THE EFFECTS OF DIAGRAMS AND QUESTIONING-WHILE-READING ON LEARNING FROM A STATISTICS LESSON

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This study examined the effectiveness of two methods of increasing student learning from posterior probability lessons: diagrams and questioning while reading. Undergraduate students (N = 245) read a lesson in one of three diagram conditions and one of three questioning-while-reading conditions (embedded questions, elaboration interrogations, and control in which they read twice). Diagrams helped students in the control group accurately solve posterior probability problems on the posttest, but only if the information presented in the diagram was also presented in the text. Contrary to expectation, students in the control condition accurately solved more posterior probability problems on the posttest than did students in the questioning conditions. Poor answer quality for the embedded questions and elaborative interrogations is a possible explanation for the unexpected results.

Keywords: Probability, Post-Secondary Education, Instructional activities and practices

Probabilistic reasoning can be difficult for undergraduate students. One type of probabilistic reasoning, calculating posterior probability, is particularly challenging (Kahneman & Tversky, 1972). Calculating posterior probability involves considering both the probability of a particular characteristic or disease in a given population (i.e., the base rate) and the probability that the identification of that characteristic or disease is accurate (i.e., the specificity). Students frequently focus on the specificity information because they consider it more salient than the base rate (Kahneman & Tversky, 1972; Sedlemeier & Gigerenzer, 2001). Therefore, it can be challenging for students to understand how to calculate posterior probability. However, it is important to teach students about probabilistic reasoning, including skills such as accurately calculating posterior probability, so that they can be better consumers and citizens in modern society (Garfield & Ben-Zvi, 2008). The present study examined the effects of two factors that may promote student learning from a lesson on calculating posterior probability: diagrams and questioning while reading.

Diagrams

One technique that may foster students' learning is including relevant visual representations. According to the *multimedia principle*, learning is improved when texts are accompanied by relevant visuals (Mayer, 2009), because students develop a verbal mental model from the text and a visual mental model from the visuals. Students are more likely to make connections among different ideas when they have the information represented in two mental models. These connections prompt deeper processing of the text and increased learning.

At present, it is unclear whether learning is improved when information presented in a diagram is also presented in text. According to the *redundancy principle*, information presented in the diagram should *not* also be presented in the text (Sweller, Ayres, & Kalyuga, 2011), because presenting information in both text and diagram increases the amount of information the student has to process, which may diminish learning (Mayer, 2009). However, the redundancy principle is based on studies using causal diagrams for scientific concepts (e.g., Chandler & Sweller, 1991). It has not been explored with numeric information in math lessons. It is possible that having the numeric information presented in both diagram and text could facilitate connections between the verbal and visual information. Students may be better able to connect the concepts presented in the text and diagram if the information presented in the diagram is also presented in the text. Therefore, it is uncertain if including the information in the diagram as well as in the text will improve student learning about posterior probability.

Questioning while Reading

A second technique that may improve student learning is to have the students answer questions about the lesson while reading. Two types of questions are commonly used: embedded questions and elaborative interrogations. *Embedded questions* are simple questions about specific ideas stated in the lesson. Embedded questions are useful for directing students' attention to important information. Answering embedded questions has been found to increase learning from text; however, these benefits may be limited to certain student populations (e.g., less-skilled readers, Callendar & McDaniel, 2007). *Elaborative interrogations* are typically "why" questions intended to prompt the student to integrate an idea from the lesson with other ideas from the lesson or with background knowledge (e.g., McDaniel & Donnelly, 1996; Pressley, Symons, McDaniel, Snyder, & Turnure, 1988). Elaborative interrogations are intended to stimulate deeper processing of the lesson, thereby increasing learning (e.g., Ozgungor & Guthrie, 2004). Elaborative interrogation has been found to improve learning across a variety of student populations (cf. Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). Given the previous literature on both embedded questioning and elaborative interrogation, it is likely that including these types of questions will improve student learning from a lesson on posterior probability.

The use of questioning while reading may be particularly beneficial when visual representations are included in the lesson. Students do not always attend to the visual representations in text (Schüler, Scheiter, Rummer, & Gerjets, 2012). Embedded questioning may be useful for directing students' attention towards the visual representations, particularly if the questions are about the visual representations. In addition, integrating visual and verbal information typically promotes learning (Mayer, 2009). Elaborative interrogation may be useful for guiding students to integrate the visual and verbal information. This can be accomplished by asking elaborative interrogations that encourage the students to use information in both the diagram and the text.

The present study examined the effects of diagrams and questioning on learning about posterior probability calculations. Given the previous literature on visual representations (e.g., Mayer, 2009), we predict that students will learn more if their assigned lesson includes a diagram. However, it is uncertain whether students will learn more if the information presented in the diagram is also presented in the text. In addition, we predict that students in the two questioning-while-reading conditions will learn more than students in the control condition, who will simply read the lesson twice. Finally, we predict that students who receive both diagrams and questions will learn more than students who receive only one or the other, or neither.

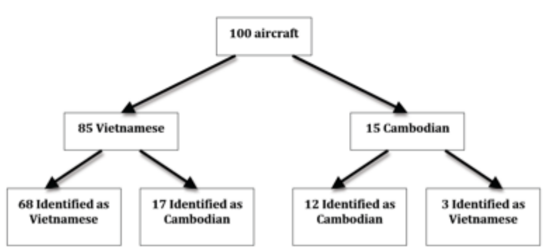
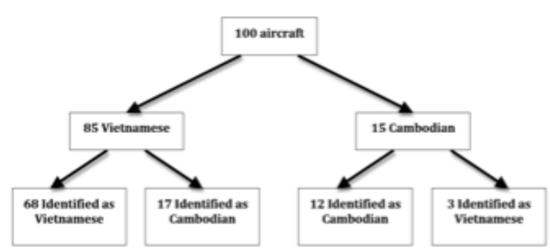
Methods

Participants were 248 undergraduates at a large, upper Midwestern university who earned extra credit in their introductory psychology course for participation. Three participants left the study before completing the posttest; their data were not included. Of the remaining 245 participants, there were 158 females and 86 males (one participant did not report gender) with an average reported age of 19.05 years (*SD* = 2.89 years). English was reported as the native language of 164 students; 80 students reported a native language other than English (one student did not report native language).

Materials

The lesson was adapted from a textbook by Heuer (1999) and included materials from Sedlmeier and Gigerenzer's (2001) experiments. There were two examples of scenarios in which base rate and specificity probabilities were presented, and then the posterior probability was calculated using natural frequencies. For the diagram conditions, there was a diagram for each of the two examples. For the diagram without redundant text condition, the information in the diagram was not also presented in the text. For the diagram with redundant text condition, the information in the diagram was also presented in the text (see Table 1).

Table 1: Lesson Excerpts from Diagram without Redundant Text Condition and Diagram with Redundant Text Condition

Diagram without redundant text	Diagram with redundant text
Imagine 100 cases in which the pilot has a similar encounter. Based on the base rate, we know how many of these encounters will be with Vietnamese fighter jets, and how many with Cambodian. Based on the specific case information, we know that 80 percent Vietnamese fighter jets will be correctly identified as Vietnamese, while 20 percent will be incorrectly identified as Cambodian. Similarly, 80 percent Cambodian fighter jets will be correctly identified as Cambodian, while 20 percent will be incorrectly identified as Vietnamese. This is shown in the diagram below.	Imagine 100 cases in which the pilot has a similar encounter. Based on the base rate, we know that 85 of these encounters will be with Vietnamese fighter jets, 15 with Cambodian. Based on the specific case information, we know that 80 percent or 68 of the 85 Vietnamese fighter jets will be correctly identified as Vietnamese, while 20 percent or 17 will be incorrectly identified as Cambodian. Similarly, 80 percent or 12 of the 15 Cambodian fighter jets will be correctly identified as Cambodian, while 20 percent or 3 will be incorrectly identified as Vietnamese. This is shown in the diagram below.
	
This makes a total of 71 Vietnamese and 29 Cambodian sightings, but not all of these sightings were correct. Therefore, when the pilot claims the attack was by a Cambodian fighter jet, the probability that the fighter jet was actually Cambodian is only 12/29ths or 41 percent.	This makes a total of 71 Vietnamese and 29 Cambodian sightings, of which only 12 of the 29 Cambodian sightings are correct; the other 17 are incorrect sightings of Vietnamese fighter jets. Therefore, when the pilot claims the attack was by a Cambodian fighter jet, the probability that the fighter jet was actually Cambodian is only 12/29ths or 41 percent.

For the embedded questioning and elaborative interrogation conditions, there was one question after approximately every paragraph. For diagram and questioning conditions, a question was asked after each of the diagrams. For the diagram without redundant text condition, answering the question correctly required using information from the diagram. However, for the diagram with redundant text condition, the question could be answered using information from the text or the diagram (or both). Embedded questions were simple (e.g., "How many fighter jets identified as Vietnamese are actually Cambodian?") and their answers were explicitly stated in the text

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and/or clearly presented in the diagram. Elaborative interrogation questions were complex "how" and "why" questions (e.g., "How are the base rate and the specific case information used to calculate the probability the fighter jet is Cambodian?"). The answers to elaborative interrogations were implicit in the text; the participant had to connect different ideas presented in the text and/or diagrams. All lessons began with the reminder that the participant would be asked to answer questions based on the information in the lesson. The lesson in the control condition also began with the reminder that participants needed to read the lesson twice. At the end of the control condition lesson, participants were reminded that if they had only read the lesson once, they needed to go back to the beginning and re-read.

Measures

Pre/posttest. Prior to reading the lesson, participants were asked to solve the following posterior probability problem: "All medical tests have error. For example, the serum test screens pregnant women for fetuses with Down syndrome. The test is a very good one, but not perfect. Roughly 100 fetuses out of 10,000 have Down syndrome. Of these 100 fetuses with Down syndrome, 90 pregnant women will have a positive test result. Of the remaining 9,900 unaffected fetuses, 99 pregnant women will still have a positive test result. What is the probability a pregnant woman who has a positive result on the test actually has a fetus with Down syndrome?" The problem was presented only as text; no visuals were included. The posttest consisted of four posterior probability problems similar to the pretest. The problems were presented as text only; no visuals were included.

Procedure

Participants were randomly assigned to conditions. Participants engaged in the experimental tasks individually in small groups of 2 to 6. All participants in a particular group were in the same condition. All tasks were paper-and-pencil (i.e., they were not administered on a computer). After providing informed consent, participants were given a posterior probability problem to solve as a pretest. Then, they were given the lesson and an answer sheet for their questions, if they were in one of the questioning conditions. The experimenter instructed them to read the lesson carefully because they would be asked to answer questions and solve problems based on its information. Participants in the control condition were instructed to read the lesson twice. Participants in the questioning condition were instructed to answer the numbered questions in the lessons when they came to them, in the appropriate places on the answer sheet. When participants finished reading the lesson, they completed a distractor task of 21 single-digit multiplication and division problems. Then, they completed the posttest. Finally, they self-reported their demographic information. Experimental tasks were completed in a single session, which were approximately 45 minutes in length.

Scoring

Pre- and posttests. Pre- and posttests were scored for accuracy. The number of accurately solved problems was the score for the pretest and posttest. The maximum posttest score was 4.

Answers to embedded questions. Answers to embedded questions were scored dichotomously as correct or incorrect. Correct answers were scored as '1' and incorrect answers as '0.'

Answers to elaborative interrogations. Because the elaborative interrogations were more complex than the embedded questions, their answers were scored using a rubric instead of dichotomously. The rubric had the following categories: ideal, adequate, inadequate, circular, wrong, and missing. Elaborative interrogations were designed to prompt integration of concepts within the lesson. Therefore, an answer was considered ideal if it correctly included three or more concepts presented in the lesson. Adequate answers correctly included two concepts. Inadequate answers included only one concept. Circular answers repeated the information in the question (e.g., EI: "Why is the base rate important when calculating probability?" Circular Answer: "Because it is important information you need to use to calculate probability."). Wrong answers provided incorrect or inappropriate information. Missing answers were either responses such as "I have no idea" or the complete absence of answers. An ideal answer was scored as '3.' An adequate answer was scored as '2.' An inadequate answer was scored as '1.' A missing, incorrect, or circular answer was scored as '0.' The scores for all 6 of the answers to the elaborative interrogations were summed for a measure of answer quality.

Results

We first examined the effects of the diagram and questioning conditions on the posttest scores. We separated the participants based on whether they answered the pretest correctly (N = 47) or incorrectly (N = 198). An ANOVA was conducted with diagram condition and questioning condition as fixed factors and posttest scores as the dependent variable. Bonferroni corrections were used for multiple comparisons. Figure 1 presents the data for each of the pretest accuracy groups by condition.

For participants who answered the pretest correctly, diagrams had a positive effect on posttest scores $F(2, 45) = 8.26$, p = .001. There was a benefit of diagrams both without and with redundant text compared to the text-only condition, $t(28) = 3.04$, $p = .01$,Cohen's $d = 1.01$; $t(28) = 3.98$, $p = .001$, Cohen's $d = 1.26$, respectively. There was no difference between the two diagram conditions. In addition, there was no effect of questioning.

For participants who answered the pretest incorrectly, there was no overall effect of diagrams on posttest performance. However, there was an interaction between diagram condition and questioning condition, $F(2, 196) = 3.04$, $p = .02$, such that diagram condition affected performance in the read-twice control condition, $t(61) = 2.56$, $p = .04$, Cohen's $d = .63$, but not the other questioning conditions. In the read-twice control condition, participants in the diagram with redundant text condition had higher scores than did participants in the text-only condition. There were no differences between the diagram without redundant text condition and the other diagram conditions. For participants who answered the pretest incorrectly, there was also a main effect of questioning condition, $F(2, 196) = 13.56$, $p < .001$. Unexpectedly, participants in the control condition had higher posttest scores than did participants in the embedded questioning condition, $t(118) = 4.49$, $p < .001$, Cohen's $d = .74$, and participants in the elaborative interrogation condition, $t(154) = 4.34$, $p < .001$, Cohen's $d = .69$.

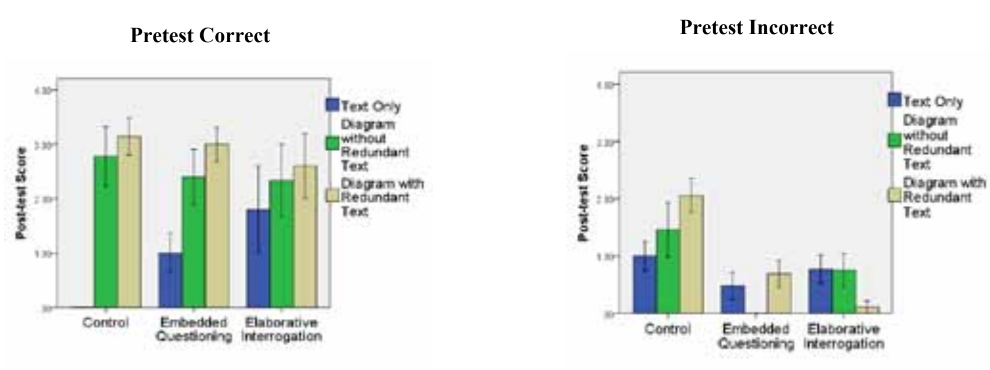

Figure 1: Post-Test Scores by Diagram and Questioning Conditions

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The results indicate that diagrams were helpful for participants who initially did well on the posterior probability problem at pretest, aiding them to continue to do well on similar problems at posttest. In contrast, participants who did not understand how to answer the pretest problem benefited from diagrams when they read the lesson twice, but not when they answered questions while reading. Moreover, diagrams appear to be helpful only if they were accompanied by redundant text for participants who answered the pretest problem incorrectly. Contrary to expectations, questioning while reading was not beneficial for learning how to solve posterior probability problems. Indeed, reading twice appeared to yield higher scores on the posttest than either elaborative interrogation or embedded questioning for participants who answered the pretest problem incorrectly.

Given the unexpected finding that embedded questioning and elaborative interrogation conditions were not helpful for learning, we examined the quality of the answers to the questions in the embedded questioning and elaborative interrogation conditions (see Scoring section for scoring of answers). Because of the different patterns of findings based on pretest accuracy, we tested for differences in answer quality based on pretest accuracy. Then, we examined associations between answer quality and learning.

For the embedded questioning condition, participants answered an average of 3.08 questions correctly (SD = 1.70) out of 6 questions total. We conducted a one-way ANOVA with accuracy of answers to the embedded questions as the dependent variable and pretest accuracy as the independent variable. There were no differences in answer quality between participants who answered the pretest correctly (M = 3.00, SD = 1.70) and participants who answered the pretest incorrectly (M = 3.11, SD = 1.72). We used Pearson product-moment correlations to test for associations between accuracy of answers to the embedded questions and posttest scores. There were no associations between answer quality and posttest scores for either participants who answered the pretest correctly or participants who answered the pretest incorrectly.

For the elaborative interrogation condition, participants received an average score of 4.80 (SD = 2.27), out of a maximum possible score of 18. Approximately 37% of the answers were missing, circular, or wrong, 51% of the answers were inadequate, 9% of the answers were adequate, and 4% were ideal. We conducted the same statistical tests with the answers to the elaborative interrogations as we did with the answers to the embedded questions. As with embedded questioning, there were no differences in answer quality between the participants who answered the pretest correctly (M = 4.82, SD = 2.39) and participants who answered the pretest incorrectly (M = 4.69, SD = 1.70). Also similar to embedded questioning, there was no association between the answer quality for the elaborative interrogations and posttest scores for participants who answered the pretest correctly. However, for participants who answered the pretest incorrectly, there was a positive correlation between the quality of the answers to the elaborative interrogations and posttest scores, $r = .39$, $p = .002$.

Discussion

The purpose of this study was to examine the effects of diagrams and questioning while reading on learning from a lesson on calculating posterior probability. We had hypothesized that including diagrams in the lesson would improve learning, but were uncertain whether including text redundant with the information in the diagram would affect learning. For students who answered the pretest problem correctly, diagrams improved learning, whether or not they were accompanied with redundant text. However, for students who answered the pretest problem incorrectly, there was a benefit of diagram with redundant text, relative to text only, but only for the control (i.e., read twice) condition. There was no reliable benefit of diagram without redundant text. These findings are consistent with the multimedia principle, which holds that including relevant visuals in lessons improves learning (Mayer, 2009).

However, our findings are inconsistent with the redundancy principle, which states that information should be presented in the text or diagram, but not both (Sweller et al., 2011). For students who solved the pretest problem incorrectly, there was no effect of redundant text. But, for students who solved the pretest incorrectly in the read-twice condition, there was a reliable benefit of diagrams only if they were accompanied by redundant text. In other words, presenting the information in a diagram *instead of* the text did not appear to be consistently helpful. For some students, the information needed to be in the diagram *as well as* the text for a benefit to be observed. It may be that presenting the information in both the text and diagram helped the students connect the two representations. The integration of the information may have led to more in-depth learning, resulting in better comprehension and application of the lesson.

We had hypothesized that answering questions while reading would have benefited learning. However, there was no effect of questioning for students who answered the pretest problem correctly. Moreover, students who answered the pretest problem incorrectly had higher posttest scores when they read twice as opposed to answer questions while reading. One possible explanation for the unexpected lack of benefit of questioning is that the quality of the answers to both the embedded questions and elaborative interrogations was generally quite poor. According to Jiang and Elen (2011), answering questions while reading only improves learning from text if students answer the questions as they were intended. On average, students answered only about half of the embedded questions correctly. This is surprising given that the answers to the questions were explicitly stated in the text; however, the undergraduate participants may have been confused by the simplicity of the questions presented to them. This confusion could have led to inaccurate answers to the embedded questions and diminished performance on the posttest for students who answered the pretest problem incorrectly. For the elaborative interrogations, students did not provide answers indicative of the deep processing these questions were intended to stimulate. The overwhelming majority of the answers to the elaborative interrogations were missing, circular, wrong, or inadequate.

Given our findings regarding answer quality, it is not surprising that both questioning conditions were detrimental, rather than beneficial, to learning for students who answered the pretest incorrectly. They were likely distracted by the questions and thereby benefited only if they read twice. However, students who answered the pretest problem correctly were not affected by questioning even though their answer quality was similar to those who answered the pretest problem incorrectly. Students who answered the pretest problem correctly may have been better able to focus on lesson content and suppress the distraction of the questions.

The results indicate that better answers to elaborative interrogations were associated with better learning from the lesson for students who lack prior understanding of the content. Therefore, benefits of elaborative interrogation might be observed if answer quality was stronger. We propose two ideas to improve answer quality in future studies. The first is practice training in which students receive examples of what types of answers are expected of them. This practice training would provide a model for the students, which could improve their answer quality (cf. Dornisch, Sperling, & Zeruth, 2011, for discussion). The second is to provide students with feedback on their answers either in the experiment, through their peers while working collaboratively (after training), or through computer-based tutoring. If these ideas could effectively improve answer quality, positive effects of elaborative interrogation might be seen.

Posterior probability, like many probabilistic reasoning concepts, is frequently challenging for students to learn. In this study, we sought to improve student learning on posterior probability problems by incorporating diagrams and questioning while reading into lessons. Our finding that diagrams assisted learning is consistent with the multimedia principle (Mayer, 2009). However, our finding that redundant text has a neutral or positive effect on learning, depending on the population, is inconsistent with the redundancy principle (Sweller et al., 2011). Our findings regarding questioning are inconsistent with our expectations based on previous literature. We believe that poor answer quality is the reason for the unexpected results, and we suggest some methods of improving answer quality. This work provides some guidance about how to improve student learning about probabilistic reasoning, while also highlighting the challenges inherent in this complex domain.

References

Callender, A. A., & McDaniel, M. A. (2007). The benefits of embedded question adjuncts for low and high structure builders. *Journal of Educational Psychology, 99*(2), 339. doi: 10.1037/0022-0663.99.2.339

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 293-332.

Dornisch, M., Sperling, R. A., & Zeruth, J. A. (2011). The effects of levels of elaboration on learners' strategic processing of text. *Instructional Science, 39*(1), 1-26. doi: 10.1007/s11251-009-9111-z

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques Promising Directions From Cognitive and Educational Psychology. *Psychological Science in the Public Interest, 14*(1), 4-58. doi: 10.1177/1529100612453266

Heuer, R.J. (1999). *Psychology of intelligence analysis*. Central Intelligence Agency: Center for the Study of Intelligence. Retrieved from https://www.cia.gov/library/center-for-the-study-of-intelligence/csi-publications/books-and-monographs/psychology-of-intelligence-analysis/art15.html

Garfield, J., & Ben-Zvi, D. (2008). *Developing students' statistical reasoning: Connecting research and teaching practice*. Springer.

Jiang, L., & Elen, J. (2011). Instructional effectiveness of higher-order questions: The devil is in the detail of students' use of questions. *Learning Environments Research*, *13*(3), 279-298. doi: 10.1007/s10984-011-9095-x

Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology, 3*(3), 430-454.

Mayer, R.E. (2009). *Multimedia learning, Second Edition*. New York, NY: Cambridge University Press.

McDaniel, M. A., & Donnelly, C. M. (1996). Learning with analogy and elaborative interrogation. *Journal of Educational Psychology, 88*(3), 508.

Ozgungor, S., & Guthrie, J. T. (2004). Interactions among elaborative interrogation, knowledge, and interest in the process of constructing knowledge from text. *Journal of Educational Psychology, 96*, 437–443.

Pressley, M., Symons, S., McDaniel, M. A., Snyder, B. L., & Turnure, J. E. (1988). Elaborative interrogation facilitates acquisition of confusing facts. *Journal of Educational Psychology, 80*(3), 268. doi: 10.1037/0022-0663.80.3.268

Royer, J. M. (2001). Developing reading and listening comprehension tests based on the Sentence Verification Technique (SVT). *Journal of Adolescent & Adult Literacy*, *45*(1)30-41. Retrieved from http://www.jstor.org/stable/40007629

Schüler, A., Scheiter, K., Rummer, R., & Gerjets, P. (2012). Explaining the modality effect in multimedia learning: Is it due to a lack of temporal contiguity with written text and pictures? *Learning and Instruction, 22*(2), 92-102. doi: 10.1016/j.learninstruc.2011.08.001

Sedlmeier, P., & Gigerenzer, G. (2001). Teaching Bayesian reasoning in less than two hours. *Journal of Experimental Psychology: General, 130*, 380-400.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Dordrecht: Springer.