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The Effects of Informational Complexity and Working Memory on Problem-Solving Efficiency

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This study investigated the influence of informational complexity and working memory capacity on problem-solving efficiency. We examined two predictions of the *situational efficiency hypothesis,* which states that the efficiency of problem solving varies as a function of situational constraints. One prediction is that informational complexity affects problem-solving efficiency. A second prediction is that working memory capacity affects problem-solving efficiency. Students completed a working memory task and solved abstract and concrete syllogisms. Participants solved abstract syllogisms more accurately than concrete syllogisms and spent more time solving abstract syllogisms. Thus participants demonstrated greater problem-solving efficiency when solving concrete syllogisms. Results indicate that there is a trade-off between problem-solving accuracy and problem-solving time when information differs with respect to informational complexity, a phenomenon we refer to as the *efficiency paradox*. Working memory capacity did not affect accuracy or efficiency. The results support the conclusion that problem-solving efficiency is situational and a function of the complexity of information. Educational implications and directions for future research are suggested.

Key words: efficiency, problem solving, working memory

One method teachers use to reach educational goals is to involve students in problem solving (Foshay & Kirkley, 2003). Problem solving is important as it promotes higher-order thinking and accelerates the transfer of knowledge to novel situations (Mayer, 2008). Models of problem solving (Bransford & Stein, 1984; Mayer, 2008; Newell & Simon, 1972; Polya, 1957) involve a defined cognitive sequence requiring the student to represent the problem, search for a solution, and then implement the solution. However, problem solving tasks can be mentally demanding and time consuming, particularly as students develop problem solving skills.

Furthermore, classroom settings do not offer the luxury of unlimited instructional time. Frequently teachers are faced with the dilemma of providing instructional tasks that promote higher-order thinking within rigid time constraints. As a result, students are asked to complete demanding problem solving tasks in limited time frames (Slavin, 2006). This practice may result in cognitive overload and inefficient or ineffective use of mental resources (Mayer & Moreno, 2003). Thus, limitations in instructional time necessitate the need to understand how the complexity of problem solving tasks affects problem-solving accuracy and

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efficiency.

Two factors that affect problem solving are the complexity of to-be-learned information (Mayer & Moreno, 2003; Pas, Renkl, & Sweller, 2003; Sweller, 1994) and characteristics of the learner, such as working memory capacity (Baddeley, 1998; Baddeley & Logie, 1999; Engle, Tuholski, Laughlin, & Conway, 1999). Working memory is the limited capacity ability to collectively organize, store, and process information as activated memory elements (Engle et al., 1999). Problem-solving tasks require that individuals use working memory to coordinate relationships between and among various pieces of information (Fleck, 2008). The complexity of to-be-learned information and working memory capacity (WMC) may affect problem-solving efficiency. Therefore, in the present study, we investigated the effects of informational complexity and WMC on problem-solving efficiency.

Problem-solving efficiency is the number of problems that are solved correctly relative to the amount of time used to solve the problems (Mory, 1992). For example, solving six problems correctly in two minutes would result in a quotient of 3 (i.e., 6/2). A higher quotient is equated with greater efficiency (e.g., 8/2 = 4) and a lower quotient is equated with lower efficiency (e.g., 4/2 = 2). We used syllogisms as a means to measure problem solving efficiency. A syllogism is a deductive scheme of a formal argument consisting of a major and a minor premise, and a conclusion (Copeland, 2006).

Participants made timed judgments about the validity of concrete (less complex) and abstract (more complex) syllogisms. Syllogisms were chosen for three reasons. First, verifying the validity of a syllogism is a problem-solving task that involves deductive reasoning (Quayle & Ball, 2000), a type of reasoning involved in many problem-solving tasks. Second, verifying the validity of syllogisms that differ with respect to abstractness places different processing demands on working memory resources and thus is likely to influence problem solving efficiency (Copeland & Radvansky, 2004; Johnson-Laird, 1999). Lastly, as syllogisms use deductive reasoning and students have little training in this area (Leighton, 2006) the role of background knowledge in the problem-solving process is low.

The complexity of to-be-learned information affects performance on problem-solving tasks (Anderson, 1987; Bruning, Schraw, Norby, & Ronning, 2004). Previous research indicates that including abstract versus concrete referents in a syllogism increases the informational complexity of the syllogism (Bucciarelli & Johnson-Laird, 1999; Johnson-Laird, 1983). Abstractness varies from low to high. For example, the following syllogism problem involves concrete referents and is less abstract:

All firefighters are brave.
Some firefighters are heroes.
Therefore: some heroes are brave.

Conversely, the next syllogism problem is more abstract because it lacks concrete referents:

Few X are Y.
All Z are X.
Therefore: Few Z are X.

To solve a syllogism, the learner must understand the deductive scheme (i.e., major premise, minor premise, and conclusion) and determine whether the conclusion is valid. To illustrate, to solve the firefighter syllogism above, you must reason that since all firefighters are brave (i.e., the major premise), and a subset of firefighters are heroes (i.e., the minor premise), one logical conclusion is some heroes are in fact brave (i.e., conclusion) whereas other heroes are not brave. As the information in the deductive scheme becomes more abstract, it becomes more difficult to solve the syllogism because the problem-solver is unable to use relevant world knowledge about familiar objects. These assumptions are consistent with the mental models approach of syllogistic reasoning (Johnson-Laird & Byrne, 1991).

Abstract syllogisms have the additional requirement of converting abstract representations into a more meaningful mental concrete representation. Since WMC is limited, more resources are used for mental representation, leaving fewer resources available for inference generation (Quayle & Ball, 2000). As a result, there is an increase in the probability of error and an increase in the time required to validate the syllogism (Byrne, Johnson-Laird, & Tabossi, 1989; Schaeken, De Vooght, Vandierendonck, & d'Ydewalle, 2000; Vandierendonck, De Vooght, Desimpelaere, & Kierckx, 2000). Thus, syllogisms with less complexity (e.g., concrete syllogisms) impose fewer processing demands than syllogisms of greater complexity (e.g., abstract syllogisms).

Individuals with higher levels of WMC perform better on problem-solving tasks (Copeland & Radvansky, 2004; Daneman & Carpenter, 1980; Johnson-Laird, 1983; Mayer, 2001). Similarly, working memory has been linked to effectiveness on complex language tasks (Haarmann, Davelaar, & Usher, 2003), the amount of cognitive resources expended on a task (Linderholm & van den Broek, 2002), the use of problem solving strategies (Bjorklund & Schneider, 1996) and problem-solving success (Passolunghi & Siegel, 2001). Additionally, WMC is positively correlated with speed of processing (Bjorklund, 2005). Collectively, these factors are potentially instrumental in an individual's ability to process information efficiently.

There has been limited research on how informational complexity and WMC affect problem-solving *efficiency*. Efficiency is important as many classroom situations have rigid time constraints. In the present study, we investigated the effects of informational complexity (i.e., syllogism problems ranging in abstractness) and WMC (i.e., an auditory letter recoding task) on problem-solving efficiency. We believe as the complexity (e.g., abstractness) of a problem increases, the demands placed on working memory will increase because problems become more complex. Problems with greater complexity should be more difficult to solve and should take longer to solve, and those individuals with greater WMC should be able to solve the problems with greater efficiency than those with less WMC. Thus, problem-solving efficiency is situational as both the complexity of the problem and processing capacity of the problem solver affect efficiency.

The Present Study

The purpose of the present study was to examine how informational complexity and WMC affect problem-solving accuracy and efficiency. Informational complexity was manipulated by varying the abstractness (low vs. high) of syllogisms. Each participant read and determined the validity of 15 true or false concrete syllogisms (e.g., All dogs are canines. All canines are mammals. Therefore: some dogs are mammals) and 15 true or false abstract syllogisms (Some L's are K's. Some K's are P's. Therefore: all L's are P's.).

According to the *situational efficiency hypothesis*, problem-solving efficiency (i.e., the ratio of problems solved correctly to the amount of time needed to solve them) varies as a function of situational constraints such as informational complexity and WMC. We examined two predictions of the situational efficiency hypothesis. The first prediction is that informational complexity affects problem-solving efficiency. If the first prediction is supported, problem-solving efficiency should decrease as informational complexity increases. Problem-solving efficiency should decrease as informational complexity increases because: a) participants solve fewer problems correctly (lower accuracy); b) participants spend more time solving the problems (greater amount of time); or c) a combination of lower accuracy and greater amount of time spent solving the problems. Previous research indicates problem complexity is related to problem-solving time (Campbell & Xue, 2001). A second prediction is that WMC affects problem-solving efficiency. Individuals with greater WMC should be able to solve problems faster than individuals with lower WMC. Since working memory resources are limited (Baddeley, 1998; Baddeley & Logie, 1999) the performance of participants with lower WMC should be impeded as a result of reduced capacity. Three groups were created based on WMC, which was measured by performance on an alphabet-recoding task. Groups were trichotomized, based upon the total number of letters correctly recoded in alphabetical order. The task was a replication of the ordered letters task used by Benton, Kraft, Glover and Plake (1984). With respect to the first assumption, we predicted greater informational complexity would decrease problem-solving efficiency because individuals would spend more time on difficult materials. With respect to the second assumption, we predicted that higher WMC would increase efficiency because individuals can process more information at any given point in time.

Testing the situational efficiency hypothesis is important for both theoretical and practical reasons. From a theoretical perspective, this study will allow researchers to understand the complex relationship between characteristics of instructional materials (e.g., informational complexity) and learner characteristics (e.g., WMC). For instance, when informational complexity is low and working memory resources are high, problem-solving efficiency should be maximized. When informational complexity is high and working memory resources are low, efficiency should be minimized. These predictions are consistent with previous research that has shown decreasing the difficulty of a task can increase learning efficiency (Mayer & Moreno, 2003; Paas et al., 2003; Sweller, 1994).

From an applied perspective, the present research enables us to examine the relative efficiency of problem solving under a variety of conditions. For example, it may be the case that problem-solving efficiency is lower for more complex information, yet students may learn the information better because they must engage in more sustained or deeper processing of the to-be-learned content. Indeed, more difficult problems could lead to an *efficiency paradox* in which individuals perform better, but take longer to do so. Easier problems may be solved more quickly, but may be less engaging to students and result in lower levels of problem-solving performance. Results of this research will provide insight into how characteristics of instructional materials and learner characteristics affect problem-solving efficiency.

Method

Participants. The study involved undergraduate students from a large university in the Southwestern United States (N=43) (13=Males, 30=Females) with a mean grade point average of 3.40 who volunteered as partial fulfillment of a class requirement. A 3 (Level of working memory: high, medium, low) X 2 (type of syllogism: concrete, abstract) mixed model analysis of variance (ANOVA) was conducted. The working memory variable was a between-subjects factor, whereas the type of syllogism variable was a within-subjects factor.

Materials. For the working memory task, individuals listened to a series of letter sequences (i.e., 15) consisting of four to six letters each that were played via audiotape. The letters were presented out of alphabetical sequence. Participants were asked to maintain the list of letters in memory, and when prompted, to write the letters in correct alphabetical order (e.g., C, T, X, B → B, C, T, X) on the answer sheet. A letter-recoding task primarily engages the phonological processing portion of working memory and to a lesser extent engages the central executive, which is recognized as coordinating attentional control (Cowan, 2005). The phonological loop has been implicated as accounting for significant variability in syllogistic reasoning (Gilhooly, Logie, & Wynn, 1999).

The syllogisms constructed for this study appear in Appendix A. Each item on the instrument was counterbalanced for length and language equivalence. The average number of words in each condition was 14.75 per syllogism. The 15 concrete and 15 abstract syllogisms were presented to students in random order. The randomized order was presented in the same sequence to each student. The first two practice items were not included in the statistical analysis. All items on the instrument were written with grammatically positive emphasis, no negative grammar was used.

Procedure. The first task completed was the working memory task. A 10 second interval was provided for each letter string to be recalled on the letter-recoding task. Upon completion of the 15 items, students returned their completed recoding task worksheet to the researcher. Participants were to recode the letters in exact alphabetical order. Participants received one point for each letter that was written in the correct alphabetical sequence for each letter string.

Next, students completed a demographic survey (i.e., sex and estimated grade-point average on a 4-point scale) and a 32-item syllogism problem-solving task via computer. Students were presented 32 syllogisms that required a "true" or "false" answer. Answering required subjects to judge the validity of a possible conclusion as valid or not, a syllogism solution method prescribed by Gilhooly (1982). The first two items of the 32-item instrument were designated as practice syllogisms designed to familiarize each student with the process and content of solving syllogisms. Each syllogism was presented individually, one appearing on the computer screen at a time. Upon designating each answer, students would click "continue". Upon clicking, "continue" the next syllogism was presented and the computer recorded the completion time for the previous syllogism and their response. Students were informed that they would not be able to view text on previous screens once they advanced to the next screen. Before beginning, the researcher indicated that participants should read at their normal rate and click "continue" when ready to read the next syllogism. Students were aware that both accuracy and problem-solving time was being recorded. There were no completion time limits during any portion of the procedure.

Performance on the working memory task was used to create three WMC groups (high (top third), middle (median third) or a low WMC group (lowest third). Trichotomizing groups is consistent with the extreme scoring approach advocated by Conway, Kane, Bunting, Hambrick, Wilhelm, and Engle (2005), which recommends an appropriation of participants into three or four groups, when feasible. Blocks were segmented based upon scoring in the lower third, middle third or upper third of respondents on the letter-recoding task.

We examined the effect of informational complexity and WMC on three separate dependent variables. The first was problem-solving accuracy, or the number of correct responses on the syllogism task. The second was problem-solving time, or the aggregate time in milliseconds used to complete all abstract or all concrete syllogisms. The third was problem-solving efficiency, or number of correct responses divided by the summed response time for abstract and concrete syllogisms.

Results

There were no interactions between working memory and type of syllogism on the three outcome measures, nor were there main effects for working memory. Therefore, only main effects in the type of syllogism variable are reported. A test of the assumption of homogeneity of variances among the repeated measures was met. Means and standard deviations of all dependent measures are presented by condition in Tables 1-3.

Scores on the letter-recoding task ranged from 1-14, with a mean of 8.43 and a standard deviation of 3.49.

Problem-solving accuracy data were analyzed using a 3 (Level of working memory: high, medium, low) X 2 (type of syllogism: concrete, abstract) mixed model ANOVA. The working memory variable was a between-subjects factor, whereas the type of syllogism variable was a within-subjects factor.

The main effect for the type of syllogism variable was not statistically significant but it was in the predicted direction, F (1, 40) = 3.53, MSE = 1.89, $p < .07$, indicating that performance was better when participants solved abstract syllogisms. Abstract syllogisms (M = 12.14, SD = 1.67) were solved with greater accuracy than concrete syllogisms (M = 11.60, SD = 1.67). Participants verified the accuracy of the abstract syllogisms with greater accuracy as compared to the concrete syllogisms. There was a medium-sized effect for type of syllogism (η^2 = .081), based on the guidelines proposed by Olejnik and Algina (2000) in which values of .01, .06, and .14 indicate small, medium, and large effect sizes when measured by eta squared.

Problem-solving time data were analyzed using a 3 (Level of working memory: high, medium, low) X 2 (type of syllogism: concrete, abstract) mixed model ANOVA. The working memory variable was a between-subjects factor, whereas the type of syllogism variable was a within-subjects factor. There was a significant main effect for the type of syllogism on problem- solving time, F (1, 40) = 40.941**,** MSE = 2.09**,** $p < .001$. Problem-solving time for abstract syllogisms was longer (M=14.25 seconds, SD = 3.90) compared to concrete syllogisms (M=12.25 seconds, SD = 3.29). Participants spent more time verifying the accuracy of abstract syllogisms as compared to concrete syllogisms.

Partial η^2 was calculated for both concrete and abstract syllogisms to determine what proportion of the problem-solving time can be attributed to type of syllogism. Partial η^2 = .506, 50% of the variance associated with problem-solving time is a result of syllogism type.

Problem-solving efficiency was analyzed using a 3 (Level of working memory: high, medium, low) X 2 (type of syllogism: concrete, abstract) mixed model ANOVA. The working memory variable was a between-subjects factor, whereas the type of syllogism variable was a within-subjects factor. There was a significant main effect for the type of syllogism on problem-solving efficiency, F (1, 40) = 11.259, MSE = 2.50 $p < .005$. Individuals solved concrete syllogisms more efficiently (M = 1.01, SD = .32) than abstract syllogisms (M =. 90, SD = .22). As the difficulty of the problem decreased, the problem-solving time decreased, resulting in higher problem-solving efficiency for concrete syllogisms.

Partial η^2 was calculated for both concrete and abstract syllogisms to determine what proportion of the problem-solving efficiency was attributed to type of syllogism. Partial η^2 = .22. In total 22% of the variance in problem-

Table 1
Means and Standard Deviations for Performance Measure by Group

	Concrete syllogisms		Abstract syllogisms		Participants
	Mean	SD	Mean	SD	
WMC					
High	11.38	1.39	12.46	1.45	13
Medium	11.87	1.55	12.40	1.72	15
Low	11.53	2.06	11.60	1.76	15
Total	11.60	1.67	12.13	1.67	43

Table 2
Means and Standard Deviations for Time Measure (in milliseconds) by Group

	Concrete syllogisms		Abstract syllogisms		Participants
	Mean	SD	Mean	SD	
WMC					
High	11.60	2.31	13.57	2.91	13
Medium	12.40	3,23	14.70	4.16	15
Low	12.67	4.10	14.39	4.52	15
Total	12.25	3.29	14.25	3.90	43

Table 3
Means and Standard Deviations for Efficiency Measure by Group

	Concrete syllogisms		Abstract syllogisms		Participants
	Mean	SD	Mean	SD	
WMC					
High	1.11	.232	.95	.210	13
Medium	1.03	.351	.88	.188	15
Low	1.01	.385	.87	.268	15
Total	1.02	.325	.90	.222	43

solving efficiency is a result of type of syllogism.

Discussion

The purpose of the present study was to examine whether informational complexity and WMC affected problem-solving efficiency. The situational efficiency hypothesis stated that problem-solving efficiency is affected by situational constraints such as informational complexity and WMC. The first prediction was supported (i.e., informational complexity affected problem-solving efficiency), whereas the second prediction regarding WMC was not supported.

The first prediction was supported because problem-solving efficiency was affected by informational complexity in two ways. First, informational complexity affected problem-solving accuracy. Abstract syllogisms were solved with greater accuracy than concrete syllogisms. Second, informational complexity affected problem-solving time. Participants spent more time solving abstract syllogisms than concrete syllogisms. Thus, informational complexity affected problem-solving accuracy and problem-solving time, the two components of problem-solving efficiency.

Participants spent more time solving abstract syllogisms and demonstrated greater problem-solving accuracy on abstract syllogisms. This difference may be due in part to the additional problem-solving time allocated to abstract syllogisms. Learners may allocate more mental resources towards information with greater complexity in an effort to identify the correct solution.

Comparison of efficiency scores revealed that concrete syllogisms were solved in less time and more efficiently than abstract syllogisms. Thus, the number of problems that were solved correctly relative to the amount of time used to solve the problems was greater for concrete, than abstract syllogisms. This difference may reflect the fact that syllogisms with less informational complexity require comparatively less effort to solve, suggesting that reducing informational complexity increases problem-solving efficiency.

However, an increase in complexity led to greater problem-solving accuracy. Learners invested more time solving abstract syllogisms and solved a greater proportion of the problems accurately. When solving syllogisms, participants must evaluate the initial two statements of a syllogism (the major and minor premises), and subsequently determining if the third statement (the conclusion) is valid. Validation is determined independent of the truth of the premise. Invalidity of a syllogism is less clear when the terms are abstract (Gilhooly, 1982), thus participants must work harder and use greater mental effort to evaluate abstract conclusions. Problem solvers who invested more time, persisted longer, and worked harder achieved superior problem-solving performance at the expense of reduced efficiency.

The WMC data did not support the situational efficiency hypothesis because WMC did not affect problem-solving accuracy or problem-solving time. Two possible explanations may explain the lack WMC findings. One explanation is the mental effort imposed by the syllogisms did not exceed available WMC. For instance, in research examining WMC and text processing, differences between low and high working memory readers are found only when the demands of the reading task exceed available resources (Linderholm & Van de Broek, 2002; Just & Carpenter, 1992). Additionally, learners with inefficient skills may use compensatory strategies resulting in only marginal performance deficits (Walczyk & Griffith-Ross, 2006).

A second explanation is that letter recoding may measure only the short-term portion of working memory and does not adequately parallel the cognitive process used in solving syllogisms. Solving syllogisms requires the individual to understand the logical structure of the problem, interpret meaning, and conceptually apply logic to arrive at solutions (Copeland & Radvansky, 2004). Baddeley's (1998) multi-component working memory model describes functioning as consisting of two subsystems: (a) an auditory component, the phonological loop, which is a speech-based mechanism; and (b) a visual component, the visuospatial sketchpad or a mental imagery device. Attentional resources and temporary storage of information of both systems is mediated by a coordinating central executive function. Additional unique variance resulting in a WMC finding may have been accounted for by central executive functioning (Swanson, 2006), not activated when solving syllogisms.

The results from the present study were inconsistent with the work of Quayle and Ball (2000) who found that working memory affects syllogistic reasoning. Their interpretation of their findings was based upon the assumption that belief bias, whereby learner's real world knowledge biases responses, is an influential factor in solving syllogisms. Perhaps the difference in the type of syllogism between this study and those of Quayle and Ball (2000) are responsible for differing results. The syllogisms used by Quayle and Ball were contextualized, which allow a participant's to use world knowledge, an influential factor in solving syllogisms, to bias responses. In the present study syllogisms were contextually neutral and apparently did not cause any discrepancies between student beliefs and the ability to problem solve. Additionally, Quayle and Bell used a different working memory task.

Our findings indicated that there is a tradeoff between informational complexity and efficiency. Tasks that demand more resources due to problem complexity may promote deeper processing that increases problem-solving accuracy, while simultaneously decreasing efficiency. Thus, if instructional objectives are limited by time constraints, an easier task may be advantageous. In situations where time constraints on tasks are less relevant, it appears greater problem complexity may support superior performance.

Manipulating the complexity of information has been found to enhance performance for less knowledgeable learners (Paas et al., 2003; Pollock, Chandler, & Sweller, 2002). Optimally designed instruction frees available resources enhancing performance, but sometimes may be at the expense of efficiency. The results from the current study support the conclusion that learning efficiency is situational and a function of informational complexity, and available time. McNamara, Kintsch, Butler, Songer, and Kintsch (1996) indicated, "What appears to be an optimal learning tool at one level can be detrimental in another" (p. 34).

Our findings demonstrate that the nature of instructional materials reveals an interesting paradox: complex information may be learned better even though it takes more time to learn it. In the present study, participants demonstrated greater problem-solving accuracy with abstract syllogisms, yet solved concrete syllogisms with greater efficiency. We conclude that it is not always optimal to reduce complexity of materials unless efficiency of learning is of primary interest. Reducing complexity may reduce learning. Educators should consider this *efficiency paradox* described above when making instructional decisions.

Educational Implications, Limitations, and Possibilities for Future Research

There are at least two educational implications based on the present study. First, instructors should assess the pace of presentation based on the complexity of instructional content and the goals of the instructional sequence. Our results support the conclusion that information with less complexity can be learned more efficiently than information with more complexity. This suggests that when strict time constraints are imposed, information with less complexity can be learned with greater efficiency than information with more complexity. For example, in a primary school setting, there are strict time constraints on the amount to time allowable for any particular subject. It may be beneficial for the teacher to present less complex information or portions of difficult concepts during class time. In turn, more complex information could be assigned as homework. This will allow the teacher to provide adequate span during class time and permit students to develop greater depth outside of the classroom so that the teacher has the opportunity to provide adequate span for multiple topics or content areas.

Second, the complexity of material may affect learning outcomes. When learning outcomes require verbatim recall or paraphrasing, a less complicated, concrete methodology may be preferred. Conversely, if the nature of the learning objective is application, analysis, synthesis or evaluation, abstract materials, requiring greater cogitation may lead to better performance. Therefore, the degree of abstraction is a factor that should be considered when establishing instructional objectives. In summary, the problem-solving efficiency is a function of time and accuracy, which are both influenced by situational constraints, such as the complexity of the to-be-solved problem.

Future research should investigate other variables that influence problem solving and efficiency. It is important to know if changes in materials will free up available resources and enhance the role of individual variables such as working memory. It is possible that in the current study, syllogisms did not exceed the threshold of working memory capacity and therefore did not influence problem-solving efficiency (Linderholm & Van de Broek, 2002; Just & Carpenter, 1992). We used syllogisms as an outcome measure due to the deductive reasoning involved and the clear distinction between levels of complexity that syllogisms afford. We encourage others to replicate these results using other tasks that involve working memory resources such as conceptual tasks and mathematics problems (Ricks, Turley-Ames, & Wiley, 2007). Different outcome measures may yield different results. Creating a greater dichotomy in informational complexity may indicate whether the individual differences of problem solvers, or the complexity of materials are more instrumental in influencing efficiency.

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Appendix A
List of syllogisms

1. Practice: Some students eat fruit. Eating fruit is healthy. Therefore: all students eat healthy.
2. Practice: Some X are Y. All Y are Z. Therefore: some X are Z.
3. Every bear is fuzzy. Some animals are bald. Therefore: some bears are bald.
4. All whales live in water. All fish live in water too. Therefore: all whales live with fish.
5. X is bigger than Y. Y is bigger than Z. Therefore: X is bigger than Z.
6. Tom wears blue boots. Tom is a man. Therefore: all men wear blue boots.
7. The wealthy are happy. The wicked are wealthy. Therefore: the wicked are happy.
8. All X are Y. Some Y are Z. Therefore: all X are Z.
9. Some dogs like cats. All dogs are mammals. Therefore: some mammals like cats.
10. Few X are Y. All Z are X. Therefore: Few Z are X.
11. Some men are beekeepers. All beekeepers are bankers. Therefore: all men are bankers.
12. All psychologists are human. All humans are mortal. Therefore: all mortals are psychologists.
13. All X's are yellow. All males are Y's. Therefore: all female X's are red.
14. All firefighters are brave. Some firefighters are heroes. Therefore: some heroes are brave.
15. Some L's are K's. Some K's are P's. Therefore: all L's are P's.
16. All dogs are canines. All canines are mammals. Therefore: some dogs are mammals.
17. Some fruits contain vitamin C. Mary eats some fruits. Therefore: Mary consumes some vitamin C.
18. Some X are Y. All Y are Z. Therefore: Some X are Z.
19. X is smaller than Y. Y is bigger than Z. Therefore: X is bigger than Z.
20. Some B's are yellow. Some B has spots. Therefore: some B's are yellow.
21. All D's beat throws. Some P's beat throws. Therefore: some D's beat P's.
22. Some B's are black. Every B is a mammal. Therefore: all B's are black.
23. Steve hates to socialize. Anyone that socializes is outgoing. Therefore: Steve is outgoing.
24. Some L's are K's. All K's are P's. Therefore: some L's are P's.
25. All dictators are mean and nasty. Fred is a tourist. Therefore: Fred is fair and just.
26. B is first when A is last. A is first. Therefore: B beat A.
27. Philosophers are all human. Some humans are fallible. Therefore: some philosophers are fallible.
28. Mary eats pears daily. Some pears are spoiled. Therefore: Mary eats spoiled pears.
29. Some boys are angry. All red heads are friendly. Therefore: some red head boys are angry.
30. It rains when the sun is behind the clouds. It is raining. Therefore: it is cloudy.
31. X barks only in cold weather. X is quiet. Therefore: it is warm.
32. Q's are rich and happy. Some X's are rich. Therefore: some X's are Q's.