How Do Proficient Learners Construct Mental Representations of Different but Related External Representations?

Rolf Schwonke
Alexander Renkl
University of Freiburg, Department of Psychology, Educational and Developmental Psychology
Engelbergerstr. 41, D-79085 Freiburg, Germany
rolf.schwonke@psychologie.uni-freiburg.de

Abstract. How do learners with good learning prerequisites regulate their visual attention during learning from multiple representations? Limitations of working memory suggest that successful mental model construction might require visually inspecting related aspects of the learning material in close temporal succession. Moreover, successful learners can be expected to begin such visual integration activities early during the inspection of external representations. In a correlative lab study 31 psychology students studied the product rule of combinatorics from worked examples (problem text, tree diagram, and equation). During learning gaze data were registered. Learners who showed triangular gaze shifts between the three most relevant elements of each worked example early during the inspection of each worked example acquired highest amounts of conceptual knowledge. The frequency of such shifts was, however, unrelated to learning. Thus, mental model construction seems to be positively related to early occurrences of successive inspections of semantically related pieces of information.

Keywords: multiple external representations; visual attention, eye-tracking.

Many learners have severe problems in learning effectively from complex displays of information (e.g., expository text accompanied by graphs, schemata and/or equations). Especially learners with poor learning prerequisites (e.g., low verbal, spatial abilities or low prior knowledge) often fail to identify relevant information or effectively transfer information from one (type of) representation to another (Stern, Aprea, & Ebner, 2003). Learners with better learning prerequisites – and especially learners with better domain-specific knowledge – on the other hand can and do profit from multiple representations. Prior knowledge facilitates and supports a deep (i.e. a principle-based) approach of identifying and extracting information instead of a superficial approach that is typical for novices in a domain (e.g., Kozma & Russell, 1997). Models of multi-media learning (e.g., Schnotz & Bannert, 2003) describe learning from multiple representations as the construction of a coherent mental representation (i.e., a mental model). The construction is assumed to rely on interacting top-down and bottom-up activations of cognitive schemata – with these schemata having both a selective and an organizing function. How are such mental processes reflected in the way that learners visually process multiple representations? In other words, how do successful learners regulate their visual attention to extract relevant information in order to construct meaning from multiple representations? Eye-tracking has evolved as a useful tracing technique that can help to answer such questions (Rayner, 1998). Successive fixations on a semantic unit (e.g. a sentence or a phrase) of the learning material indicative of the visual attention allocated to this unit, and gaze shifts between semantic units are indicative of shifts of visual attention. Taking into account the limited capacity of human working-memory (e.g., Baddeley, 1992) it might be reasonable to assume that learners visually inspect semantic units that they intend to contrast, relate, and integrate in close temporal succession. Thus, we expected gaze shifts between different semantic units to reflect attempts to integrate these units into a mental model. Moreover, we expected successful mental model construction also to be reflected in early attempts of such integrative visual processes.

Method

In order to investigate this we presented a set of sixteen worked examples on the product rule of combinatorics to first year psychology students (N = 31; age: M = 23.35, SD = 6.41). Each worked examples consisted of a problem text of four line length. Each line provided a specific aspect of the product rule. This structure was consistent over all worked examples. The first line of the problem statement always referred to the number of drawings (e.g., "You have forgotten the last two numbers of the pin code of your mobile phone…"), the second line referred always to the number of possibilities at the first drawing (e.g., "…but you remember that you have only used the numbers 1, 3, 4, and 6."), the third line always to the unknown value (e.g., "How many combinations of the forgotten part of the code are possible"), and the last line always referred to an important boundary condition (e.g., "…if you might have used the numbers multiple times). The problem text was accompanied by an equation that represented the number of options at the successive drawings (e.g., 4 * 4 = 16) and a tree diagram that represented the structure of the problem with lines (e.g., 4 lines at each end of 4 initial lines). In each worked example the last line of the problem statement was the most important line of text as it allowed inferring the rule to be applied to the current problem (e.g., 'with replacement'). From the tree diagram the structure of a problem (and of the product rule) could be inferred by comparing the number of possibilities at the first drawing (from the left side of the diagram) and second drawing (from the right side). These three external referents of the product rule had to be integrated to develop a complete understanding of a worked example, and thus, potentially to be visually inspected in close temporal succession. As indicators of attempts of visual integration of this relevant information, we analysed *triangular* gaze shifts between these semantic units. The frequency of such triangular gaze shifts was taken as an indicator of the extent of visual integration. The first occurrence of such a triangular shift was taken as an indicator of the beginning of visual integration processes. Directly before and after the learning phase all participants worked on an identical pre-test and post test (procedural and conceptual knowledge). In procedural tasks (6 items; 1 point per item; max. 6 points) learners were asked to solve combinatorics problems (three problems relatively similar to those encountered during the learning phase [near transfer] and three more demanding problems on probability [far transfer]). In conceptual tasks (8 items; 1 point per item; max. 8 points) learners had, for example, to explain the product rule of combinatorics or had to decide whether a problem was solvable by applying the product rule, or learners had to explain why a given worked example was incorrect (in conceptual tasks no calculations where required).

Results

On average our participants had a relatively high level of prior knowledge in the domain of combinatorics (pre-test score: M = 64.8 % correct; SD = 18.1 %). Regressing the learning outcome measures on the indicators of visual attention and prior knowledge (multiple hierarchical regression) we found that apart from prior knowledge which explained 26 % ($p < .01$; $ß = .51$; $p < .01$) of the variance in the post-test score of conceptual knowledge, another 23 % ($p < .01$) could be explained by the position of the first occurrence of a triangular transition between the external referents of the product rule. The frequency of such triangular transitions could, however, only explain another 5 % ($p < .10$). Another 9 % (ns) could be explained by the proportions of transitions between the problem line and those parts of the worked example that represented the first and second drawing (relative to all transitions on a worked example); ($R^2 = .63$; $F(6,24) = 6.870$; $p < .001$; adj. $R^2 = .540$). For procedural knowledge the pattern of results was similar but less pronounced. A negative beta-coefficient of first occurrences of triangular gaze shifts ($\beta = -.39$; $p < .05$) showed that early shifts of visual attention between the most relevant elements of the worked examples were positively related to the acquisition of conceptual understanding. The frequency of such triangular gaze shifts, however, was even marginally negatively related to conceptual knowledge ($\beta = -.31$; $p < .10$). Thus, many such gaze shifts rather indicated problems of integration.

Summary and Discussion

The aim of the reported analyses was to get a better understanding of how proficient learners regulate their visual attention during learning to construct meaning from different but related external representations. The strongest predictor of the acquisition of conceptual knowledge (besides of prior knowledge) was the position of the first successive inspections of the three most relevant aspects of a worked example. Thus, successful learners looked for relevant and related pieces of information that was distributed over the different external representations and tried to (visually) integrate these pieces as soon as possible. It is important to note that the frequency of such triangular inspections (that followed this first important one) was unrelated (or even negatively) related to the acquisition of conceptual knowledge. This might be explained by characteristics of our learning material. In order to make sense of the relatively easy combinatorics problems it was more important to understand which external referent referred to which variable of the product rule than to compare the small number of related aspects several times. Therefore, additional triangular transitions rather seemed to indicate unsuccessful initial attempts to integrate the information. This might be different in more complex materials and/or more complex tasks. In our context, the indicators of visual attention were better able to predict conceptual knowledge than procedural knowledge. From this it might be concluded that the regulation of visual attention is more closely related to acquisition of a deeper understanding than to the acquisition of procedural skills. Importantly, learning outcomes were largely unrelated to most of the simple (and common indicators) of visual attention such as the number of fixations on or the number of gaze shifts.

References

Baddeley, A. (1992). Working memory. *Science*, *255*, 556–559.

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching, 34*, 949–968.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 3*, 372–422.

Stern, E., Aprea, C., & Ebner, H. G. (2003). Improving cross-content transfer in text processing by means of active graphical representation. *Learning and Instruction, 13*, 191–203.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*, 141-156.