognitive load, their effect on the reduction is limited. A possible explanation for this limitation might be attributed to a gap between existing schemas and new information.

From the three think-aloud protocols, we could infer that when Rina had a solid schema (as in the case of the multiplication), she had difficulties understanding the new information (Egyptian multiplication algorithm). Rina's existing schema relates to multiplying two numbers as a whole, while in the Egyptian multiplication method, the multiplicand is decomposed into a sum of numbers represented in powers of 2. Rina's adhering to her solid schema prevents her from deciphering the new algorithm. As to the second think-aloud protocol, there is also a conflict between the existing schema - the algebraic method for solving two equations with two unknown variables, and the Babylonian method, for which the solution is geometric. In this case, the gap between the existing (algebraic) schema and the new (geometric) knowledge has a different nature than the one that is manifested in the first text, a fact that allowed Rina, through asking questions, to progress further in her process of understanding the text at hand. In the third protocol (Vedic method for squaring two-digit numbers), Rina understood the algorithm and provided formal proof. That success can be attributed to the fact that she had no existing schema for squaring two-digit numbers. That brings into discussion the connection between bridging among existing schemas and new information and the cognitive load learners experience. Neumann and Kopcha (2018) indicated the importance of the existence of schemas in learners' minds for the absorption and assimilation of new knowledge. However, studies show that the existence of solid schemas can also interfere with the assimilation of new knowledge (Van Kesteren & Meeter, 2020), as in fact, happened in the present study. The above results are consistent with Van Kesteren and Meeter (ibid.), who claimed that while schemas are presumed to help memory encode and consolidate new data, solid schemas can also lead to unwanted side effects, as was found in the present study. In the think-aloud protocols, we can see both- the positive and negative effects of schema. The positive effect is expressed in recalling data from memory (e.g., how to calculate the area and perimeter of rectangles and squares, short multiplication formula), a knowledge that was crucial for understanding the historical algorithms. The negative effect is expressed in Rina's attempts to prove the new algorithms (Egyptian and Babylonian) holding on to her solid existing schema with no success. For example, referring to the third text (Vedic method for calculating a square of two-digit natural numbers), the fact that Rina did not have an existing schema for calculating the square of two-digit natural numbers helped her by using QA, to come up with alternative ways of thinking and eventually to provide a formal proof to the Vedic method. Thus, the second observation is that QA supports the process of assimilating new information up to a certain point. Since solid schemas might interfere in bridging existing knowledge and new information, although QA of the second type might be efficient in reducing the cognitive load, its effect is depended on the nature of the gap between existing schema and new information. To conclude, further research is needed to characterize the appropriate questions for reducing the cognitive load generated by the gap between existing schemas and new information. Finally, to examine whether the content of the text influences the cognitive load, further research should be conducted in which the texts will be given in random order to different PMTs.

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