

THE POSSIBLE INFLUENCE OF SPLIT-ATTENTION EFFECT ON LEARNERS' RESPONSES TO MATHEMATICAL PROBLEM SOLVING TASKS

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ABSTRACT-This paper reports on a quasi-experimental research study conducted involving a convenient sample of 706 Grade 10 mathematics students/learners. All participants displayed poor performance in mathematics problem solving. The study implemented a problem solving instruction⁴ intervention in the experimental group and conventional instruction in the control group. To improve the efficacy of problem solving instruction the researcher generated instructional conditions to test and monitor the split-attention⁵ effect in terms of mathematical problem solving performance. Split-attention may increase the cognitive load, which may impact on problem solving performance. Data were collected through a cognitive load self-reporting questionnaire and semi-structured interviews. The results indicate that meaningful learning and enhancement of problem solving performance is achievable when knowledge of the split-attention effect is utilized to improve instructional design.

Keywords: Cognitive load theory; split attention effect; problem solving performance

1. INTRODUCTION

Learners' problem solving performance in mathematics classrooms is a worldwide concern (Jonassen, 2000). In many instances efforts have been explored to generate effective instruction to elevate learners' problem solving status in mathematics. Performance in mathematics is thought to be largely linked to problem solving ability (Sweller, 1988). Hence problem solving ability is central in addressing learners' performance in mathematics classrooms. This link has been emphasized by several researchers (for examples, see, Baloyi, 2011; Dhlamini, 2016; Dhlamini & Mogari, 2013; Gaigher, 2006; Sepeng, 2011; Sweller, 1988) with Voskoglou (2008) concluding that problem solving is a principle component of mathematics performance. Sweller, Clark and Kirschner (2010) acknowledge that "problem solving is central to mathematics" (p. 1303). The importance of problem solving in any mathematics study cannot be overemphasized. Kilpatrick, Swafford and Findell (2001) explained that in most studies conducted in the domain of mathematics, results have demonstrated that problem solving provides an important context in which learners can learn about numbers and other mathematical topics. Kontra (2001) proposed that "any mathematical problem solving performance is built on a foundation of basic mathematical knowledge" (p. 4). The study that is reported in this paper focused on one of the instructional options suggested by cognitive load to accelerate learners' problem solving performance in Grade 10 mathematics.

Problem solving is a cognitive activity (Dhlamini, 2012). According to Jonassen (2000), problem solving is generally regarded as "the most important cognitive activity in an everyday and professional context" (p. 63). Given this background, it is reasonable to acknowledge that when addressing the notion of learners' problem solving performance it is imperative to recognise the role of cognition. Sweller and Chandler (1991) noted that the final objective of a theory in cognition should be to assist in

⁴. The word *instruction* is used in this context as a reference to teaching and learning activities taking place in mathematics classrooms. In this investigation, learners in Grade 10 mathematics classrooms were studied.

⁵. *Split-attention* is a cognitive phenomenon thought to be experienced when a learner has to mentally integrate two or multiple sources of information to understand the learning material such as a diagram and its explanatory text.

the development of useful instructional design recommendations. Traditionally cognitive load theory (CLT) has focussed on improving the quality of teaching methods for problem solving by suggesting several options to enhance the design of instruction. One such instructional option is paying attention to the split-attention effect when designing problem solving instruction. Split-attention is a cognitive phenomenon thought to be experienced when a learner has to mentally integrate two or multiple sources or representations of information in order to understand the learning material such as a diagram and its explanatory text. Split attention can be best explained against the background of CLT using the notion of *split-attention effect*. The knowledge of the latter may help to improve the effectiveness of instructional design by replacing multiple sources of mathematical information with a single integrated source of information. It is believed that this instructional approach may lower learners' cognitive load and subsequently enhance mathematical problem solving performance.

The study that is reported in this paper was a part of a larger PhD study, which investigated the effect of a context-based problem solving instruction (CBPSI) on the performance of learners who were taking mathematics as a subject in Grade 10 (see, Dhlamini, 2012). The results of the quasi-experiment that investigated the effect of CBPSI are well documented in Dhlamini (2012). The Dhlamini (2012) article explored various instructional options suggested by CLT in an attempt to accelerate participants' problem solving performance in the experimental group (see, also, Dhlamini & Mogari, 2013; Dhlamini, 2016). The aim of this paper is to illuminate only the component of the PhD study that explored the influence of split-attention effect on the participants' problem solving performance. The results of the entire PhD study have been documented in various other publications (see, Dhlamini, 2016, 2012; Dhlamini & Mogari, 2013).

2. BACKGROUND ON THE SPLIT-ATTENTION EFFECT AND LEARNING

Problem solving performance may be established within the broader theoretical framework of cognitive load theory (Dhlamini, 2016). One of several instructional design recommendations derived from cognitive load theory (CLT) suggests the physical integration of separate but mutually referring information sources (such as text and diagrams) when both sources of information are required for understanding complex problem solving material (Ginns, 2006; Van Merriënboer & Sweller, 2010). Tarmizi and Sweller (1988) were the first to demonstrate that in some cases the profitable effects of worked-out example studies on problem solving and schema construction can fail to occur. A *worked-out examples approach* is an instructional device that provides a model for solving a particular type of problems by presenting the solution in a step-by-step fashion (Renkl & Atkinson, 2010). This instructional approach is intended to provide the learner with a sample of an expert's solution, which the learner can study and use as a model for his or her own problem solving steps (Dhlamini, 2015). According to CLT, worked-out examples can play a crucial role in guiding the learning process (Atkinson, Derry, Renkl & Wortham, 2000). However, worked-out examples should be presented in a manner that minimizes the negative effects of cognitive load on problem solving performance.

In their study Tarmiz and Sweller (1988) examined a number of worked-out examples and observed that almost all these examples contained separate sources of information. This means that the diagram and the explanatory text of the problem were not physically integrated. As a result, the learner's attention is split between two sources of information. Sweller (1999) labelled this cognitive phenomenon a *split-attention effect* and further hypothesized that it interfered with learners' acquisition of problem solving schemas representing the basic domain concepts and examples needed for learning through worked examples to take place (Tarmizi & Sweller, 1988). Some of the studies have illuminated the influence of split-attention effect on the learning of crucial cognitive skills such as problem solving. The experiment conducted by Tarmizi and Sweller (1988) on learners assigned participants in one experiment of a multi-experiment study to a conventional problem solving condition (control). Learners in an experimental worked-out examples condition were asked to solve six pairs of problems, which were similar to those handled in the control group (Atkin *et al.*, 2000). Learners in both groups were given a fixed period of time to study their "respective condition-specific

material” (Atkin *et al.*, 2000, p. 187). The results of the experiment supported the hypothesis that requiring learners to integrate multiple sources of information during problem solving instruction would be ineffective, even when presented in a worked-out format (Atkin *et al.*, 2000; Tarmizi & Sweller, 1988).

In a subsequent study Ward and Sweller (1990) further investigated the effect of split-attention effect. In this study Ward and Sweller altered and modified the design of the Tarmizi and Sweller (1988) study. In three long-term experiments conducted with physics learners in a high school they found that the split-attention effect was manifested when learners were presented with worked-out examples that required them to simultaneously attend to multiple sources of information related to geometry optics problems (Atkin *et al.*, 2000, p. 188). However, they also noted that simply reformatting the examples to integrate verbal explanations, such as the description of problem sub-goals supported productive learning (Atkin *et al.*, 2000, p. 188). There are several other studies conducted in the name of cognitive load theory to illuminate the role of split-attention effect in learning problem solving skills by learners (for examples, see, Cierniak, Scheiter & Gerjets, 2009; Huk & Ludwigs, 2009; Kalyuga, Chandler & Sweller, 2004). Most of these studies are in unison that when the learning material is presented to learners in formats the require them to allocate some of their cognitive resources in integrating the information, learning is compromised.

3. DEMONSTRATING THE SPLIT-ATTENTION EFFECT

Split-attention is the phenomenon that occurs as a result of physically separating problem solving information (Cierniak *et al.*, 2009). It is the process of simultaneously attending to two distinct sources of information (Paas, van Gog & Sweller, 2010). Given that split-attention creates unnecessary visual search, it may heighten learners’ cognitive load (Paas *et al.*, 2010). Research has shown that reduction in split-attention effect improves learning and problem solving performance (Huk & Ludwigs, 2009). To illustrate this cognitive phenomenon further we consider a learner who attempts to study a conventionally structured worked-out example in geometry (see, Figure 1). In most cases learners are expected to learn geometry from diagrammed problems with textual explanations referring to the same concepts (Atkinson, Derry, Renkl & Wortham, 2000). This kind of conventional learning to problem solving might impose heavy cognitive load on learners if it is not effectively managed.

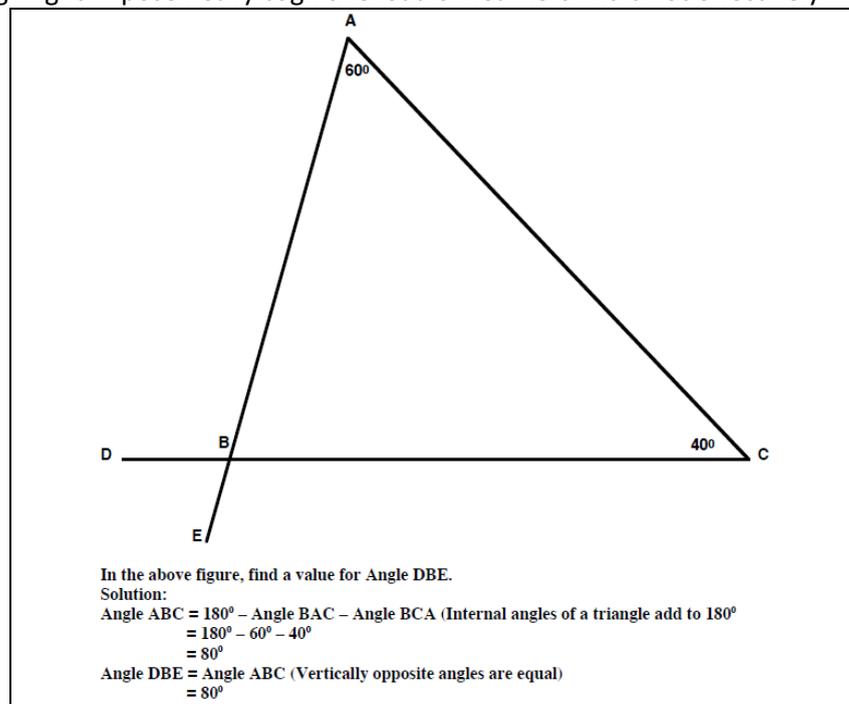


Figure 1: An example of a conventional, split-attention diagram and text [Source: Sweller (n.d., p. 1504)]

Figure 1 demonstrates a separation between a diagram (triangle ABC) and the accompanying solution steps of the problem. According to Sweller (n.d.), the associated statements such as $\text{Angle } DBE = \text{Angle } ABC$ are unintelligible without a diagram. To derive meaning in Figure 1 one has to mentally integrate the diagram and the associated solution statements (Sweller, n.d.). An attempt to integrate (reconcile) the diagram (triangle) and the solution statement, will require a lot of cognitive resources (working memory resources). This cognitive process is likely to heighten the cognitive load, which in turn may adversely influence the problem solving performance. However, the integration of the diagram (triangle) and the accompanying auxiliary solution statements in Figure 1 may ease the need to retrieve cognitive resources to facilitate problem solving performance (see, Figure 2 for an improved presentation of Figure 1).

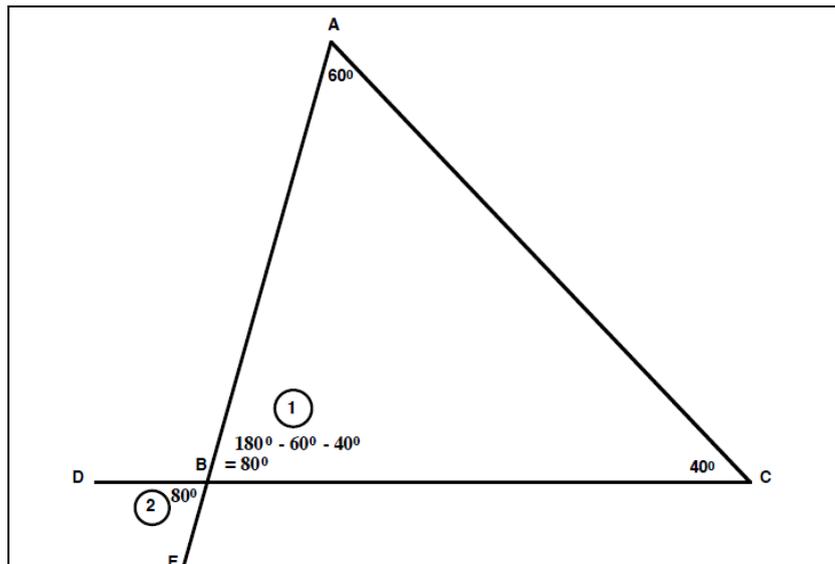


Figure 2: An example of an integrated diagram and solution statements [Source: Sweller (n.d., p. 1505)]

The working memory load (cognitive load) is reduced in Figure 2 by physically integrating the triangle (diagram) and the solution statements. In this instance the learner is released from the effort of having to engage in mental reconnection of a diagram and text, which requires a extensive cognitive resources. Conventionally, the accompanying solution statements would be placed either below or next to the diagram (triangle). In Figure 2 the search for “referents” is eliminated (Sweller, n.d., p. 1505). Several studies have been conducted in the name of cognitive load theory to demonstrate gains in learning by minimizing the effect of split-attention (for examples, see, Atkin *et al.*, 2000; Bannert, 2002; Tarmizi & Sweller, 1988; Ward & Sweller, 1990). In relation to their findings on the split-attention effect, Tarmizi and Sweller (1988) proposed that the “presentation of geometry worked-out examples in a format reducing the multiple sources of information should increase the facilitatory effect of the material” (p. 425). Their works provide empirical evidence that when learners are presented with the diagrammatic problem representations and textual explanations relevant to the diagram, problem solving performance is accelerated because the burden of split-attention effect is alleviated (Atkin *et al.*, 2000).

The study presented in this paper was largely aimed at documenting the effect of a context-based problem solving instruction (CBPSI) on the problem solving performance of participants, when CBPSI is compared to conventional problem solving instructions. Split-attention conditions were generated in the experimental group where CBPSI was implemented. At the beginning of a quasi-experiment, which largely characterized the design of the PhD study, the researcher divided the participants in the experimental group into two. The same task was given to both groups. However the presentation of a problem solving task was such that in one group the problem stament and the associated questions appeared in the same page. In another group the same work appeared on separate pages with a

problem statement appearing in one page and related questions appearing in the other. In terms of Tramizi and Sweller’s (1988) hypothesis the two conditions are more likely to induce and impose split-attention effect differently to participants in both conditions. The objective of doing this experiment was to explore ways of improving the design of CBPSI to enhance its efficacy by optimization of participants’ problem solving performance. In the next sections this experiment is discussed.

4. METHODOLOGY

In this section the research methodology of the study is discussed.

4.1 The research design

The PhD study employed a quasi-experimental approach with a non-equivalence control group design (Gay, Mills & Airasian, 2011). In this design two groups are formed, namely the experimental group and control group. The researcher introduced CBPSI in the experimental group while four teachers implemented conventional problem solving instructions (CPSI) in control schools. Within this design the researcher explored the influence of split-attention in the experimental group.

4.2 Sample of the study

The study sample consisted of a convenient group of 706 learners (experimental group n=378; control group n=328). At the beginning of the study all participants wrote a pre-test to measure the initial problem solving status. The maximum score for the pre-test was 60. The pre-test mean (*M*) scores of experimental group and control group ($M_{\text{experimental}}=20.9$; $M_{\text{control}}=22.0$) differed by almost 1.1, suggesting baseline equivalence of the two groups before intervention. The pre-test results confirmed the poor problem solving status of the two groups at the initial stages of the study when judged by designated performance classifications in Table 1.

Table 1: Classification of learners’ pre-test scores

CRITERIA	CODE	DESCRIPTION
Low performing	LO	Below 24 marks
Average performing	AO	Between 24 and 42 marks
High performing	HI	Above 42

4.3 Data collection instruments

The principal instrument in the PhD study was an achievement test administered in both groups at pre- and post-stages of the experiment. The test had been set on the following topics in Grade 10 Financial Mathematics: *simple and compound interest, hire purchase, inflation and exchange rates*. Hence the task on the split-attention worksheet addressed the work covered in the same topics. The choice of topics was motivated by the perceived challenging nature of the topics for Grade 10 mathematics learners (Dhlamini & Mogari, 2013). These topics were identified when teachers were asked prior to the commencement of the study about topics that were problematic in Grade 10.

A worksheet, which was followed by a self-reporting questionnaire and semi-structured interviews was administered to the experimental groups. The items in the worksheet were sampled from a Grade 10 state-approved textbook used in most of the participating schools. The self-reporting instrument used in the current study was developed by Paas, Van Merriënboer and Adams (1994). The instrument is a self-rating scale of cognitive load (mental effort) that, based on early work by Bratfisch, Borg and Dornic (1972), uses a post-test questionnaire in which test takers are asked to report the amount of mental effort invested in performing problem solving tasks in a test. Mental effort is therefore the cognitive capacity that is actually allocated to solve the problem and can be considered to reflect the cognitive load (Sweller, van Merriënboer & Paas, 1998). The use of this instrument in the current study is justified because split-attention has been recognised as one of the variables that regulates CLT (Paas *et al.*, 1994). The self-rating scale of mental effort consists of a nine-point scale: 1 (extremely easy); 2 (very easy); 3 (easy); 4 (quite easy); 5 (neither easy nor difficult); 6 (quite difficult); 7 (difficult); 8 (very difficult); and, 9 (extremely difficult).

In addition, there were instances outside the worksheet session in which the researcher documented the effect of split-attention on participants’ problem solving performance and an example of such is

presented in this paper (see, Example 1). The worksheet activities formed part of the research experiment. The Example 1 shows how the split-attention effect can also occur when learners perform their calculations out over two pages. The two conditions of split-attention in which participants answered a worksheet task are presented in the next section.

4.3.1 First condition

In this condition the split-attention effect was maximized by presenting two parts of the context-based problem task on two pages (both sides of the task sheet page) (see, Figure 3). Participants were distributed equally in both conditions (condition 1, n=189; condition 2, n=189). The format in Figure 3 meant that participants would engage in a visual search to track down two mutually referring pieces of information (information belonging to the same problem task but separately located) related to the problem, which appeared on different sides of the *same* page. In terms of cognitive load theory the resulting visual search in the first condition could elevate participants' cognitive load and eventually place problem solving performance at a detriment (Paas *et al.*, 2010; Sweller, 2010; Sweller, 1988).

Side 1 of page 1		Side 2 of page 1															
Problem The table below shows the exchange rate of the Rand (R) against other countries. Use the information below to answer the questions that follow.		Questions Sipho won a competition where he can fly to three international destinations free of charge with spending money. The destinations he chose were Germany (€), Hong Kong (\$) and England (£). He was allocated €9 000, \$30 000 and £2 500 for Germany, Hong Kong and England respectively.															
<table border="1"> <thead> <tr> <th>Currency</th> <th>One foreign unit = R</th> </tr> </thead> <tbody> <tr> <td>Euro €</td> <td>9.178</td> </tr> <tr> <td>UK £</td> <td>14.484</td> </tr> <tr> <td>US \$</td> <td>9.925</td> </tr> <tr> <td>Australia \$</td> <td>5.556</td> </tr> <tr> <td>Botswana Pula</td> <td>1.621</td> </tr> <tr> <td>Canadian \$</td> <td>6.452</td> </tr> <tr> <td>Hong Kong \$</td> <td>1.274</td> </tr> </tbody> </table>	Currency	One foreign unit = R	Euro €	9.178	UK £	14.484	US \$	9.925	Australia \$	5.556	Botswana Pula	1.621	Canadian \$	6.452	Hong Kong \$	1.274	Use the exchange rates in the previous page to calculate the total amount Sipho had been allocated in Rands. If Sipho were to fly to Botswana, Canada and Australia with allocations of 9 500 Pula, \$15000 and \$21 500, respectively. How much will be his total allocation for this trip?
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Figure 3: A split-attention problem solving worksheet presented in a non-integrated format

4.3.2 Second condition

In this condition the same task was given to the other group of the experimental group (n=189). In this case the problem statement, the accompanying diagram and the questions all appeared on the same page (one side of the page) (see, Figure 4). In terms of the cognitive load theory the split-attention effect in the second condition has been reduced. Participants are not subjected to a visual search of information that is separately positioned but belonging to the same problem. According to Cierniak *et al.* (2009), unnecessary visual searches during problem solving should be avoided as it may result in heightening cognitive load.

At the end of the worksheet participants in both conditions completed a cognitive load self-reporting questionnaire to indicate the level of effort experienced in relation to the positioning of the worksheet material. This exercise was followed by semi-structured interviews with a purposive sample of five participants from each split-attention condition. The selection of interview respondents was based on the observed types of responses from both conditions.

Side 1 of page 1

Problem

The table below shows the exchange rate of the Rand (R) against other countries. Use the information below to answer the questions that follow.

Currency	One foreign unit = R
Euro €	9.178
UK £	14.484
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Figure 3: A split-attention problem solving worksheet presented in an integrated format

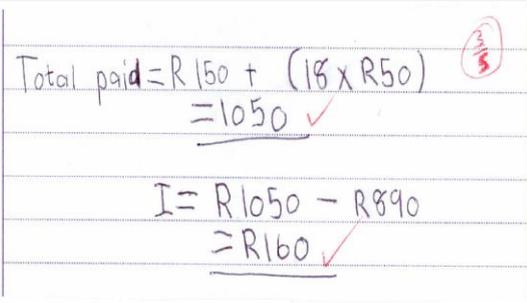
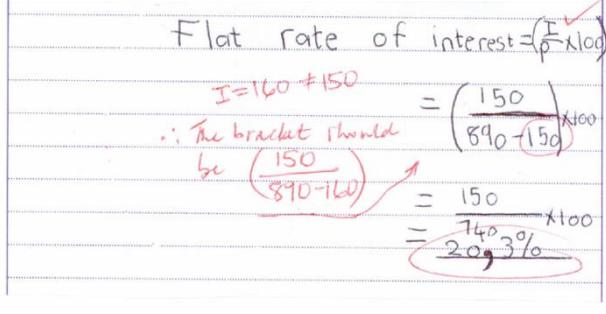
4.4 Results of the experiment

The results are discussed in terms of a worksheet task, the self-reporting questionnaire and the semi-structured interviews.

4.4.1 Results from the worksheet task and other related classroom tasks

The results of the worksheet showed that participants in the second condition performed relatively better than their counterparts in the first condition. In addition, participants in the second condition tended to spend less time in the completion of the problem solving task in the worksheet. In terms of the cognitive load theory the problem solving performance variations in both conditions could be as a result of presenting worksheet material in both conditions. The level of visual search (in terms of location problem solving material) experienced in the first condition is seemingly minimal while this level appeared to have been heightened in the second condition. These observations are corroborated by the results of the self-reporting questionnaire.

To further demonstrate the split-attention effect, which was constantly monitored during the implementation of CBPSI in the experimental group, a related problem solving activity is provided in Example 1. While solving the task the participant in Example 1 had to flip over to another page. However, as this participant paged over she fell into a trap of committing an error. As shown in Example 1 the problem solver started quite well while on page 1 of the answering sheet. Things seemed to fall apart when the problem solver attempted to continue with her solution step in the next page (page 2). In terms of the cognitive load theory this lapse of concentration, and the resulting problem solving error, could have been caused by the burden of having to simultaneously process information that is differently placed. According to the CLT, the processing of information in the working memory becomes more difficult to carry out when sources of information are separately positioned.

Solution sheet ONE (page 1 of 2)	Solution sheet TWO (page 2 of 2)
 <p>Handwritten solution for Solution sheet ONE (page 1 of 2): $\text{Total paid} = R150 + (18 \times R50)$ $= 1050$ $I = R1050 - R890$ $= R160$</p>	 <p>Handwritten solution for Solution sheet TWO (page 2 of 2): Flat rate of interest = $\frac{I}{P} \times 100$ $I = 160 \neq 150$ \therefore The bracket should be $\frac{150}{890 - 150}$ $= \frac{150}{740} \times 100$ $= 20.3\%$</p>

Example 1: A problem solving error committed possibly as a result of split-attention effect

4.4.2 Self-reporting questionnaire

The data in the questionnaire were collected from 189 respondents in the first split-attention condition and 189 in the second condition. All worksheet participants completed the worksheet at the end of the problem solving task. Questionnaire results are presented in Table 2 and Table 3.

Table 2: Frequency table with distribution of participants' scores in the first condition

Rating	Level of mental effort	n	% of occurrences
1	Extremely easy	-	-
2	Very easy	-	-
3	Easy	7	3.70
4	Quite easy	21	11.11
5	Neither easy nor difficult	25	13.23
6	Quite difficult	30	15.87
7	Difficult	38	20.11
8	Very difficult	59	31.22
9	Extremely difficult	9	5.56
	TOTAL	189	100

Table 2 shows that more than a third of respondents in the first condition felt the worksheet task was generally very difficult (31.22%).

Table 3: Frequency table with distribution of participants' scores in the second condition

Rating	Level of mental effort	n	% of occurrences
1	Extremely easy	2	1.06
2	Very easy	11	5.82
3	Easy	16	8.47
4	Quite easy	39	20.63
5	Neither easy nor difficult	40	21.16
6	Quite difficult	38	20.10
7	Difficult	33	17.46
8	Very difficult	10	5.29
9	Extremely difficult	-	-
	TOTAL	189	100

Almost more than two third of respondents in Table 3 responded between “quite difficult” and “quite easy” when asked about the worksheet task. To further probe the respondents on their questionnaire responses, semi-structured interviews were conducted with five respondents drawn from each condition. The selection was based on the types of responses in Tables 2 and 3.

4.4.3 Feedback from the interviews

The problem solver in Example 1 was also probed in relation to the problem solving error committed while transferring the solution steps to another page. The problem solver replied:

“When I went to page two I made a substitution mistake. I was going to get total marks”

Example 1 provides a snippet of learner’s work to illustrate how the researcher dealt with elements of split-attention effect to maximize learners’ problem solving performance in experimental schools. According to CLT, when the problem solver in Example 1 disintegrated the problem solution into two pages possibly two mutually referring sources of problem information were generated. To attend to the two information supplying sources (sheet/ page ONE and sheet/ page TWO) the problem solver would be expected to split her attention. The splitting effect could create processing problems for the working memory as evidenced by the resulting problem solving error. Most likely, the working memory may have had to temporarily hold pieces of information in sheet ONE while the visual search for the associated information in sheet TWO was made. The demand on the working memory may have become too great for the problem solver in Example 1 and the error occurred.

In relation to the two split-attention conditions some of the interview item probed respondents on their experience of solving a worksheet task in relation to the conditions allocated to them. Most participants in the first conditions complained that time allocated to the task was insufficient; that the task was not easy; and some respondents indicate that the fact that the task information appeared in more than one page adversely hindered their performance. Some of the direct responses from participants are presented:

“I could not finish this task the time was little”

“Why did you write this task at the back page? That was disturbing for me”

“I think I made mistakes because I was paging between this page”

Clearly the latter respondent referred to the fact that she had to flip the worksheet over in order to view the other parts of the problem solving task. The first respondent raises the issue of time. The time allocated to the task was sufficient. However, it seems that the first condition experiment time was insufficient as some portion of it had to be spent on the process of paging over and also on remembering and reconciling separate information. Some respondents seem to have noticed that placing problem information on more than one page was problematic for them.

5. CLOSING DISCUSSION AND CONCLUSION

The results of this study show that the splitting effect of learning material may create problems for the working memory. In the first condition of Table 1 the problem task information appearing on different sides of the page will have to be processed differently in the working memory. Each time the learner navigates from one page to another, pieces of information belonging to the problem solving task in the previous page must be held and processed separately in the working memory. The other problem solving information in the second page would also have to be processed separately. In the end the separate processing of worksheet information due to the split-attention effect compromises problem solving performance. Participants in the first condition are possibly disadvantaged by the separate placing of information. Their experiences are not only reflected in the questionnaire results but are illuminated in their interview responses.

The results of this study are not unique. These results provide empirical evidence to support the hypothesis that learners who are presented with problem solving tasks that separate two sources of information experience less problem solving success than learners who receive the same material in an integrated format (see, Cierniak *et al.*, 2009; Huk & Ludwigs, 2009; van Gog, Kester, Nieuvelstein,

Giesbers & Paas, 2009; van Merriënboer & Sweller, 2005, 2010). CLT emphasises the necessity for instructional techniques should be aligned with the basic operational principles of the human cognitive system (Kalyuga *et al.*, 2004; Paas *et al.*, 2010; Sweller, 2010; Sweller *et al.*, 2011). In effect, the basic premise of CLT is that learning will be severely hindered if instructional materials overwhelm a learner's cognitive resources.

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