Cognitive Load Factors in Formatting Assessment Items

Slava Kalyuga and Chee Ha Lee
The University of New South Wales

Introduction

Improving testing instruments using knowledge of cognitive processes and structures involved in learning and competent performance, and applying cognitive models to the assessment design process are important trends in the educational assessment field (see Pellegrino, Chudowsky, & Glaser, 2001, for an overview). However, this knowledge has not been yet used broadly in educational practice outside academic institutions and experimental studies. Most practitioners involved in the design and development of various assessment instruments are not well familiar with the basic architecture and limitations of our cognitive system that influence students' test performance and actual item difficulty levels.

Human cognitive capacity is restricted: we can process only a very limited amount of information at any one time. One of the major components of our cognitive architecture - working memory - is very limited in capacity and duration when processing unfamiliar information. According to Miller (1956), it can contain no more than about seven units of information. When many elements of information are processed simultaneously, working memory may become overloaded, thus inhibiting problem solving process and making the task difficult. Working memory load is usually referred to as cognitive load.

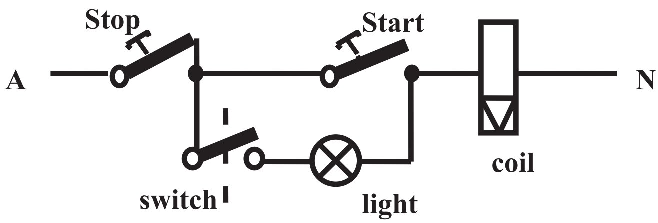
Answering any test items would obviously involve cognitive load that is required by the nature of the task (e.g., performing operations required to solve a problem). Such relevant and inevitable load is usually called intrinsic cognitive load. However, for any type of test, the way items are formatted and presented to students could also influence the level of cognitive load involved in solution processes. Sometimes, the test items are formatted in a way that may impose unnecessary load that is not actually required by the solution procedure. This unnecessary additional load is sometimes referred to as extraneous cognitive load. This paper suggests some methods of evaluating extraneous cognitive load caused by item design and presentation formats and possible means of reducing such load.

Evaluating Extraneous Cognitive Load in Test Items

Some test items may be difficult for students to comprehend because they ignore limitations of the human cognitive processing system and impose a heavy unnecessary cognitive load on students because of their design characteristics rather than internal features of the tasks. Spending limited cognitive resources on irrelevant activities (e.g., integration of information separated over distance or time, or processing redundant information) may inhibit comprehension (see Sweller, Ayres, & Kalyuga, 2011; Sweller, van Merriënboer, & Paas, 1998, for an overview of cognitive load theory). Evaluation of such extraneous cognitive load that might be imposed on students has to be a part of the assessment design process.

The way test items are formatted and presented to students could significantly change the level of cognitive effort involved in solution process. There are situations when task statements require significant cognitive resources to be processed. In some of such situations, cognitive load could be reduced by restructuring these statements, for example, by breaking down complex explanations into smaller elements that can be comprehended separately. However, even such smaller explanatory modules may impose significant cognitive load. For example, diagrams in geometry or physics are usually accompanied by brief textual statements and neither text nor diagrams are intelligible in isolation. Such tasks could be understood only by mentally integrating corresponding statements in the text and on the diagram which requires additional cognitive efforts. These tasks require students to split their attention between diagram and text by searching and matching elements from the text to the appropriate entities on the diagram.

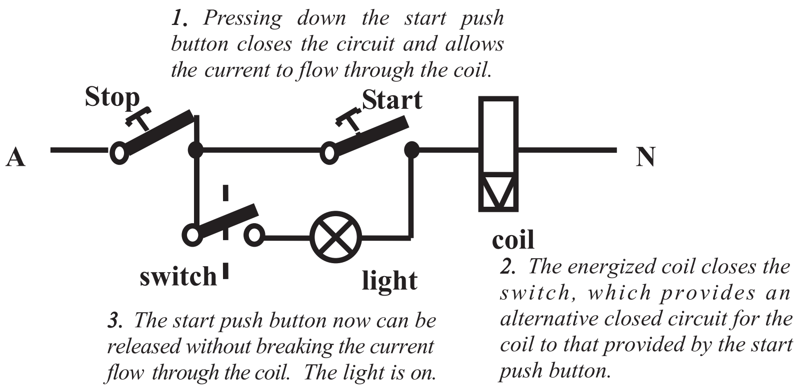
The search and match process could be reduced if textual statements are located near their matching entities on the diagram. Physically integrating textual information with the related diagram may improve task comprehension. For example, the following explanation of the operation of a wiring diagram included in the task statement may cause an extraneous cognitive load due to the need to mentally integrate separated elements of information:



Pressing down the start push button closes the circuit and allows the current to flow through the coil. The energized coil closes the switch, which provides an alternative closed circuit for the coil to that provided by the start push button. The start push button now can be released without breaking the current flow through the coil. The light is on.

How can the light be turned off?

The same explanations could be physically embedded into the diagram to reduce unnecessary search processes:

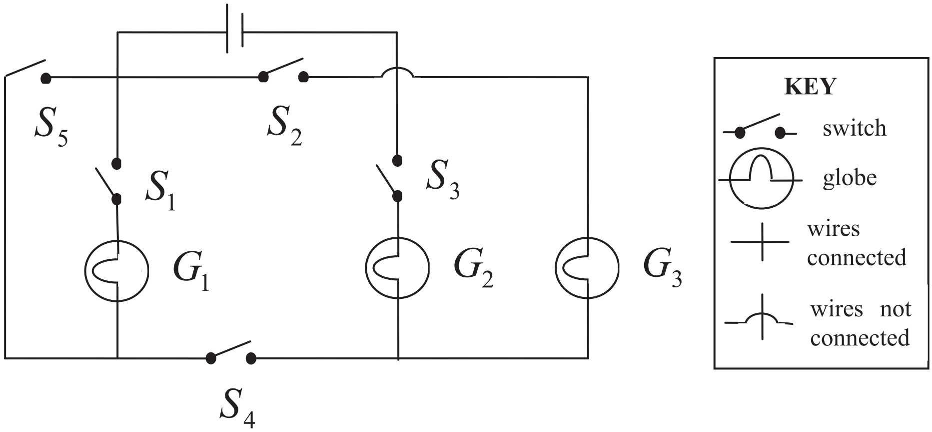


How can the light be turned off?

Physical integration of related sources of information (statements, diagrams, equations, etc.) decreases extraneous cognitive load by reducing search processes involved with conventional split source task formats. In general, the split-attention effect occurs when learners are required to split their attention unnecessarily between multiple sources of information. Sweller, Chandler, Tierney, and Cooper (1990) observed the effect using materials from coordinate geometry and computer programming. Chandler and Sweller (1991) demonstrated the effect using biology, electrical engineering, and computer programming materials. Mayer and his colleagues found that materials consisting of separate text and unlabelled diagrams were less effective than diagrams that contained labels that clearly connected text and diagram (Mayer, 1989; Mayer & Gallini, 1990). The labeled diagrams could be considered as a kind of physical integration of the diagram and text, as both techniques reduce the need to search. Lee and Kalyuga (2011) also found that a vertical presentation format of Chinese characters, pinyin and English translation was more effective than a horizontal presentation format in learning Chinese characters for novice second language learners. The advantage of the vertical layout was attributed to the reduced split-attention by putting the corresponding pinyin exactly below the matching characters.

The following item illustrates a split-attention situation:

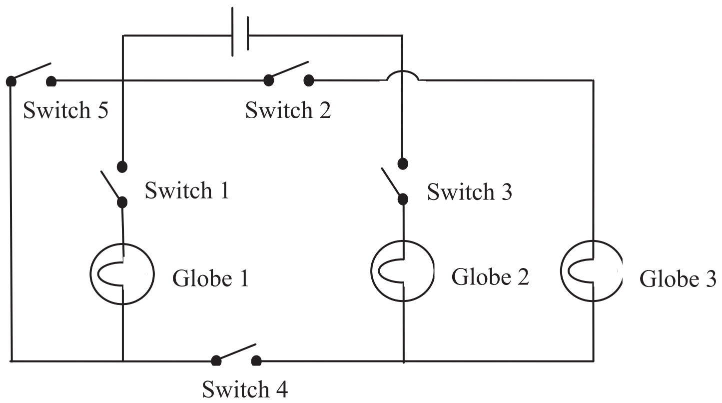
The diagram shows an electric circuit



The student wishes to light G2 and G3 only by c losing the minimum number of switches. Which switches should she close?

With the key table placed separately from the diagram, students may need to split their attention when referring to the table while studying the diagram. The following modified version of this item represents the same task statement with reduced extraneous cognitive load:

The diagram shows an electric circuit



The student wishes to light Globe 2 and Globe 3 only by closing the minimum number of switches. Which switches should she close?

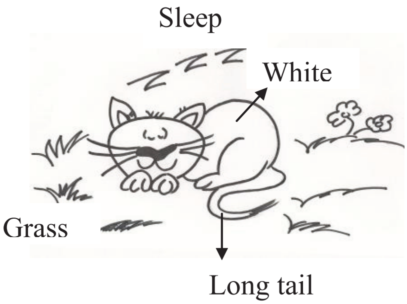
Below is another item that illustrates a split-attention situation in a worked example for an English writing task for primary one English as second language learners.

Look at the example and write five sentences about Michael's pet.

 Hints: Mimi/white/sleep/cute	***Amy's pet*** This is my cat, Mimi. She has a long tail. She is white. She is sleeping on the grass. She is cute.
 Hints: Bobby/black and white/eat/lovely	***Michael's pet*** This is my ______________ ________________________ ________________________ ________________________ ________________________

The hints in the diagrams might cause split-attention in this writing task due to searching and matching the vocabulary items with the relevant parts of the pictures. Extraneous cognitive load could be reduced by putting the descriptions physically closer to the corresponding parts of the picture. Also, the provided sentences were used as guides to complete the task with a suggested sequence of descriptions. Students may need to split attention when searching for the corresponding sentences in their current writing. The location of the hinted words and the provided sentences could be rearranged to reduce extraneous cognitive load (i.e., with the descriptions located next to the relevant parts of the picture and the five example sentences located next to the writing space):

Look at the example and write five sentences about Michael's pet.

<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Amy's pet

This is my cat, Mimi.
She has a long tail.
She is white.
She is sleeping on the grass.
She is cute.</td>
<td>Michael's pet
Hints: Bobby/black and white/eat/lovely

This is my ________________
____
____
____
__________________________</td>
</tr>
</table>

Similar techniques could be used in text-only task statements. If students have to hold a segment of the text in working memory while searching for another segment that is related to the first one and is necessary for its understanding, a split-attention situation may occur. The integrated format may have the related segment placed in brackets next to the original one.

Thus, the split-attention effect may occur in different areas with different types of related sources of information involved. Interestingly, physically embedded textual narratives have been used for many years in comic books for children, thus demonstrating their effectiveness in assisting children to comprehend complex materials (most reading materials are cognitively demanding for children). However, this technique was rarely used in general instructional and assessment materials until its cognitive efficiency had been investigated and appropriate recommendations suggested. A similar situation applies to the redundancy effect that is considered next.

Research generated by cognitive load theory indicates that integrated presentation formats are beneficial if the sources of mutually referring information need to be mentally integrated in order to be understood. However, physical integration of text and diagram may not always be appropriate. Often individual sources of information are self-contained, i.e. provide all of the required information in isolation. The elimination rather than integration of redundant information could be beneficial for comprehension. If the redundant information is integrated physically with essential information, learners have no choice but to process it. This imposes an extraneous cognitive load that may interfere with the learning process. Chandler and Sweller (1991) demonstrated the redundancy effect in the areas of electrical wiring and biology. When text and diagrams did not have to be mentally integrated in order to be understood, physically integrated materials were no more effective than conventional ones. One self-explanatory source of information could be superior to two redundant sources of information in either a conventional, or an integrated format. Using a paper-folding task with primary school students, Bobis, Sweller, and Cooper (1993) demonstrated that diagrams (rather than textual explanations) could be redundant too.

Redundancy effect had been effectively demonstrated on a number of occasions in the past. For example, Lesh, Behr, and Post (1987) found that mathematical word problems become more difficult with additional information in the form of concrete materials: processing these materials may impose an extraneous cognitive load. Holliday (1976) used a flow diagram to present the nitrogen, water, oxygen and carbon dioxide cycles to high school students. One diagram represented the elements in the cycles as small pictures; another showed them as verbal labels. Students viewed either one of the diagrams or one of the diagrams alongside a text that presented the same material, or the text alone. On a multiple-choice verbal test of comprehension, students who studied the diagram only outperformed the other two groups. Students who were presented with text and diagrams performed no better than those who studied just text. The advantages of diagrams disappeared when they were used with text. Under these conditions, the text appeared to be redundant.

The following item provides an example of redundant information presented in a table:

A taxi costs $2.00 to hire plus $1.55 for each of the first 3 km traveled, and $1.45 for each kilometer that follows. A table of charges appears inside the vehicle as shown.

Distance	**travelled**
Less than 1 km	$3.55
More than 1 km but less than 2 km	$5.10
More than 2 km but less than 3 km	$6.65

How much does it cost to travel more than 3 km but less than 4 km?

The following version of this task statement eliminates redundant information but requires essentially the same set of operations:

A taxi costs $2.00 to hire plus $1.55 for each of the first 3 km traveled, and $1.45 for each kilometer that follows. How much does it cost to travel more than 3 km but less than 4 km?

Redundancy effect could also happen for items presenting irrelevant information. The following item provides an example:

Da Da Department Store is having a promotion.

Da Da Department Store

Spend 150 dollars to receive a stamp.

Collect the stamps to redeem the electrical appliances below.

Collect 12 stamps	Collect 18 stamps	Collect 25 stamps

Michael has to spend at least ________ dollars in order to redeem a toaster.

The item requires students to perform a multiplication operation. Unless the item is used to test a student's ability to understand the vocabulary for electrical appliances, the figures and information of the other two appliances are redundant. (The original item was written in Chinese and was used for assessing primary 4 students' mathematics calculation skills. Those students should not have problems with understanding these words written in their first language).

The following word problem version of this task eliminates redundant information and requires only essential calculation operation:

Da Da Department Store is having a promotion. Collect 25 stamps by spending $150 for each stamp at Da Da Department Store and receive a free toaster. How much does Michael need to spend at least in order to receive a free toaster?

Conclusion

In summary, the two most important item design features that may cause extraneous cognitive load are associated with split-attention and redundancy effects. The split-attention effect occurs when presented materials require learners to unnecessary split their attention between multiple sources of information. Physical integration of the elements of information may reduce extraneous cognitive load and enhance comprehension. If individual sources of information are self-contained, the elimination rather than integration of redundant sources of information is beneficial. An additional extraneous cognitive load caused by inappropriate design can inhibit comprehension only when presented material contains many interacting elements of information and, therefore, is characterized by heavy intrinsic cognitive load. In contrast, when information has a low intrinsic cognitive load due to low element interactivity, redesigning the presentation format to reduce extraneous cognitive load might not be as crucial. Both effects should be of concern only when task statements have an intrinsically high level of element interactivity for students. Estimates of element interactivity could be obtained by evaluating the number of elements that need to be processed concurrently.

Acknowledgement

Some example items were taken from Australasian Schools Mathematics Assessment (2004) by Educational Testing Centre, UNSW.

References

Bobis, J., Sweller, J., & Cooper, M. (1993). Cognitive load effects in a primary school geometry task. *Learning and Instruction, 3*, 1-21.

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

Holliday, W. G. (1976). Teaching verbal chains using flow diagrams and texts. *AV Communication Review, 24*, 63-78.

Lee, C. H., & Kalyuga, S. (2011). Effectiveness of different pinyin presentation formats in learning Chinese characters: A cognitive load perspective. *Language Learning, 61*, 1-20.

Lesh, R., Behr, M., & Post, T. (1987). Rational number relations and proportions. In C. Janvier (Ed.). *Problems of representation in the teaching and learning of mathematics*. Hillsdale, NJ: Erlbaum.

Mayer, R. E. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81*, 240-246.

Mayer, R., & Gallini, J. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology, 82,* 715-726.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Pellegrino, J., Chudowsky, N., & Glaser, R., (Eds.). (2001). *Knowing what students know: The science and design of educational assessment.* Washington, DC: National Academy Press.

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

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load and selective attention as factors in the structuring of technical material. *Journal of Experimental Psychology: General, 119*, 176-192.

Sweller, J., van Merriënboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251-296.

Authors' e-mail: Slava Kalyuga s.kalyuga@unsw.edu.au
Chee Ha Lee chee.lee@unsw.edu.au