Interactivity and Ego Depletion in Insight Problem Solving

Frédéric Vallée-Tourangeau
Department of Psychology, Kingston University
Kingston-upon-Thames UNITED KINGDOM KT1 2EE
f.vallee-tourangeau@kingston.ac.uk

Abstract

In the triangle of coins problem coins are arranged to create a triangle pointing down and the solution involves moving a few coins to change its orientation. The task ecology can be designed such that participants can work on it in a low interactivity environment, maintaining a mental representation of simulated moves, or in a high interactivity environment, thinking with and through a physical model of the problem. These task ecologies involve working memory to a different degree: Problem solving draws more on working memory the lower the degree of physical interaction. Participants first engaged in a writing task that required vigilance to inhibit common word choices, a degree of self regulation designed to induce a so-called ego depletion; participants then worked on the ToC problem in either a low or high interactivity environment. Solution rates were determined by level of interactivity; the preceding depletion experience did not impact performance.

Keywords: Interactivity, ego depletion, insight problem solving, working memory

Introduction

The relative contribution of working memory in analytic and insight problem solving has been explored using a broad range of methodologies. Prototypical analytic problems such as those requiring arithmetic operations would involve the maintenance and updating of interim results, the strategic allocation of attentional resources, and retrieval of long term memory knowledge, processes that draw heavily on working memory resources; high working memory capacity (WMC) is a reliable predictor of analytic problem solving performance (Wiley & Jarosz, 2012). In turn, insight problems are designed to resist initial analytic efforts or the direct transfer of long term memory knowledge. They are presented in a manner that trigger prepotent responses, but these lead to an impasse. Solving these problems then requires letting go of the incorrect interpretation. Less rather than more focus and attentional control might facilitate abandoning the incorrect interpretation, and hence a lower or transiently lowered WMC may better predict insight problem solving success (DeCaro & Beilock, 2010).

However, there is also evidence that working memory capacity is involved in solving insight problems (Gilhooly & Fioratou, 2009). For example, verbal working memory scores predict solution rates for compound remote associates (Chein & Weisberg, 2014) and spatial working memory scores correlate significantly with solution rates for the nine-dot problem (Chein, Weisberg, Streeter, & Kwok, 2010). Weisberg's (2015) integrated framework stresses the central role of analytic processes in solving insight problems, processes that draw on WMC.

A temporary reduction in deliberate executive function skills using a self-control exercise prior to engaging in an insight problem solving task might offer an interesting means to throw light on these somewhat conflicting findings. Hoffman, Schmeichel and Baddeley (2012) proposed that key features of executive functioning subserve self-regulation. So-called ego depletion tasks involve participants actively inhibiting a response set; these inhibitory efforts have negative aftereffects in subsequent tasks that require executive functions. For example, in Schmeichel (2007) participants' backward digit span was significantly lower after they engaged in a writing task that prohibited the use of the letters *a* and *n* than after an unconstrained writing task. Such findings support a fuel metaphor: executive control processes rely on a limited resource that fluctuates as a function of effort, rest and, more controversially, glucose level. The transient depletion of executive functions may impact analytic and insight problem solving differently. For example, performance on a mental arithmetic problem that requires temporary storage, retrieval of long term arithmetic knowledge and the strategic allocation of attentional resources, might be influenced by prior exposure to an ego-depletion manipulation. The prediction for insight problem solving however depends on the purported involvement of WMC. If a looser focus and 'leaky' attention (Wiley & Jarosz, 2012) are important, then ego depletion might actually enhance insight problem solving. In contrast, if, as Weisberg (2015) contends, analytic processes are implicated in insight problem solving, then an ego-depletion manipulation should have a negative aftereffect on performance.

Interactivity

The debate concerning the mental processes and capacities involved in problem solving reflects a commitment to methodological individualism (Vallée-Tourangeau & Vallée-Tourangeau, 2017): that the locus of cognition is person, or more specifically, skull bound. Problem solving outside the laboratory naturally involves interacting with the world, recruiting artefacts, building models of proto solutions, assembling non-mental resources that scaffold creativity and problem solving. The world is there to see and act upon, its dynamic configuration triggers different actions and guides attention. As such, then, the working memory burden of keeping a detailed representation of the problem is not the same when participants can interact with a physical model of the problem. In some sense, interactivity might result in a functional increase in WMC (Vallée-Tourangeau, Sirota, Vallée-Tourangeau, 2016), and profiling participants in terms of their WMC might not be as informative as profiling the working memory resources of the agent-environment system created through interactivity.

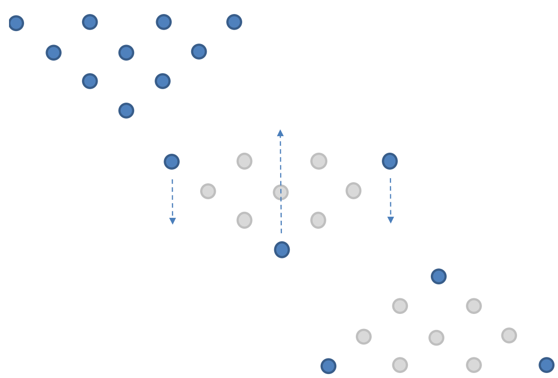

Figure 1: The triangle points down: Which three coins should be moved to make the triangle point up? Solving the triangle of coins problem involves moving the coins that mark the three vertices.

Real-world interactivity can be scaled down under laboratory conditions if the problem solving environment, or the cognitive ecosystem (Hutchins, 2010) affords interacting with a physical model of the problem (Vallée-Tourangeau, Sirota, Vallée-Tourangeau, & Makri, 2015). For example, Fleck and Weisberg (2013) used the triangle of coins problem (ToC see Fig. 1), among other insight problems, to explore problem solving strategies (based on verbal protocols). For this problem, they supplied participants actual coins to manipulate to determine the solution. They quote, at length (see p. 452) the protocol of one participant who works on the problem by initially moving coins in a trial and error fashion. The changes in the problem configuration guide and constrain the problem solving trajectory. Fleck and Weisberg also describe what they term 'data-driven' restructuring, or how a productive interpretation of the problem is triggered by manipulating the physical model; for example, an exploratory rotation of the entire model helped a participant notice that only the three vertices should be moved and the hexagonal core should be untouched (see pp. 452-453). Thus a productive strategy to solve the problem was triggered by changes in the physical model of the problem, not through the mental manipulation of a problem representation.

The Present Experiment

The present experiment explored the impact of an ego depletion task and level of interactivity on insight problem solving using the ToC problem. The experiment employed a 2x2 between subjects design. The first independent variable was the nature of a six-minute writing task before participants tackled the ToC problem: Half the participants had to closely monitor and inhibit certain responses to ensure that words containing the letters *a* or *n* were not used, while the other half wrote freely. The second independent variable was the level of interactivity. After the writing task, half of the participants worked on the ToC in a low interactivity condition, that is by looking at a static visual display of the problem and dictating possible moves to an experimenter. They did so by keeping their hands palm down in front of them and could not point at the coins or simulate movements with their fingers. The other half of the participants worked on the problem in a high interactivity condition: Participants were presented with a physical model of the problem and they could touch, point to or move the tokens in determining which three could be moved to change the triangle's orientation. The low interactivity condition draws more heavily on WMC since participants must mentally simulate move, keeping track of the simulated movements of certain tokens, while evaluating the movement of which other token(s) would mentally change the orientation of the triangle. None of this mental activity could be supported with complementary actions (Kirsh, 1995). To the extent that the constrained writing exercise prior to working on the ToC problem depletes executive functions and solving the ToC problem requires analytic processes that draw on WMC, then performance should be better after the free writing session than after the constrained writing session. On the other hand, if solving the ToC does not proceed from focused deliberate analytic efforts, then participants might actually perform better with prior exposure to the ego depletion task, that is a transient reduction in executive functions might be beneficial. Participants working on the ToC in the high interactivity condition are not confronted with the same kind of WMC taxing environment, and as such we predict a much higher rate of problem solving success in the high than in the low interactivity condition. In the high interactivity condition, participants think with and through the physical model of the problem. Transient executive functions depletion might have little or no impact on problem solving performance.

Method

Participants

Eighty undergraduate and postgraduate students (60 females) received course credits for their participation (M_{age} = 24.2, *SD* = 7.3).

Procedure

Participants were tested individually in a quiet cubicle. The experimental session was composed of three parts. Once an information sheet was read and understood and a consent form signed, participants first engaged for six minutes in a writing exercise modelled after the one reported in Schmeichel (2007). They were instructed "to write a short story describing a trip you have taken recently". Half of the participants experienced the depletion version of the task, where they were further instructed that the letters 'A' or 'N' could not be used: "you must pay close attention to the words you are using and aim to describe the trip with words that don't use these two letters". The other participants wrote freely without having to inhibit word choice responses.

During the second part of the experiment, all the participants were shown a sheet of paper (size A4) on which 17 digits were randomly printed. They were instructed to add these numbers as quickly and accurately as possible; however, participants had to keep their hands palm down on the table top and hence the mental arithmetic could not be supplemented or supported by complementary actions, such as touching the printed numbers of pointing at them.

In the third and final part of the experiment participants worked on the triangle of coins problem for five minutes; half of the participants were allocated to the low interactivity condition, half to the high interactivity condition. The problem was illustrated on a 9x9 grid printed on a sheet of paper: Columns were labelled with letters (A-I) and rows with numbers (1-9). Ten tokens were arrayed on that grid, each token labelled with an individual letter (see Fig. 2); the solution to the problem involved moving tokens R, W, A to cells E4, B7, and H7 to reorient the triangle such that it pointed up rather than down. Participants in the low interactivity condition worked on the problem with hands palm down on the table top, and voiced their proposed moves to the experimenter in groups of three moves: They would name the token and then the cell coordinate where it should be moved. The experimenter noted the moves on a record sheet hidden from the participants' view, and provided feedback. It's important to note that the problem configuration always remained the same, that is participants had to mentally project moves on the grid and verbalise these moves, while looking at the instruction sheet show in Figure 2; the experimenter never modified the triangle as such, and only provided feedback. In addition, feedback provided was all or none, that is participants were not informed if the projected position of one or two tokens was right on a given trial. In the high interactivity condition, participants worked with a laminated 9x9 grid (measuring 21cm x 29cm) with rows and columns labelled as in the low interactivity condition. Ten tokens (2.2cm in diameter) were arrayed as in the low interactivity condition, creating a triangle pointing down; each token had a letter printed on it, just as it did in the low interactivity condition. The token and grid coordinates helped the experimenter record the participants' moves, but the participants were not required to verbalise moves by identifying tokens and cell destinations. Rather participants were invited "to touch the tokens" and "trace their movement with your finger". If after moving the three tokens, the pattern created did not result in the correct answer, the experimenter put the tokens back to their original place, and participants could try to move a new set of three tokens

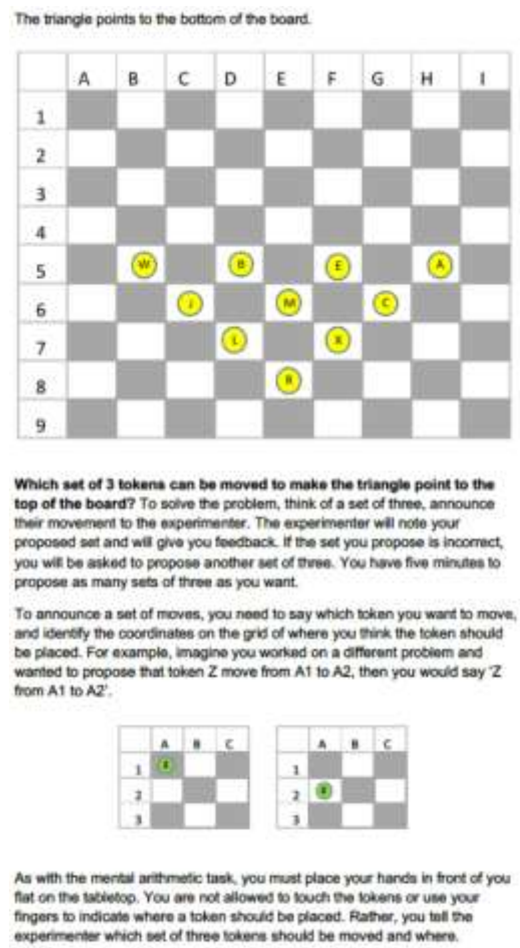

Figure 2: The problem instructions in the low interactivity condition.

The experimental design was thus a 2 (Depletion: constrained writing or free writing) x 2 (Interactivity: low, high) between subjects design. Participants were allocated randomly to each of the four experimental conditions.

Results

The mean number of words written in the constrained-ego depletion version of the story writing task ($M_{depletion}$ = 28.7, *SD* = 12.26) was significantly lower than in the unconstrained free version of the task ($M_{no\ depletion}$ = 122.7, *SD* = 25.48), $t(56) = -20.8$, $p < .001$ (the degrees of freedom were adjusted to account for heterogeneity of variance). Thus participants complied with the task instructions and struggled to write a story when they had to suppress words containing the letters *a* or *n*. However, performance on the mental arithmetic task, immediately following the story writing task, was unaffected by the prior exposure to the ego depletion manipulation in terms of the magnitude of absolute calculation errors ($M_{depletion}$ = 3.45, *SD* = 5.16, $M_{\text{no depletion}}$ = 5.23, *SD* = 8.18) $t(66) = -1.16$, $p = .250$, or latency (s) to solution ($M_{depletion}$ = 71.1, *SD* = 42.64, $M_{no\ depletion}$ = 79.4, *SD* = 57.81), $t(72) = -0.729$, $p = .469$ (degrees of freedom were adjusted to account for heterogeneity of variance).

Performance on the triangle of coin problem is illustrated in Figure 3. With low interactivity, 4 participants (or 20%) solved the problem following the constrained writing task, while 5 (or 25%) did so after the unconstrained writing task. With high interactivity, 14 participants (or 70%) and 10 (or 50%) solved the problem following the constrained and unconstrained writing task, respectively. Summing across depletion levels, more participants (60%) solved the ToC problem in the high interactivity condition, than in the low interactivity condition (23%), χ^2 (1, N = 80) = 11.61, $p = .001$; solution rates between the two high interactivity conditions did not differ significantly, χ^2 (1, N = 40) = 1.67, $p = .196$.

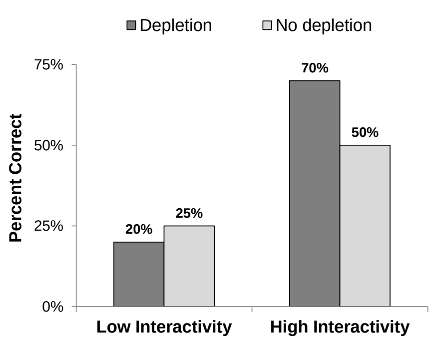

Figure 3: Percentage of correct solutions for the triangle of coins problem in the low and high interactivity task environment after engaging in a self-regulation task (depletion) or not (no depletion).

The solution rate data were analysed using a binary logistic regression. The outcome variable was the probability of solving the triangle of coin problem. Three models were tested: the first included only depletion as a predictor variable, the second included both depletion and interactivity as predictors, and the third model included depletion, interactivity, and their interaction as predictors. The first model was not significant, χ^2 (1) = 0.465, p = .495; adding interactivity produced a significant model, χ^2 (2) = 12.026, $p = .001$, Nagelkerke $R^2 = .195$; however, adding an interaction term did not increase the significance of the model, χ^2 (1) = 1.280, $p = .258$. The only significant predictor of success using the Wald criterion was level of interactivity ($p = .001$) with an odds ratio of 5.231 (see Table 1).

Table 1: Summary of Binary Logistic Regression with the Model Involving Depletion and Interactivity as Predictors.

Variable	*B*	*SE*	OR	95% C.I. for OR Lower	Upper	Wald	*p*
Depletion	0.363	0.494	1.438	0.546	3.789	0.541	.462
Interactivity	1.655	0.500	5.231	1.962	13.947	10.937	.001

Discussion

The triangle of coins problem was difficult to solve within the time allocated for participants in the low interactivity conditions; the success rate was very similar between those who had undergone the ego-depletion manipulation and those who had engaged in the free writing exercise. In turn, the success rates were substantially higher for participants in the high interactivity conditions. The interaction between ego-depletion and level of interactivity was not a significant predictor of the solution rate, however.

The level of interactivity afforded by the thinking environment substantially influenced problem solving performance, and corroborates recent findings with other types of insight problems (e.g., matchstick algebra, the 17 animals problem, see Weller, Villejoubert, & Vallée-Tourangeau, 2011; Vallée-Tourangeau, Steffensen, Vallée-Tourangeau, & Sirota 2016). The overall solution rate in the high interactivity condition in this experiment is similar to the one reported in Fleck and Weisberg (2013) who presented the ToC problem in a high interactivity environment, even if their work did not explicitly explore and contrast levels of interactivity in insight problem solving. A physical and modifiable model of the problem reduces working memory demands because changes in the problem configuration cue new actions and guide attention. Moves need not be premeditated, and need not be mentally simulated; participants observe the results of their action, and changes in the world, that is changes in the physical model of the problem, convey new information. Participants can more readily see how to solve the problem, they need not mentally represent possible changes, imagine their outcome, and while maintaining this simulated modification to the problem in working memory, project and simulate the next move.

As for the ego-depletion manipulation, whether the constrained writing task achieved its purpose of temporarily reducing executive functions, remains uncertain. On the one hand, word production was much lower in the constrained writing condition than with the free writing task. This suggests that participants complied with the task instructions and struggled to write. Assuming that the sustained inhibition of common word choices led to a depletion in executive functions, the predicted impact of such transient depletions on insight problem solving depends on the prominence attributed to deliberate analytical processes. What is less controversial is how such an ego-depletion manipulation should have influenced performance on the mental arithmetic task immediately following the writing exercise, but it did not; if anything absolute calculation errors were marginally lower following ego depletion. As for the ToC problem, performance in the low interactivity conditions was very poor, and such a floor effect might have masked any influence of ego depletion. Thus, on the one hand, the potential window on the importance of WMC in insight problem solving that a purported depletion in executive functions might offer was undermined by the very low rates of success in both low interactivity conditions. On the other hand, the mental arithmetic data suggest that the depletion manipulation did not work. In the final analysis, the controversy surrounding the very existence of the ego-depletion phenomenon (Hagger, Chatzisarantis, Alberts, Anggono, Batailler, et al., 2016) suggests that such a manipulation does not offer an interesting tool to gauge the importance of WMC and executive functions in problem solving. There is also the possibility that the mental effort invested in the mental arithmetic task depleted executive functions more so than the constrained writing exercise, and the low solution rate in the low interactivity conditions reflects this depletion. Thus, possible avenues for future research involve eliminating the intervening mental arithmetic task (and devising an alternative ego depletion manipulation check) or employing a more exacting depletion task such as a computation span test of the kind used to gauge WMC.

Fleck and Weisberg (2013) reported that some participants solved the ToC problem through an analytic and incremental strategy while for others the solution appeared to reflect a non-incremental insight. On the basis of concurrent verbal protocols or post-participation interviews future research could thus better determine the strategies and processes employed by a given participant, and make more specific predictions as to the degree of WMC involvement in solving that particular problem (I thank Robert Weisberg for this point).

In light of the controversy surrounding the concept of depletion and its potential negative aftereffects on performance, perhaps an altogether more productive research programme could look at burdening working memory with a secondary task (e.g., Lavric, Forstmeier, & Rippon, 2000) to determine how it would affect insight problem solving as a function of the level of interactivity afforded by the task environment. Recent work suggests that the impact of articulatory suppression on mental arithmetic was much greater in a low than in a high interactivity environment (Vallée-Tourangeau et al., 2016). Such a paradigm might be usefully employed with insight problem solving, not only as means to adjudicate the different proposals concerning the involvement of working memory but also to assess how working memory capacity is functionally enhanced in a high interactivity environment.

Concluding Remarks

Individual differences in cognitive capacities and thinking dispositions are often measured to throw light on thinking processes (e.g., Stanovich & West, 1998). Correlational and latent variable analyses are conducted to determine the underlying factors that best account for thinking performance. This strategy is employed in problem solving research as reviewed earlier (see also Chuderski, 2014). The tests designed to measure cognitive capacities—such as working memory—and the problem solving tasks typically involve little or no interactivity with physical problems. Thus, the commitment to methodological individualism is implicitly reinforced rather than challenged. The substantial improvement in problem solving performance in the high interactivity environment observed in this and other experiments (e.g., Vallée-Tourangeau, Abadie, & Vallée-Tourangeau, 2015; Vallée-Tourangeau et al., 2016) suggests that researchers should be mindful of the importance of interacting with a physical model when solving a problem.

Acknowledgements

I would like to thank Juan Aracena and Paige Edwards for recruiting and running the participants, as well as Emma Henderson, Gaëlle Vallée-Tourangeau and Robert Weisberg for thoughtful comments on a previous version of this manuscript.

References

Chein, J. M., & Weisberg, R. W. (2014). Working memory and insight in verbal problems: Analysis of compound remote associates. *Memory & Cognition, 42*, 67-83.

Chein, J. M., Weisberg, R. W., Streeter, N. L., & Kwok, S. (2010). Working memory and insight in the nine-dot problem. *Memory and Cognition, 38*, 883-892.

Chuderski, A. (2014). How well can storage capacity, executive control, and fluid reasoning explain insight problem solving. *Intelligence, 46*,258-270.

DeCaro, M. S., & Beilock, S. L. (2010). The benefits and perils of attentional control. In B. Bruya (Ed.), *Effortless attention: A new perspective in the cognitive science of attention and action* (pp. 51-73). Cambridge, MA: MIT Press.

Fleck, J. I., & Weisberg, R. W. (2013). Insight versus analysis: Evidence for diverse methods in problem solving. *Journal of Cognitive Psychology, 25*, 436-463.

Gilhooly, K. J., & Fioratou, E. (2009). Executive functions in insight versus non-insight problem solving: An individual differences approach. *Thinking and Reasoning, 15,* 355-376.

Hagger, M. S., Chatzisarantis, N. L., Alberts, H., Anggono, C. O., Batailler, C., Birt, A., & Zwienenberg, M. (2016). A multi-lab pre-registered replication of the ego-depletion effect. *Perspectives on Psychological Science, 11*, 546-573.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Science, 16*, 174-180.

Hutchins, E. (2010). Cognitive ecology. *Topics in Cognitive Science, 2,* 705-715.

Kirsh, D. (1995). Complementary strategies: Why we use our hands when we think. In J. M. Moore & J. L. Lehman (Eds.), *Proceedings of the Seventeenth Annual Conference of the Cognitive Science Society* (pp. 212-217). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Lavric, A., Forstmeier, S., & Rippon, G. (2000). Differences in working memory involvement in analytical and creative tasks: An ERP study. *NeuroReport, 11,* 1613-1618.

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology: General, 136*, 241-255.

Stanovich, K. E., & West, R. F. (1998). Individual differences in rational thought. *Journal of Experimental Psychology: General, 127,* 161-188.

Vallée-Tourangeau, F. (2014). Insight, materiality and interactivity. *Pragmatics & Cognition, 22,* 27-44.

Vallée-Tourangeau, F., Sirota, M., & Vallée-Tourangeau, G. (2016). Interactivity mitigates the impact of working memory depletion on mental arithmetic performance. *Cognitive Research: Principles and Implications, 1,* 26.

Vallée-Tourangeau, F., Steffensen, S. V., Vallée-Tourangeau, G., & Makri, A. (2015). Insight and cognitive ecosystems. In D. C. Noelle, R. Dale, A. S. Warlaumont, J. Yoshimi, T. Matlock, C. D. Jennings, & P. P. Maglio (Eds.), *Proceedings of the Thirty-seventh Annual Conference of the Cognitive Science Society* (pp. 2457-2462). Austin, TX: Cognitive Science Society.

Vallée-Tourangeau, F., Steffensen, S. V., Vallée-Tourangeau, G., & Sirota, M. (2016). Insight with hands and things. *Acta Psychologica, 170*, 195-205.

Vallée-Tourangeau, G., & Vallée-Tourangeau, F. (2017). Cognition beyond the classical information processing model: Cognitive interactivity and the Systemic Thinking Model (SysTM). In S. J. Cowley, & F. Vallée-Tourangeau (Eds.), *Cognition beyond the brain: Interactivity, cognition and human artifice* (2nd Edition, pp. 133-154). Dordrecht: Springer.

Vallée-Tourangeau, G., Abadie, M., & Vallée-Tourangeau, F. (2015). Interactivity fosters Bayesian reasoning without instruction. *Journal of Experimental Psychology: General, 144,* 581-603.

Weisberg, R. W. (1995). Prolegomena to theories of insight in problem solving: A taxonomy of problems. In R. J. Sternberg & J. E. Davidson (Eds.), *The Nature of Insight* (pp. 157-196). Cambridge MA: MIT Press.

Weisberg, R.W. (2015). Toward an integrated theory of insight in problem solving. *Thinking & Reasoning, 22,* 5–39.

Weller, A., Villejoubert, G., Vallée-Tourangeau, F. (2011). Interactive insight problem solving. *Thinking & Reasoning, 17,* 429-439.

Wiley, J., & Jarosz, A. F. (2012). Working memory capacity, attentional focus, and problem solving. *Current Directions in Psychological Science, 21*, 258-262.