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Attention Guidance during Example Study via the Model's Eye Movements

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Abstract

Research has shown that guiding students' attention guides their thought, and that attention can be communicated via eye movements. Therefore, this study investigates whether such a procedure can further enhance the effectiveness of examples in which a solution procedure is demonstrated to students by a (expert) model. Students' attention was guided by showing them not only the model's problem-solving actions on the computer screen, but also the model's eye movements while doing so. Interestingly, results show that combined with a verbal description of the thought process, this form of attention guidance had *detrimental* effects on learning. Consequences for further research on attention guidance and instructional design are discussed.

Keywords: Example-based learning; eye tracking; cognitive load; attention

Attention Guidance during Example Study via the Model's Eye Movements

Eye tracking research has shown that students' attention can be guided on the basis of an expert's eye movements. This can be done directly, that is, by showing students' the experts' eye movements (Velichkovsky, 1995) or indirectly, that is, by a cueing procedure based on the experts' eye movements (Grant & Spivey, 2003). This study investigates whether showing the model's eye movements in examples in which a solution procedure is demonstrated to students, can enhance their learning.

Eye tracking in Research on Multimedia Learning

Eye tracking provides insight in the allocation of visual attention and therefore can provide very useful information on multimedia learning processes. However, in the field of learning and instruction, eye tracking has not been applied much as a research tool. When it was used, it was primarily in reading research (see Rayner, 1998, for a review), with some notable exceptions in other areas such as text and picture comprehension and problem solving (e.g., Hannus, & Hyönä, 1999; Hegarty & Just, 1993; Verschaffel, De Corte, & Pauwels, 1992). This has changed over the last years. Eye tracking is applied more and more in research on instructional design. Especially in research using multimedia learning materials, that is, materials that consist of spoken or written text and pictorial information (e.g., picture, diagram, video, animation), or materials consisting of multiple representations (e.g., formula, diagram, graphic), eye tracking can provide unique information concerning what medium or representations are visually attended to, in what order, and for how long (see e.g., Holsanova, Holmberg, & Holmqvist, in press; Louwerse, Graesser, McNamara, & Lu, in press; Schwonke, Berthold, & Renkl., in press).

However, eye tracking offers more than just a research tool. Modern eye tracking technology allows not only for recording of eye movements, but also for replaying this record integrated with other actions such as mouse and/or keyboard operations visible on the PC screen (cf. Van Gog, Paas, Van Merriënboer, & Witte, 2005). This provides the opportunity to apply it as a tool to enhance learning processes, by using eye movement records in the design of instruction. For example, by developing modelling examples in which the model's performance as well as his/her eye movements during performance, are captured and replayed to students.

Example-based Learning

A large body of research has demonstrated that for novices, engaging in problem solving is not an effective way to acquire problem-solving skills. In the initial phases of cognitive skill acquisition, it is far more effective and efficient to study a good problem solution (this is known as the 'worked example effect'; for overviews, see Atkinson, Derry, Renkl, & Wortham, 2000; Paas & Van Gog, 2006; Renkl, 2005; Sweller, 2006; Sweller, Van Merriënboer, & Paas, 1998). Studying a good problem solution can be obtained by different means. It can take the form of modelling examples, in which a solution procedure is demonstrated to students by a model who is often an expert or an advanced peer (e.g., Braaksma, Rijlaarsdam, Van den Bergh, & Van Hout-Wolters, 2004; Kitsantas, Zimmermann, & Cleary, 2000), which play an important role in Bandura's (1977) social learning theory. It can also take the form of worked-out examples, in which students are given a written account of a model's solution procedure to study (e.g., Carroll, 1994; Cooper & Sweller, 1987; Paas, 1992; Paas & Van Merriënboer, 1994; Sweller & Cooper, 1985; Van Gog, Paas, & Van Merriënboer, 2006), which play an important role in cognitive load theory. In this line of research, the 'model' is often a didactically behaving expert, that is, the examples contain an 'ideal' solution procedure detailing how students should learn to solve a problem, rather than a reflection of a "naturally" behaving expert's solution procedure (as experts have automated procedures and are likely to skip certain steps). Finally, with current technology, animated models can be created in which the solution procedure is not demonstrated by the model or written out, but is provided in the form of an animation (Wouters, Paas, & Van Merriënboer, 2008).

Example-based learning as applied here in this study combines elements of the worked examples and the modelling examples tradition, in the sense that a solution is demonstrated to students, as in modelling examples, but the expert is not visible (only the actions s/he does are visible on the computer screen) and more importantly, the expert is behaving didactically, in other words, is performing the task not as s/he would normally do, but as the student should learn to perform it. As such, the situation is a bit less social as it normally would be in modelling examples and the examples resemble worked-out examples in the sense that an 'ideal' solution is shown that could also have been written out for the student to study, although this would have been rather impractical.

Cognitive load theory (Sweller, 1988; Sweller et al., 1998; Van Merriënboer & Sweller, 2005) explains the effectiveness of worked examples in terms of reduced extraneous, or ineffective cognitive load during training. The theory distinguishes cognitive load inherent to the task, and cognitive load imposed by the instructional design. The former is called intrinsic cognitive load, and results from the number of interacting elements in a task. The latter is called extraneous cognitive load when it is ineffective for learning and germane cognitive load when it is effective for learning. The aim of instructional designers should be to minimize extraneous and enhance germane load imposed by instruction (Sweller et al., 1998).

Instructional measures that successfully induce a germane load, stimulate learners to invest mental effort in the development of rich cognitive schemata during training, that subsequently allow for effective and efficient test performance. Examples of instructional measures that are known to induce a germane cognitive load in studying worked examples are for example increasing the variability (Paas & Van Merriënboer, 1994) or contextual interference (Van Merriënboer, Schuurman, De Croock, & Paas, 2002) in series of worked examples, or prompting students to self-explain the rationale behind solution steps (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997).

However, even though self-explaining can be beneficial for learning, this is not necessarily the case for all learners; it rather depends on whether they are able to self-explain, as well as on the quality of their self-explanations (Chi et al., 1989; Renkl, 1997). Nevertheless, typical examples usually require some self-explaining, as they show students only the steps required to reach the solution (i.e., the end product; these can therefore be called product-oriented worked examples; Van Gog, Paas, & Van Merriënboer, 2006, 2008). However, these solution steps are consequences of inner thought and attention processes, and these processes are usually not made explicit in the examples. That is, product-oriented examples only show *what* steps are taken, not *how* these steps are selected (e.g., is this the only option or are there different options?) or *why* they were selected (e.g., why is this option better –more likely to lead to a good solution- than the other one?). Not presenting this additional information can compromise students' learning and understanding of the solution procedure (unless they are able to self-explain this correctly). Understanding a solution procedure is required to be able to flexibly apply learned procedures in novel situations (i.e., transfer; Detterman & Sternberg, 1993). Process-oriented examples (Van Gog et al., 2006, 2008) do provide additional information on the rationale that led to the solution procedure.

Enhancing the Effectiveness of Examples: Guiding Attention and Thought

Research has shown that for novices, process-oriented examples that made the rationale behind the worked-out solution procedure explicit were more effective initially for learning and transfer than product-oriented examples (Van Gog et al., 2008). As yet, however, no studies have been conducted on the effects of making the model's (visual) attention processes explicit in examples. This might be relevant, especially in the context of computer-based modelling examples, where solution steps are not written out, but are demonstrated to the learner by the model (e.g., the learner is shown a screen capture of a model's task performance). Bandura (1977) has stressed the fact that "people cannot learn much by observation unless they attend to, and perceive accurately, the significant features of the modelled behaviour" (p. 24). However, eye tracking research on expertise differences has shown that the allocation of visual attention between the model providing the example, and the novice studying the example, is likely to differ.

Attention can shift in response to exogenous and endogenous cues (Rayner, 1998; Stelmach, Campsall, & Herdman, 1997). Exogeneous shifts occur mainly in response to salient features in the environment, whereas endogenous shifts are driven by knowledge of the task, of the environment, and of the importance of information sources. In other words, endogenous attention shifts are influenced by expertise (see e.g., Charness, Reingold, Pomplun, & Stampe, 2001; Haider & Frensch, 1999; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). Research has shown that individuals with higher expertise are likely to allocate their (visual) attention faster and/or in greater proportion to relevant information in the task (see e.g., Charness et al., 2001; Haider & Frensch, 1999; Van Gog, Paas, & Van Merriënboer, 2005). This implies that the expert model performing the task and the student observing the performance, may not be attending to the same information. This could be problematic, as students may miss information necessary to understand what the model is doing, or why s/he is doing what s/he is doing, in particular when information is transient (there one moment and gone the next). Being able to see where the model is looking at what moment, may help students to better process the example. For example, depending on the type of task, the model's eye movements may also make the strategy s/he is using (e.g., different options under consideration) clear to students.

As mentioned above, research by Velichkovsky (1995) on cooperative puzzle problem solving by expert-novice pairs, in which eye movements were used to demonstrate on what task aspects the partners focused their attention, has shown that attention can be guided by showing students an expert's eye movements. In this study, the novice could control the mouse to solve the problem, and the expert indicated with his gaze what the novice should do. The question is, however, whether attention guidance can not only be used to enhance communication as in Velichkovsky's study, but whether such guidance can also enhance learning outcomes, for example when applied while studying modelling examples. The study by Grant and Spivey (2003) suggested this might be the case. Based on eye movement patterns of participants who could successfully solve Duncker's radiation problem in one experiment, Grant and Spivey developed a cueing procedure (visual highlighting) implemented in a second experiment, which enhanced learning outcomes. However, Duncker's radiation problem is an insight problem. Modelling examples typically focus on problems that require a series of solution steps, that is, are dynamic and involve steady progression towards the goal state. Thus, the question remains whether attention guidance could also be effective in studying modelling examples to enhance learning, and whether eye movements could be used directly to guide attention, rather than being translated into a cueing procedure.

Therefore, this study addresses the question of whether attention guidance by showing students the model's eye movements can enhance their learning in combination with product-oriented examples that show only the solution steps, and process-oriented examples that show the solution steps and contain a verbal explanation of why these steps are taken. It is hypothesized that this form of attention guidance would help learners to better attend to and encode the relevant features of the examples, which would contribute to learning. This effect is expected to be greater in combination with process-oriented worked examples, that convey both thought and attention processes to the learner.

Method

Participants

Seventy-seven students from the University of Tübingen (16 male; age $M = 23.84$, $SD = 3.35$), volunteered to participate in this study. Participants received a financial compensation of 5 Euro. They had no prior knowledge of the task, which was established by showing them the initial problem state and asking them whether they knew this type of task (see task description in materials section for details).

Design

To investigate our hypotheses, a 2 x 2 factorial design was used with factors Example Type (Product vs. Process) and Attention Guidance (Yes vs. No), resulting in four conditions: (1) product-oriented example ($n = 16$), (2) product-oriented example with attention guidance ($n = 16$), (3) process-oriented example ($n = 17$), and (4) process-oriented example with attention guidance ($n = 17$). In addition, a smaller problem-solving condition ($n = 11$) was implemented to establish whether the well-known worked example effect, that is, that example study is more effective than problem solving, also applies to the task used here.

Materials

Problem-solving task. The problem-solving task used is known as Frog Leap (http://www.addictinggames.com/frogleap.html; see Figure 1A). The begin state showed three frogs on stones in a river on the right side and three frogs on stones on the left side, with an empty stone in the middle. The goal was to switch their sides, that is, to get the frogs on the right side to the left side and those on the left side to the right side (with people instead of frogs this problem is known as 'traffic jam', see e.g., http://mathforum.org/tpow/jam/Jam.html; as one of the reviewers pointed out, this should not be confused with another popular game called ‘traffic jam’ that involves cars). By clicking on a frog it would move (only in the direction in which it was headed) to the free space if that space was directly in front of it, or was separated from it by one other frog (jump). Only one frog could move at a time and they could not go back, or jump over two frogs. There is only one correct solution path consisting of 15 moves, which are shown in Figure 2. Errors (incorrect moves) cannot be corrected. So once an error is made, the problem can no longer be solved (although a few more moves may be made before getting stuck).

Example and test problems. The examples consisted of digital videos with a duration of 115 s., showing screen (and audio) captures of: (1) the model performing the task (i.e., only solution steps shown; Product-oriented Example –No Attention Guidance), (2) the model performing the task including his/her eye movements (solution steps plus eye movements shown; Product-oriented Example With Attention Guidance), (3) the model performing the task while verbalizing the underlying thought process (i.e., solution steps shown plus thought process presented auditory; Process-oriented Example –No Attention Guidance), or (4) of the model performing the task, including his/her eye movements, while verbalizing the underlying thought process (solution steps and eye movements shown plus thought process presented auditory; Process-oriented Example With Attention Guidance). For a static impression of the attention guidance see Figure 1B.

The model was an expert in performing the task (one of the experimenters who had had extensive practice and could solve this type of problem fast and without error), but was instructed to behave didactically, that is, the expert was deliberately showing a learner how to go about solving such a problem. This makes the process and the eye movement pattern somewhat different from a “natural” situation, in which the expert would be able solve the task very fast, making it difficult for learners to see what the expert is doing, and in which the expert would not steadily consider all possible moves, because the right moves are known.

The examples were created with the Tobii 1750 50Hz eye tracker (www.tobii.com), using the screen capture recording mode of the ClearView software. The model's eye movements (fixations) during problem-solving were shown as yellow dots that became smaller or larger with decreasing or increasing fixation duration (the gaze trail option provided by ClearView was not used). Fixations were defined as gaze points that fell within a radius of 50 pixels and together had a duration of at least 300 ms. Except for the model's eye movements and/or verbalizations, all examples were identical (i.e., they had the same runtime, steps were performed at exactly the same time, etc.).

The test consisted of the same problem-solving task, which had to be performed twice, the first time by starting with the frogs on the side shown in the example (right side), the second time by starting with the frogs on the other side (left side). As mentioned before, errors (incorrect moves) cannot be corrected, so once an error is made, the test problem can no longer be solved. Performance was therefore scored dichotomously, in terms of whether the problem was correctly solved or not.

Mental effort. The perceived amount of mental effort invested in observing the examples and solving the test problems was indicated on the 9-point rating scale developed by Paas (1992), ranging from 1, *very very low mental effort*, to 9, *very, very high mental effort.*

Test environment and data recording. The examples, mental effort rating scales, and test problems were presented in a web environment, preceded by a short demographical data questionnaire and general instructions. In the attention guidance condition, the general instructions also contained an example of an eye movement record on an unrelated task to familiarize participants with the depiction of eye movements. They could watch this example as long as they wished. The experimental sessions were recorded with Camtasia screen recording software, and based on these records, performance was scored.

Procedure

The experiment was run in individual sessions of approximately 15 minutes, with participants seated behind a PC in a lab room. Participants were randomly assigned to one of the conditions. In the web environment, they first filled out their demographic data and then read the general instructions (which in the attention guidance condition also contained an example of an eye movement record). After that, the learning phase started. Participants in the examples conditions first studied the example of their respective condition twice, participants in the problem-solving condition got two attempts to solve the problem. Immediately after each example and after each problem, participants were asked to rate the amount of mental effort they invested in studying the example or attempting to solve the problem on the 9-point rating scale. After this learning phase, the test phase followed. Participants were required to solve the problem twice themselves, the first time starting on the right side as in the examples, the second time starting on the left side. Again, immediately after each test problem, participants rated the amount of mental effort they invested in attempting to solve the problem. Participants' entire experimental session was recorded (screen capture), and after the experiments the performance and mental effort data were derived from these records for analysis.

Results

Table 1 presents the performance and mental effort data. In the analyses reported here, a significance level of .05 is used.

Performance

As participants could not correct errors, and therefore could no longer solve the problem once an error was made, performance on the test tasks is scored as either correct or incorrect. In the product-oriented examples conditions, 50% of the students in the condition *without* attention guidance managed to solve the first test problem, against 31.3% in that *with* attention guidance. A proportions test for two independent groups using StatsDirect (http://www.statsdirect.com/) showed that this difference was not significant ($p > .05$)[1]. Interestingly, however, in the condition *with* attention guidance, 80% of the students who managed to solve the first test problem, also solved the second test problem, against 37.5% of their counterparts *without* attention guidance (this difference neared significance, $p = .07$).

In the process-oriented examples conditions, 58.8% of the students in the condition *without* attention guidance managed to solve the first test problem, against only 23.5% in that *with* attention guidance. A proportions test for two independent groups showed that this difference was significant ($p < .05$). Of the students who managed to solve the first test problem, 40% in the condition without attention guidance also managed to solve the second problem, against 25% in the condition with attention guidance, but this difference was not significant ($p > .05$).

None of the participants in the problem solving condition managed to solve the first test problem. Proportions tests indicate that this is significantly different from the product-oriented examples without attention guidance ($p < .01$), product-oriented examples with attention guidance ($p < .05$), process-oriented examples without attention guidance ($p < .001$), but not significantly different from the process-oriented examples condition with attention guidance ($p > .05$).

Mental Effort

Only the example conditions are analysed here, as the problem-solving condition was only used as an indicator of whether example study benefitted test performance more than problem solving. However, data from the problem-solving condition can also be found in Table 1. Mental effort invested during example study showed a trend towards significance of Example Type, $F(1, 62) = 3.63$, $MSE = 243.68$, $p = .06$, $\eta_p^2 = .06$, suggesting that participants in the process-oriented examples conditions invested more mental effort ($M = 4.62$, $SD = 2.05$) than students in the product-oriented example conditions ($M = 3.69$, $SD = 1.86$).

On mental effort invested during the test phase, a main effect of Example Type was found, $F(1,62) = 5.71$, $MSE = 192.5$, $p < .05$, $\eta_p^2 = .08$, indicating that participants in the process-oriented examples conditions invested more effort ($M = 6.16$, $SD = 1.78$) than students in the product-oriented example conditions ($M = 5.13$, $SD = 1.93$), as well as an interaction effect of Example Type and Attention Guidance, $F(1,62) = 5.55$, $MSE = 192.5$, $p < .05$, $\eta_p^2 = .08$, indicating that when combined with process-oriented examples, but not with product-oriented examples, attention guidance led to higher investment of mental effort.

Discussion

The fact that none of the participants in the problem-solving condition managed to solve the first test problem, even though they had two practice opportunities, illustrates that the examples in general fostered learning (i.e., a ‘worked example effect’; Sweller, 2006).

Our hypothesis that attention guidance would be helpful for learning, and more so when combined with process-oriented examples, was not confirmed. Quite in contrast, combined with process-oriented worked examples, attention guidance by showing the model’s eye movements *hampered* learning. Interestingly, when attention guidance was combined with product-oriented examples, there were no differences in the ability to solve the first test problem in the groups with and without attention guidance, but relatively more students in the condition with attention guidance then managed to solve the second problem as well. Although this finding has to be interpreted carefully, it might suggest that the effect of attention guidance only becomes apparent on transfer tasks. In a sense, this would be logical, as for retention (solving similar tasks) a solution procedure can be copied, but understanding of the procedure is required to be able to flexibly apply it, which transfer (solving slightly different tasks) requires (Detterman & Sternberg, 1993).

The mental effort data indicate that presumably, in the process-oriented examples with attention guidance condition, the combination of verbal explanations and eye movements led to processing difficulties. During the learning phase, both process-oriented example groups seemed to invest more mental effort, but the learning *outcomes* suggest that this higher investment of effort was invested in processes detrimental for learning (i.e., imposing an extraneous load) in the group *with* attention guidance, and invested in beneficial processes (i.e., imposing a germane cognitive load) for the group *without* attention guidance. That is, the learning outcomes show that students in the process-oriented examples condition *with* attention guidance not only were less successful at test performance, they also had to invest much more effort in the test problems, which indicates that the problem-solving schemata they acquired were of lower quality and as a result, test performance was less efficient (see Paas & Van Merriënboer, 1993; Van Gog & Paas, 2008).

There are two possible explanations for this finding. First, attention guidance may have been redundant for this task. Research has shown that redundant information tends to distract students' attention, which can lead to detrimental effects on learning outcomes (e.g., Kalyuga, Chandler, & Sweller, 1999). At each move, the choice was always between two frogs. It was expected that attention guidance through the model's eye movements would have the added value of making participants more aware of the importance of considering both options. However, in this task, not only the eye movement, but also the verbal data pointed towards the two frogs under consideration at each step. Secondly, it might be the case that students have difficulty attending to both the verbal and visual process information simultaneously, especially because the model's eye movement data might move a few milliseconds ahead of the verbal data, and the learner's eye movements might follow a few milliseconds after that (see e.g., Richardson & Dale, 2005). Whereas this may be less of a problem in a communication situation like that of Velichkovsky (1995) it is possible that it might have interfered with learning here.

Future research using tasks in which the eye movements communicate information regarding attention that is not (easily) conveyed by the verbal data, may shed light on which explanation is more likely. In addition, research using more perceptually complex tasks would be interesting. That is, even though the task used in this study was a highly visual task and the problem was not trivial (i.e., it was complex enough, as evidenced by the fact that many participants were not able to solve it even after having had two examples, and none were able to solve it after two trials), this task was not perceptually complex. It is likely that under conditions of information transience (as in some animations for example; see e.g., Ayres & Paas, 2007), attention guidance through eye movements plays a more crucial role. When information is not always present but appears and disappears, it will be missed by the learner when it is not attended to timely.

Of course, an alternative to showing eye movements directly, would be to develop other types of cues based on the eye movement data, comparable to Grant and Spivey (2003) who developed an effective cueing procedure based on eye movement patterns of participants who could successfully solve a static insight problem (Duncker's radiation problem). However, conveying attention directly via eye movements could play an important role in situations were it is desirable to guide attention in real-time. Provided that technical challenges could be overcome, which seems possible in the near future given the fast developments in the field, eye movements might for example support video conferencing about complex content, collaborative learning or problem solving (cf. Velichkovsky, 1995), or observational learning of complex visual skills as in certain surgical or military operations.

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Footnote

[1] This test examines the difference between two independent binomial proportions. StatsDirect provides an hypothesis test for the equality of the two proportions (i.e. delta = 0) and a confidence interval for the difference between the proportions. An exact two sided P value is calculated for the hypothesis test (null hypothesis that there is no difference between the two proportions) using a mid-P approach to Fisher's exact test.

Table 1

Overview of Data on Test Performance and Mean Invested Mental Effort during Learning and Test Phase per Condition

	Product-or. Example No Attention Guidance (*n* = 16)	Product-or. Example With Attention Guidance (*n* = 16)	Process-or. Example No Attention Guidance (*n* = 17)	Process-or. Example With Attention Guidance (*n* = 17)	Problem Solving (*n* = 11)
Performance Test 1 correct: *n* (%)	8 (50%)	5 (31.3%)	10 (58.8%)	4 (23.5%)	0 (0%)
Also Test 2 correct: *n* (% of *n* Test 1)	3 (37.5%)	4 (80%)	4 (40%)	1 (25%)	n.a.*
Mental effort learning phase: *M* (*SD*)	3.59 (1.81)	3.78 (1.95)	4.41 (2.06)	4.82 (2.08)	6.22 (1.78)
Mental effort test phase: *M* (*SD*)	5.25 (1.85)	5.00 (2.07)	5.26 (1.67)	7.06 (1.42)	7.05 (1.40)

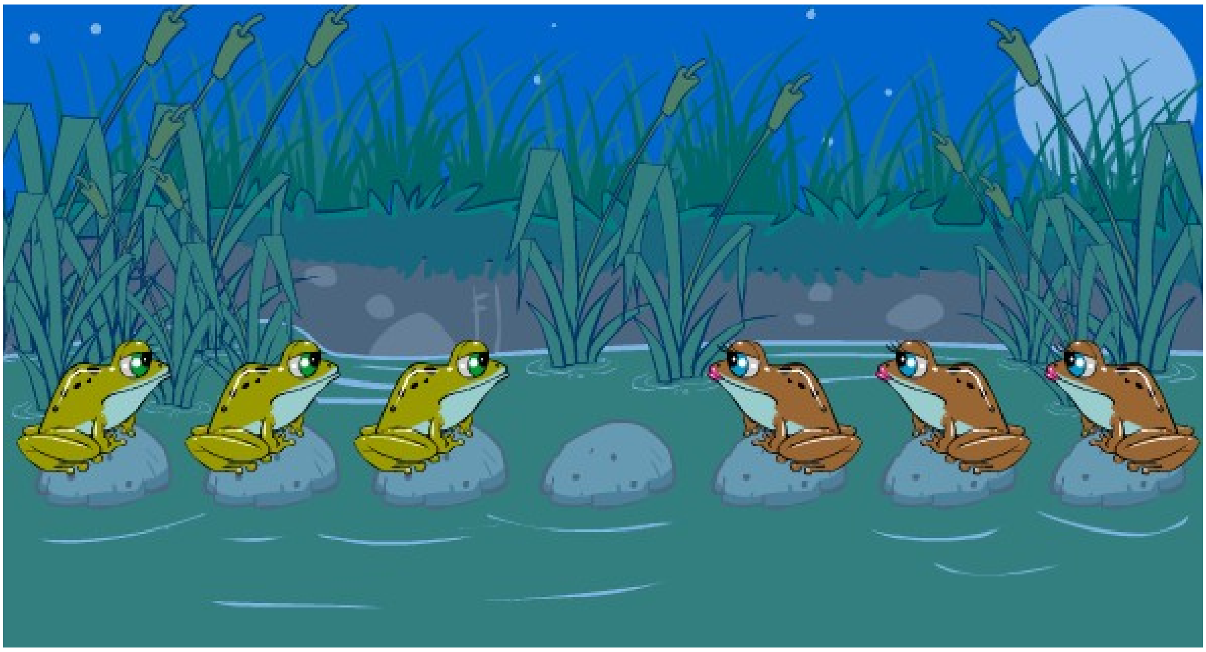
*n.a. = not applicable

Figure Captions

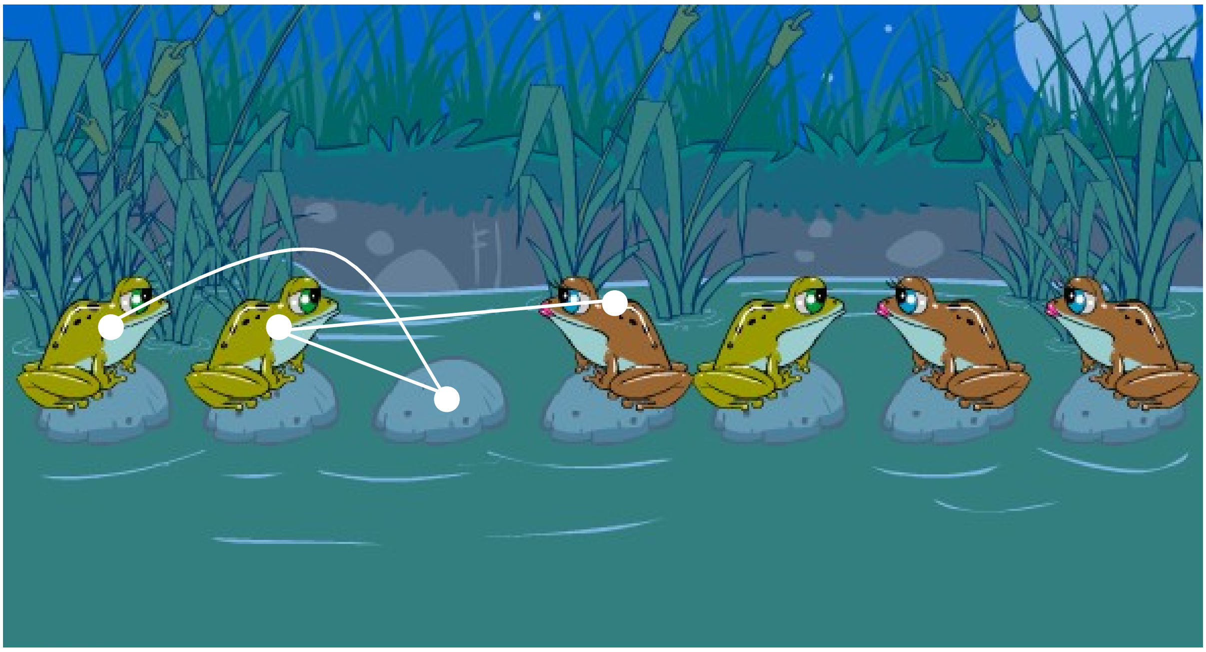
Figure 1. The initial state of the task is shown in Figure 1A. Figure 1B. shows a screen shot of the Frog Leap task with the eye movements simulated. The students saw a white dot, indicating fixations, which moved across the screen. This movement is fictitiously displayed here through multiple dots connected by lines.

Figure 2. Schematic overview of the solution procedure, with the gray and black circles indicating the frogs on each side and the white square marking the empty space.

1.A



1.B



Initial State	○	○	○	□	●	●	●
1	○	○	○	●	□	●	●
2	○	○	□	●	○	●	●
3	○	□	○	●	○	●	●
4	○	●	○	□	○	●	●
5	○	●	○	●	○	□	●
6	○	●	○	●	○	●	□
7	○	●	○	●	□	●	○
8	○	●	□	●	○	●	○
9	□	●	○	●	○	●	○
10	●	□	○	●	○	●	○
11	●	●	○	□	○	●	○
12	●	●	○	●	○	□	○
13	●	●	○	●	□	○	○
14	●	●	□	●	○	○	○
15	●	●	●	□	○	○	○