Learning and Individual Differences 51 (2016) 81–90

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

Reducing intrinsic cognitive load in percentage change problems: The equation approach☆

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ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form 11 August 2016
Accepted 19 August 2016
Available online xxxx

Keywords:
Intrinsic cognitive load
Mathematics education
Percentage change problems
Problem solving

ABSTRACT

We compared the equation approach and unitary approach in helping students ($n = 59$) learn percentage change problems from a cognitive load perspective. The equation approach emphasized a two-part learning process. Part 1 revised prior knowledge of percentage quantity; Part 2 integrated the percentage quantity and the original amount in an equation for solution. Central to the unitary approach is the concept of unit percentage (1%). The unitary approach would expect to incur high element interactivity because of the intrinsic nature of its solution steps, and the need to search and integrate quantity and percentage in order to act as a point of reference for calculating the unit percentage. Test results and the instructional efficiency measure favored the equation approach. It was suggested that the equation approach reduced the intrinsic cognitive load associated with percentage change problems via sequencing and prior knowledge.

1. Introduction

There is evidence to indicate that instructional approaches depicted in mathematics textbooks may cultivate shallow mathematical reasoning and thinking skills (Vincent & Stacey, 2008). For example, there is little evidence of requiring students to solve geometry problems by setting up an equation such as, $(2\times - 6)^0 + 32^0 = 70^0$ in which they need to build on prior knowledge of algebraic expressions, $(2\times - 6)^0$. Thus, how can mathematics educators help middle school students understand and learn percentage change problems, such as "*Last semester Nikki scored 80 marks for a mathematics test. She has improved her mathematics marks by 10% this semester. Find Nikki's mathematics marks for this semester*" is an important issue. How do we know whether a particular instruction is effective in fostering understanding and learning percentage change problems?

Our ability to solve a range of real-life problems (e.g., *If 5 kg oranges cost \$20, what is the cost of 1 kg oranges?*) relies on the efficient use of mental computation of what is known as a 'unitary' concept. Unsurprisingly, based on this unitary concept, the unitary approach is one of the popular methods in mathematical problem solving (McSeveny, Conway, & Wilkes, 2004). In contrast, mathematics textbooks rarely advocate the equation (algebra) approach for mathematical problem solving (e.g., McSeveny et al., 2004). The equation approach requires students to integrate relevant information in an equation for subsequent generation of a solution.

Several researchers have designed mathematics instructions and test their effectiveness by conducting randomized, controlled experiments in a regular classroom with school age students (Jitendra, Star, Rodriguez, Lindell, & Someki, 2011; Rittle-Johnson & Star, 2007). In the current study, differing from previous inquiries, we compared the *unitary approach* and *equation approach* that could facilitate effective learning of percentage change problems from a cognitive load perspective.

2. Cognitive load theory

Recent development in cognitive load theory (Sweller, 2012) has stipulated five major components that have implications for instructional designs and pedagogical practices in mathematics education. These are:

1. *Information store principle* refers to a huge long-term memory capacity to store organized information in the form of schemas that can be handled as a single element in working memory. Thus, one main aim of instruction is to acquire schemas and store them in long-term memory. For example, once the learner has acquired a schema for percentage quantity (e.g., $15\% \times 72$), the learner can retrieve the schema from long-term memory and treat this as a single element in working memory.

☆ This research was supported with funding from the University of New England, School of Education, grants RE22778. Correspondence regarding this paper should be directed to Bing Hiong Ngu, School of Education, University of New England, Armidale, NSW, Australia, 2351.

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http://dx.doi.org/10.1016/j.lindif.2016.08.029
1041-6080/

2. *Borrowing and reorganizing principle* refers to the acquisition of schemas in educational practices that rely on learning from experts in the domain, as well as imitation from peer students. One of the strongest empirical evidence is the worked examples effect (Atkinson, Derry, Renkl, & Wortham, 2000; Paas & van Gog, 2006). The worked examples effect is relevant to this article.
3. *Randomness as genesis principle* refers to random testing during problem solving to generate novel information. Only those problem solving moves that result in generating novel information will be retained in long-term memory. When solving a mathematics problem, the problem solver who lacks the schemas may resort to use a trial and error method to generate problem solving moves. Successful problem solving moves that contribute towards the solution will be stored in long-term memory as schemas.
4. *Narrow limits of change principle* refers to a restriction imposed on the limited working memory to process a large amount of novel information from external environment because it will result in too many combinations. Processing a large number of novel mathematics problems that will result in too many combinations of solution paths would put a strain on the limited working memory.
5. *The environmental organizing and linking principle* refers to the limitation of working memory that will disappear when processing schemas that can be retrieved from long-term memory. As will be discussed later, the percentage quantity (e.g., $20 × 5%) schema retrieved from long-term memory allows the learners to process the percentage change problems using fewer elements in working memory.

The five mentioned principles of cognitive load theory feature, centrally, in the operational nature of working memory and long-term memory. The long-term memory serves as storage for a large number of schemas, whereas the limitation of working memory (Miller, 1956) is restricted to process novel information but not schemas that can be retrieved from long-term memory. In view of this, how does the interaction between long-term memory and working memory contribute to effective instructional design?

Interacting elements constitute element interactivity, whereby an element is anything that requires learning (e.g., a number or a mathematical concept). In recent development of cognitive load theory (Sweller, 2012; Sweller, Ayres, & Kalyuga, 2011), element interactivity is regarded as a common factor for both intrinsic and extraneous cognitive loads. Intrinsic cognitive load is imposed by the element interactivity of the learning material, at hand. The higher the degree of element interactivity, the more the intrinsic cognitive load. Nevertheless, intrinsic cognitive load varies in accord with the knowledge base of the learners. Multiple interactive elements for a learner who has a low level of knowledge base can be a single unit of element for another learner who has a high level of knowledge base (Kalyuga, 2007). In essence, the prior knowledge of a domain could reduce the extent to which elements within the learning material interact, and therefore its intrinsic cognitive load.

Extraneous cognitive load, in contrast, is imposed by the element interactivity that arises from inappropriate instructional design. For example, when solving geometry problems, a split-attention effect will occur if the learners are required to integrate elements in the diagram and the text from disparate sources (Tarmizi & Sweller, 1988). Germane cognitive load, likewise, does not represent an independent source of cognitive load; rather, it refers to cognitive resources that are directed to learn the element interactivity and thus intrinsic cognitive load of the learning material. Hence, overall, the total cognitive load depends on both intrinsic and extraneous cognitive loads. Effective instructional designs aim to minimize extraneous cognitive load and stimulate the learners to devote their cognitive resources to deal with the intrinsic cognitive load of the learning material. In view of this current formulation of cognitive load theory, how can element interactivity influence the design of mathematics instructions?

3. Element interactivity, understanding and working memory

In numeral identification, learning to recognize an individual number such as 2 or 5 constitutes a low element interactivity task because learning to recognize individual numbers can be learned independently of each other. In other words, there is limited relationship between individual numbers (i.e., in this case 2 and 5, individually). In contrast, however, learning to make sense of $70 × 20% = $14 requires simultaneous assimilation of several interacting elements – for example: $70, 20%, $14 and their relationship (e.g., multiplicative relation between $70 and 20%). Each element (e.g., $70) has no meaning when considered in isolation. What is notable is that it is the understanding of the relationship between the elements, rather than the individual elements that poses challenges and deters effective learning.

Low element interactivity tasks (i.e., simple task) where elements do not interact, imposes low intrinsic cognitive load. High element interactivity tasks (i.e., complex task) where understanding of the task requires assimilation of multiple interacting elements, in contrast, imposes high intrinsic cognitive load (Carlson, Chandler, & Sweller, 2003; Leahy & Sweller, 2008; Sweller & Chandler, 1994). The intrinsic cognitive load that is associated with a complex task cannot be altered, but the task itself can be altered to a different task through instructional manipulations. For example, as will be discussed later, by sequencing the percentage change problems to a two-part learning process, the intrinsic nature of the task can be reduced and thus schema acquisition facilitated. Furthermore, the intrinsic cognitive load depends not only on the complexity of the task, but also the knowledge base of the learners. As learners gain expertise in the domain of functioning, they can treat multiple elements as a single element (i.e., chunk), and thus reducing the intrinsic cognitive load.

4. Learning complex tasks

One strategy that learners could utilize to learn complex tasks involving high element interactivity is to sequence the learning process into two separate parts. The isolated element effect is a clear example (Pollock, Chandler, & Sweller, 2002), whereby learners learn individual elements, initially, without having to learn the relationship(s) between them. Learners are required to learn isolated elements in the initial phase of instruction. The relationship between isolated elements is presented to the learners in the subsequent phase of instruction. According to Pollock et al., 2002 this manner of presenting a complex task reduces the intrinsic nature of the task, and thus allows schema acquisition to occur more readily.

In mathematics learning, presenting an algebraic expression such as $-3(4\times - 3) + 8(3 - 2\times)$ in isolated steps, serially, in which each step only focuses on the multiplication of two entities (e.g., $-3 \times 4\times$), is superior to the presentation of the algebraic expression in an integrated format (e.g., $-3 \times 4\times - 3 \times -3 + 8 \times 3 + 8 \times -2\times$), where the two brackets are being expanded simultaneously (Ayres, 2006). Ayres argued that the part-tasks approach reduces the intrinsic nature of the algebraic expression, as working memory only deals with individual steps, one at a time in the initial phase of learning, and then the relationship(s) between the steps at a later stage. In other words, the part-tasks approach enables a learner to acquire individual schemas that correspond to individual steps, gradually. This process of correspondence, in turn, results in the construction of a schema for the algebraic expression. The work of Gerjets, Scheiter, and Catrambone (2004) also supports the benefit of breaking down the task into separate modules, sequentially, in order to facilitate schema acquisition for probability problems. Again, the instructional manipulation does not change the intrinsic cognitive load of the task itself, but it does change the task to a different task that comprises separate modules. Each module, in this case, is associated with low element interactivity, and thus reducing working memory load that is required to learn the task in sequential modules.