

Designing instruction to promote mathematical problem solving performance of high school learners

Joseph J Dhlamini¹ & David Mogari²

¹Department of Mathematics Education, University of South Africa

²Institute for Science and Technology Education, University of South Africa

Email:dhlamjj@unisa.ac.za; mogard@unisa.ac.za

The paper describes and discusses the design of context-based problem solving instruction (CBPSI). This is an instructional approach that relies on the learners' real-world experience or outside school activities to hone problem solving skills by reducing cognitive load memory. Learners work in collaborative groups to resolve given real-world tasks. Based on how CPBSI is designed and described it is concluded it has potential to improve learners' problem solving skills

Keywords: Context-based problem solving instruction; problem solving; cognitive load theory.

Introduction

The reformed curriculum in South Africa recognizes problem solving as one of the critical skills in the learning of mathematics (Department of Education [DoE], 2006). In the mathematics curriculum document it is emphasized that “mathematical problem solving enables us to understand the world and make use of that understanding in our daily lives” (DoE, 2006, p. 20). Furthermore, the incoming curriculum viz. National Assessment Policy Statement (CAPS) also highlights the importance of teaching mathematical problem solving strategies in schools. For example, it indicates that “mathematical problem solving enables us to teach us to think creatively” (Department of Basic Education [DBE], 2011, p. 6).

Mathematics includes both knowledge and skills as focal areas where the domain of knowledge includes numbers and relationships, patterns and algebra, space and shape, measurement and data handling, as areas of importance, and skills would include representation and interpretation, calculation, reasoning, problem posing and solving amongst others (National Department of Education [NDE], 2002).

From this background it reasonable to argue that one of the goals of teaching mathematics is to improve mathematics problem solving performance of the learners. Even though problem solving has such prominence in the mathematics curriculum its importance appears not evident in the learners' outcomes. Evidence of the existence of the poor performance problem includes results from standardised national tests such as grade 12 end-of-the-year examination results. The analysis of the learner performance in the examination reveals numerous deficiencies that may be attributed to generally the way mathematics is taught in the schools. The apparent ineffective instruction generally used in the schools

appears to have led to learners performing poorly in international and cross-national performance studies such as the Trends in International Mathematics and Science Study (TIMSS) of 1995, 1999 and 2003; the Monitoring Learning Achievements (MLA) initiative; the Southern Africa Consortium for Monitoring Educational Quality (SACMEQ) - initiated studies; and the Performance in International Student Achievement (PISA). When taking part in these educational competitions the problem solving performance of South African learners has always revealed poor mathematical skills when compared with other participating countries (Bansilal, James & Naidoo, 2010; Howie, 2006; Reddy, 2007). Furthermore, after the analysis of 2008 grade 12 mathematics and science results the Maths Excellence (2009, p. 1) reported that “recently *The World Economic Forum* ranked South Africa 120th for mathematics and science education, well behind our troubled neighbour Zimbabwe (ranked 71st)”.

It is also reasonable to conclude that there is an urgent need to develop an instructional approach that can improve problem solving performance. The envisaged instruction should contribute immensely in finding a sustainable solution to the perennial problem of poor performance in mathematics.

Framing the design of the instructional approach

This paper delineates the design of an instructional approach, viz. a context-based problem instruction (CBPSI). The design of CBPSI is influenced by the assumptions of cognitive load theory (CLT) which is concerned about the limitations of the human working memory. According to the CLT, the limitations of working memory result in a cognitive load (working memory load) which may inhibit learning and problem solving performance. Therefore to promote learning and problem solving performance cognitive load must be kept at a manageable level, that is, ways should be designed to minimize the negative influence of cognitive load.

To this end, CBPSI is designed to minimize the effect of cognitive load on learners' problem solving performance. To achieve this, CBPSI places heavy reliance on the following effects of CLT: worked-out examples approach; self-explanation effect; and split-attention effect. Then real-world tasks or activities that are familiar to the learners are used to reduce of cognitive load. What is critical here is to bridge the gap between real-world or outside school activities and what is learnt in class. This is informed by the fact that the knowledge acquired in class, arguably, is not always used or transferred to real-world settings or outside school activities.

The objectives of CBPSI are: (1) to strengthen problem solving skills; (2) to expand the scope of problem domain that the learner works on; (3) to expand the range of problem solving skills of the learners; and, (4) to identify and analyse problems that are personal, social, or non-academic and problems that do not have a single answer (Greeno, 1977). It is therefore deduced that problem solving is a process by which learners experience the power and usefulness of mathematics in the world around them (NCTM, 2000).

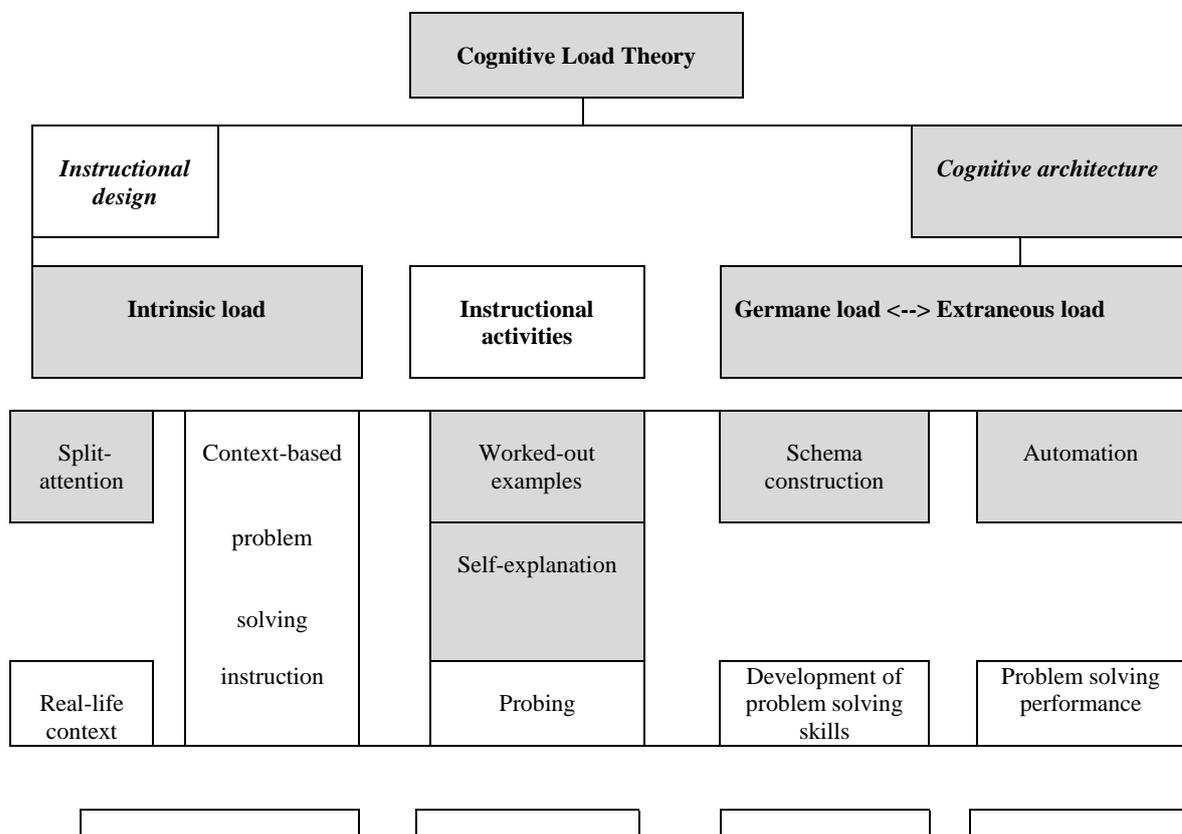
Description of cbpsi

In describing a CBPSI it should be noted that it is not simply the inclusion of problem solving activities to otherwise abstract and structured body of knowledge, but rather more of body of knowledge that based on real-world tasks or activities. In other words CBPSI prioritises making connections between classroom knowledge and outside school knowledge should be fore-grounded. One way to achieve this is to formulate problem solving tasks or activities that relate directly to learners' every day experience. This helps make mathematics more accessible to learners.

Furthermore, when using CBPSI a teacher begins the lesson by posing a real world problem, then the teacher teaches a skill that will help learners to solve the problem (NCTM, 2000). The newly acquired skill should help the learners find a solution to the problem. In this context problem solving becomes both the starting and the ending point for a mathematics lesson.

CBPSI consists of four stages, namely, the design stage, the actualization of instruction, realization of learning, and finally exhibition of problem solving performance (see Figure 1). In terms of this design framework, learning is conceptualized as an increase in problem solving expertise due to the construction of problem solving schemas. A schema is defined as a knowledge structure that represents a class of things, events and situations (Song, 2011). Put simply, a schema can be anything that has been learnt and is treated as an entity.

Figure 1: A summary of a context-based problem solving instruction (CBPSI)





The construction of participants' problem solving schemas was central to the design of CBPSI. The latter was achieved in the following manner:

The design stage

The first stage of the lesson aimed to minimize the effect of the intrinsic load. This load refers to the complexity of the learning material that a learner intends to mentally learn (Van Gog & Rummel, 2010). Intrinsic load might be optimal at the initial stages problem solving learning. The effect of intrinsic load can be neutralized by designing context-based problem solving tasks and this will minimize the effect of split-attention. It should be noted that the split-attention creates unnecessary visual search that may heighten learners' cognitive load (Paas, Van Gog & Sweller, 2010) and reducing the effect of split-attention can improve learning and thus enhance problem solving performance.

The stage entails arranging the participants in groups to promote collaborative learning. When learners solve problems within the context of a group approach, information can be divided across a larger reservoir of cognitive capacity and learning becomes favourable. This is possible because the risk of overloading each group member is lowered as the individual's working memory capacity is freed up while the group's reservoir of cognitive capacity is expanded (Kirschner, Paas & Kirschner, 2009). In addition, incorporating real-life experiences that fell within the scope of participants generated interest and participation in group discussions, this also contributed to the reduction of cognitive load.

Actualization of instruction

During this stage participants engage in context-based problem solving activities. A worksheet with examples can be given to learners at the beginning of instruction. Then learners will work with peers in groups to study examples and solve problems, and teacher provides assistance where necessary.

While participants go through the worked-out examples the teacher may also encourage them to verbalize or explain their understanding of problem solving solutions. Probing can be also used to encourage and motivate participation in group discussions. Subsequent to the worked-out examples phase, participants are given context-based problem solving tasks to exhibit their problem solving knowledge. At this point participants are given an opportunity to demonstrate their acquisition of problem solving schemas that are developed through immersion into worked-out examples process.

Realization of learning

The lesson efforts are made to transform extraneous cognitive load to germane load. Germane load is also known as effective cognitive load. This is because, unlike extraneous

load, germane load is conceptualized as a load that contributes directly to learning and schema formation. Questions are posed to learners as they work through context-based problem solving tasks. The learners' responses can be coded to indicate whether they reflect a schema or not.

Therefore, the third stage (learning) in Figure 1 represents the phase at which learners demonstrate their level of problem solving ability and expertise in problem solving process. They engage actively in problem solving tasks and demonstrate their problem solving abilities without being aided. Also, this is observed through the learners' problem solving actions and feedback towards probing initiatives.

Problem solving performance

The final stage in Figure 1 is when learners demonstrate problem solving abilities and skills, and whether their skills are automated. Learners should be able to solve novel problems using skills gained in previous stages of CBPSI. Finally, the learners' problem solving skills can be verified with some form of assessment task.

Conclusion

The paper discussed the design of a context-based problem instruction and how it can be used to improve the learners' problem solving skills. In addition, the paper illustrated that the beneficial effect of CBPSI was largely due to its design which embraces aspects of cognitive load theory. In particular, the following effects of cognitive load theory accounted for a significant reduction of learners' cognitive load: presenting context-based problem solving tasks in a form of worked-out example solutions; designing context-based problem solving tasks in a manner that minimized the split-attention effect; facilitating a self-explanation approach that afforded the learners an opportunity to verbalize their problem solving thoughts and actions. It is therefore concluded that CBPSI has potential to improve the learners' problem solving performance.

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