USING A WORKED-OUT EXAMPLES INSTRUCTION TO INDUCE PROBLEM SOLVING PERFORMANCE IN SOUTH AFRICAN SCHOOLS

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ABSTRACT–The dawn of democracy in the mid-1990s has seen South African schools exploring different curriculum models to mitigate endemic deficiencies in learner performance. These curriculum initiatives have proposed different instructional strategies to teach content in school subjects. For instance, the recently introduced Curriculum and Assessment Policy Statement (CAPS) largely espouses the idea of using step-by-step worked-out examples to facilitate learning in mathematics. While one could argue that the teaching of mathematics has always incorporated the use of examples to facilitate learner understanding, but a seemingly stronger reliance of CAPS on worked-out examples calls for an enquiry on the perceived benefits of this teaching technique. The aim of this paper is to initiate a dialogue of advocacy to facilitate CAPS initiatives to optimally use worked-out examples for pedagogical purposes in South African mathematics classrooms. Using Cognitive Load Theory, the author highlights certain aspects of human cognitive system, which impact on the learning and development of problem solving skills. In addition, the author draws from previous studies to explore the relative efficiency of teaching material that is presented in the worked-out examples format. It is recommended that learning settings should be constructed such that they value the influence of worked-out examples in mathematics teaching to substantially profit learners' problem solving performance in mathematics.

Keywords: Worked-examples approach; cognitive load theory; cognitive load; problem solving.

1. INTRODUCTION

In 2012 the Curriculum and Assessment Policy Statement (CAPS) replaced the National Curriculum Statement (NCS) in all Grade 10 South African classrooms (Department of Basic Education [DBE], 2011a; Department of Education [DoE], 2005; DoE, 2002). The rationale for the staggered introduction of CAPS by starting it in Grade 10 was to enforce a progressive implementation model in which CAPS is introduced in phases at various grade levels. In terms of this implementation model, CAPS was introduced in Grade 11 classrooms in 2013, and in 2014 it was introduced and implemented in Grade 12 classrooms (DBE, 2011b). The same model has been followed in junior classes to ensure that at a specified point in time the cycle of CAPS implementation would have been completed in all grade levels in South African schools (DBE, 2011a).

Although both the CAPS and the NCS subscribe to the Outcomes-Based Education approach, which is largely learner-centred, the methods of content delivery espoused in each curriculum is not necessarily similar (DBE, 2011a; DoE, 2006; DoE, 2005, DoE, 2002). While the NCS approach is well known for its advocacy of foregrounding the teaching of SKVAs, which is an acronym for Skills, Knowledge, Values and Attitudes, it has suffered strong criticisms for spending enormous time on these attributes while less time is left to focus on subject content. Hence the introduction of CAPS in South African schools has been viewed by other educational stakeholders as an appropriate initiative to encourage teachers to promote instruction that largely emphasizes the teaching of content in mathematics classrooms. Coupled by these observations are the participation indicators of South African learners in national and international science and mathematics competitions, which highlight a need to strengthen learners' domain specific content knowledge, particularly in subjects like mathematics (Gerard, 2011; Mji & Makgato, 2006; Reddy, 2006; Van der Berg & Louw, 2006).

Given that the CAPS pedagogy is perceived as an attempt to strengthen the teaching of subject content, some have loosely dubbed it the *back to basics* mode of teaching. As one of its recommended teaching approaches of the content, CAPS seems to emphasize the importance of using *worked-out examples* as an instructional tool to facilitate learning, and eventually elevate learner performance in schools. A *worked-out examples approach* is a familiar concept to some of the mathematics education research communities. Several studies have argued for the use of worked-out examples to significantly improve instructional efficacy (for examples, see, Dhlamini, 2012; Dhlamini & Mogari, 2012; Dhlamini, 2011; Dhlamini & Mogari, 2011; Paas & Van Gog, 2006; Renkl & Atkinson, 2010; Renkl, Atkinson & Maier, 2000; Renkl, Hilbert & Schworm, 2009; Retnowati, Ayres & Sweller, 2010).

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 (Dhlamini, 2011; Dhlamini & Mogari, 2011; Renkl & Atkinson, 2010; Van Gog & Rummel, 2010). This instructional approach is intended to provide to the learner a sample of expert's solution, which the learner can study and use as a model for his or her own problem solving steps. This feature is largely emphasized in most of the CAPS textbooks that are currently used in South African mathematics classrooms (see, Example 1 & Example 2).

Example 1: A worked-out example from a CAPS textbook explaining a problem on surds

WORKED EXAMPLE 5

Simplify: $(\sqrt{2} + \sqrt{8} + \sqrt{7})(\sqrt{2} + \sqrt{8} - \sqrt{7})$

SOLUTION

$(\sqrt{2} + \sqrt{8} + \sqrt{7})(\sqrt{2} + \sqrt{8} - \sqrt{7})$	Reduce surds.
$= (\sqrt{2} + 2\sqrt{2} + \sqrt{7})(\sqrt{2} + 2\sqrt{2} - \sqrt{7})$	Add like surds.
$= (3\sqrt{2} + \sqrt{7})(3\sqrt{2} - 7)$	Multiply out difference of two squares.
$= 9(2) - 7$	
$= 11$	

Source: *Bradley, Campbell and McPetrie, 2011, p. 16*

Example 2: A worked-out example from a CAPS textbook demonstrating how to solve for x by completing the square

WORKED EXAMPLE 4

Solve for x by completing the square if $ax^2 + bx + c = 0$.

SOLUTION

$ax^2 + bx + c = 0$	
$x^2 + \frac{b}{a}x + \frac{c}{a} = 0$	Divide through by a, the coefficient of x^2.
$\left(x + \frac{b}{2a}\right)^2 - \frac{b^2}{4a^2} + \frac{c}{a} = 0$	(x + half the coefficient of x)^2 – (half coefficient of x)^2
$\left(x + \frac{b}{2a}\right)^2 = \frac{b^2 - 4ac}{4a^2}$	Isolate perfect square on LHS; simplify the RHS.
$x + \frac{b}{2a} = \pm\frac{\sqrt{b^2 - 4ac}}{2a}$	Square root both sides; remember ± on RHS.
$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	You will use this quadratic formula in Unit 2, page 30.

Source: *Bradley, Campbell and McPetrie, 2011, p. 26*

What comes out as a sticking feature in the two worked-out examples of Example 1 and Example 2 is the emphasis given to a step-by-step explanation of a problem to facilitate learner comprehension and understanding of mathematics. Although in traditional classrooms examples have enjoyed a long history of instructional consideration as tools to facilitate comprehension in mathematics lessons and in textbooks, but learner performance in traditional classrooms has consistently reflected poor learning gains. According to Gerjets, Scheiter and Catrambone (2004), traditionally designed worked examples turn to focus on information that is related to problem-category membership, structural task features, and category-specific solution procedures. Meaning, the inclusion of examples in traditional instruction tended to promote rote learning and shifted away from cultivating problem solving skills. Cognitive research has argued that studying examples in the traditional format might be cognitively demanding because procedures in this approach would need learners to "simultaneously hold active a substantial amount of information in working memory" (Gerjets *et al*., 2004, p. 33), thus imposing a significant hindrance to the learning process.

Unlike traditional techniques of using examples in mathematics classrooms, the *worked-out examples approach* that is reported in this paper offers alternative and beneficial instructional techniques to reinforce examples-based learning (see, Example 1 & Example 2). The worked-out examples approach is often undertaken by providing the learner with one example and then, in successive presentations of similar examples, to systematically remove sub-steps in order to encourage the learner to provide the missing input until, at the end of the learning experience, the learner is able to insert all missing steps to solve the novel problem (Gerjets *et al*., 2004). A key theoretical reason often cited for the benefits of learning with worked-out examples in comparison to learning by problem solving, which characterizes traditional instruction, is cognitive load theory [CLT] (Paas, Renkl, & Sweller, 2003; Sweller, Van Merriënboer, & Paas, 1998). CLT is a major theory that provides a useful framework for investigations into cognitive processes and instructional designs that are linked to problem solving activities, particularly in structured disciplines such as mathematics. As such, CLT is mainly concerned with the design of instructional methods that efficiently use people's limited cognitive processing capacity (see later discussions in this paper). Since its development CLT has identified different effects such as worked examples, temporal and spatial split-attention, redundancy, modality and expertise reversal that are capable of influencing instructional designs (for summaries, see, Sweller, 1999; Van Merriënboer & Sweller, 2005). Among these, the worked-out example effect forms the focus of the discussions in this paper.

Compared to traditional methods of using examples or conventional problem solving approaches, CLT-generated worked-out examples turn to substantially lessen the cognitive load, which refers to the difficulty that is associated with the use of cognitive resources for mental processes, such as searching for a suitable solution during problem solving activity (Dhlamini, 2011; Dhlamini & Mogari, 2011; Yousoof, Sapiyan & Kamaluddin, 2007). While in traditional classrooms search methods such as means-ends analysis might be regarded as critical in problem solving activity, in terms of CLT such approaches impose a significant strain to cognitive resources that should be used for learning purposes. However, by providing learners with a set of systematic worked-out solutions to study the need for search is eliminated and learners can focus on the construction of cognitive schemas, so they can more readily solve similar problems in future (Konopka & Benjamin, 2009; Taconis, Ferguson-Hessler & Broekkamp, 2001; Van Merriënboer & Sweller, 2005). Problem solving schemas are defined as "mental constructs that allow patterns or configurations to be recognized as belonging to a previously learned category and which specify what moves are appropriate for that category" (Sweller & Cooper, 1985, p. 60). A widely proposed instructional method for fostering the acquisition of problem solving schemas is to provide learners with multiple worked-out examples for each problem category conveyed (Cooper & Sweller, 1987; Gick & Holyoak, 1983; Reed & Bolstad, 1991; Sweller & Cooper, 1985; Quilici & Mayer, 1996).

In terms of schema theory, once a problem is identified as belonging to a familiar problem category the relevant schema can be retrieved from memory, specifically from long-term memory (LTM), and the solution procedure that is associated to the schema is executed to stimulate a solution procedure to the problem. This is what makes the CLT-generated worked-out examples more effective to learners who are low-performing or who possess low prior knowledge in the domain of interest. When such learners go through worked-out examples solution their cognitive load is lowered as a results of schema construction, and subsequently, the initial learning is maximized (Paas, Renkl & Sweller, 2004; Tricot, Sweller, Amadieu, Chanquoy & Mariné, 2008). However, schema construction could be enhanced through exposure to and execution of a multiple worked-out examples. Sweller and his colleagues have found that providing learners with many worked-out examples is more effective in schema construction than providing them with a few worked-out examples followed by traditional or conventional instruction (Cooper & Sweller, 1987; Sweller & Cooper, 1985).

In this paper a review of studies that explored relative learning effects of incorporating worked-out examples in mathematics instruction is explored, and in turn, this paper uses the results of these studies to support the recently emerging efforts to use worked-out examples as a teaching device in South African mathematics classrooms.

2. RELATED RESEARCH ON WORKED-OUT EXAMPLES

More recent studies have demonstrated that successful learning in knowledge-rich domains such as mathematics is enhanced by the availability of abstract problem-type schemas whose acquisition can be supported by presenting learners with worked-out examples (Gerjets *et al*., 2004; Paas *et al*., 2003). Using selected topics in algebra, Cooper and Sweller (1987) and Sweller and Cooper (1985) demonstrated enhanced learner performance on subsequent problems after learners studied the worked-out examples solutions. Both studies claimed that solving the same problems rather than studying them as worked-out examples eventually reduced participants' cognitive load. In another study, Zhu and Simon (1987) provide empirical evidence of substantial performance gains when worked-out examples were used as a substitute for lectures and other conventional classroom activities. Their carefully designed and sequential presentations of worked-out examples were sufficient to induce problem solving skill acquisition and abstract problem representations without providing explicit instruction (Zhu & Simon, 1987). In their study Kalyuga and colleagues found that as a teaching resource worked-out examples are more favorable in earlier stages of learning, while problem solving could be more useful in later stages (see, Kalyuga, 2007). The results of these studies can only be explained by the notion that problem solving requires substantial working memory capacity that counteracts learning in terms of schema formation and development, that given this load, too few resources are left for the induction of abstract and generalizable problem solving schemas (Sweller, 1994; see also, Dhlamini & Mogari, 2011).

In recent initiatives to bolster problem solving performance of low-performing learners Dhlamini (2012) conducted a study that incorporated the design of a context-based problem solving instruction (CBPSI) (see also, Dhlamini & Mogari, 2013). In the study Dhlamini (2012) constructed quasi-experimental conditions to demarcate the problem solving performance of the experimental group (n=413) and the control group (n=370) (for an overview of the methodological design of this experiment see, Dhlamini & Mogari, 2013). In the experimental group Dhlamini (2012) implemented CBPSI, which largely embraced aspects of CLT-generated worked-out examples. When the problem solving performance of the experimental group was compared with that of the control group, which was subjected to traditional problem solving instruction, the results of the experiment showed more learning profits for the experimental group (see, Dhlamini, 2012; Dhlamini & Mogari, 2013; Dhlamini & Mogari, 2012). Given that the methodological designs of the studies discussed in this section placed heavy reliance on worked-out examples, it is reasonable to ask: What aspects of worked-out examples accounted for the beneficial influence of learner performance in these studies? In the next section this issue is given special attention.

3. ACCOUNTING FOR THE BENEFICIAL INFLUENCE OF THE WORKED-OUT EXAMPLES EFFECT

A worked-out examples effect flows out directly from the cognitive load theory [CLT] (Sweller, 1988). Therefore, what are the elements of worked-out examples approach that exclusively account for the reinforcement of learning activities? In order to understand why worked examples are successful, it is necessary to begin with a systematic review of the underpinnings of human learning. CLT uses current knowledge about the human cognitive architecture to generate instructional techniques that promote learning and development of problem solving skills (Dhlamini, 2011; Dhlamini & Mogari, 2011; Dhlamini & Mogari, 2012). Cognitive architecture can be defined as an "underlying infrastructure that influences cognitive processes for an intelligent system, such as a human being" (Langley, Laird & Rogers, 2009, p. 1). In that way all human mental life and behaviour involve the cognitive architecture. For instance, perceiving everything around us involves using our cognitive system so that we can recognize and categorize what we see, hear, taste, touch and smell.

The basic premise of CLT is that learners' cognitive architecture consists of a working memory (WM) with severely limited processing capacity and duration when dealing with novel information. Concerning its processing duration "almost all information stored in working memory and not rehearsed is lost within 30 seconds" (Paas, Van Gog & Sweller, 2010, p. 117). Also, its capacity cannot deal with information more than about 7 elements of information simultaneously (Miller, 1956). Hence, if the WM capacity is exceeded while processing information then some, if not all, of that information will be lost. However, the limitations of the WM can only apply to new, yet to be learned information (Paas, et. al, 2010). Well-learned material, held in long-term memory (LTM), suffers from neither of these limitations when brought into WM (Ericsson & Kintsch, 1995). This means WM should be occupied by task-relevant operations, especially when dealing with complex material. Hence CLT pleads for a proper use of WM by means of efficient training.

According to CLT, human cognitive architecture also consists of an effectively unlimited long-term memory which interacts with a WM to process information. Because LTM has unlimited capacity, it can permanently store chunks of domain-specific skills and related schemas. Schemas categorize elements of information according to how they will be used, thereby facilitating accessibility later when they are needed for related tasks (Sweller, Van Merriënboer & Paas, 1998). In terms of CLT, the presence of schemas in LTM is considered a prerequisite because schemas reduce the amount of mental effort, or cognitive load, in WM that is needed to perform particular tasks (Van Gog & Rummel, 2010). Mainly, CLT focuses on how constraints on our WM help to determine what kinds of instruction are effective. According to CLT, teachers should design problem solving tasks that minimize the demand for processing in WM. Hence learning activities should minimize the processing and storage of information that is not directly relevant for learning in order to avoid taxing the WM processing capacity. The inclusion of worked-out examples in instructional designs helps to minimize the demand that goes with the processing of problem solving information in the working memory. Therefore cognitive load theory helps us to get plausible explanations to account for the benefits of constructing worked-out examples environments in mathematics classrooms.

4. DISCUSSION AND CONCLUSION

Given that most of the empirical studies on worked-out examples that have been discussed in this article have been conducted in countries outside South Africa, there is a need to conduct similar studies within the context of a local educational setting. This need is largely necessitated by the observed prevalence of step-by-step worked-out examples approaches incorporated in the CAPS textbook, suggesting a need to refine teaching strategies to improve learner performance in mathematics. Therefore, there is a need to train teachers effectively in the use example related pedagogy to facilitate learning in South African mathematics classrooms. The latter could provide a useful avenue in moving teachers away from viewing the worked-out examples in CAPS documents using a traditional lens.

The results from these studies discussed in this paper provide useful insights into the design of instruction to elevate learners' problem solving performance in mathematics. In addition, the results and findings from these studies highlight the need to provide teachers with solid training to incorporate worked-out examples in their instruction.

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