Cognitive Load Theory Conference, Wollongong, 29 Feb-2 March 2008.

Strategies used by humans to reduce their own cognitive load

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A strategy (or *modus operandi*) is a way to perform a task. Some strategies can be planned and implemented consciously, supported by controlled knowledge. Other strategies are implemented unconsciously, supported by automatic knowledge. In order to accomplish the same task, different strategies can be implemented and they may implicate different types of cognitive load. Experiments on problem solving within an instructional design context have led to a better understanding of strategies. Some of these studies illustrate that either extraneous or intrinsic cognitive load can be reduced by participants' strategies. The aim of this paper is to review some empirical results which show that strategies are used by people to manage their own cognitive load, that is to reduce it - consciously or not - when it is too high. These strategies can be interpreted as a way to reduce the amount of information that needs to be processed. The fact that these strategies can be implemented both by experts and novices, by adults and young children, is compatible with the hypothesis that cognitive load reducing strategies proceed from biologically primary knowledge (Geary, 2007).

1. Strategies in problem solving

There are several empirical studies whose methodology and results can be interpreted as providing evidence for the hypothesis that people will characteristically attempt to use strategies intended to reduce their cognitive load. Bastien (1987) designed four versions of the same problem. Seventh graders were asked to rank 62/185, 66/170 and 62/170 in numerical size. One version of the problem was presented to a group of 21 pupils. The ratio concerned value for money (a pencil A that cost 62 cents and can write 185 pages, a pencil B that cost 66 cents and can write 170 pages, etc.) where the fraction reflected a "non representable" notion (*i.e.*, it is not possible to develop a mental picture of such a ratio in contrast to "representable" which means that a mental image of the notion can be built.) and the units of the numerator and the denominator were different entities. The second version of the problem was presented to another group of 21 pupils with a statement on rates of participation in a singing group such as 62 pupils from a school of 185 pupils joining a singing group: the fraction corresponded to a "non representable" concept and units in the numerator and the denominator were identical because both refer to numbers of pupils. The third problem concerned precipitation such as 62 millimetres of rain in 185 days (representable; different units). It is easy imagine pupils, but it is very difficult to imagine the ratio of pupils in school, then to compare three different ratios. On the contrary, it is easy to imagine the density of the rain. The fourth problem was about the ski slopes (height 62 meters, length 185 meters) (representable; same units). The results were as follows and have been widely replicated since.

Table 1. Number of students (out of 21) who solved the ranking problem (Bastien, 1987)

	Representable	Not representable
Same units	5 students	11 students
Units different	11 students	19 students

Analysis of the results and how students proceeded to deal with the problems shows that when the ratio is representable, many pupils do not address this problem as a mathematical problem, but as a "concrete problem" (e.g., they draw the slopes); when units in the numerator and the denominator are identical, many students do not identify the mathematical objects to be processed (they use subtraction instead of processing a ratio). In contrast, when the problem is not representable and the units of the numerator and the denominator are different (e.g., the value for money problem), the students solve the problem. In other words, the way the problem is presented influences the strategy which is implemented and that, in turn, influences the outcome.

This result can be interpreted as problem solvers attempting to reduce the intrinsic cognitive load associated with a problem and in the process, mis-representing the problem. Students, by eliminating some of the essential interacting elements of a problem, convert a more difficult problem into an easier one. Unfortunately, in the process, because essential problem elements are omitted, the solutions obtained are incorrect. In other words, the manner of presentation of some problems allowed pupils to reduce the intrinsic cognitive load by processing some information inappropriately. In contrast, other forms of presentation encourage pupils to focus on all the relevant interacting elements needed to perform the task. Intrinsic cognitive load is increased but since all relevant elements are being processed, the problem can be solved correctly. This experiment shows that understanding a problem implies not only understanding the text (i.e., elaborating a situation model), but also identifying the relevant information to be processed.

Another experiment (Bastien, Pélissier & Tête, 1990) illustrates another aspect of the consequences of problem solving strategies. First and 2nd grade participants were presented a set of 18 buttons, which could have two forms (square, round), three colours (black, white, grey) and three sizes (large, medium, small). Participants were asked "to remove all buttons, which were not large, square and black." The 18 buttons were presented in a random pattern on a computer screen (Figure 1).

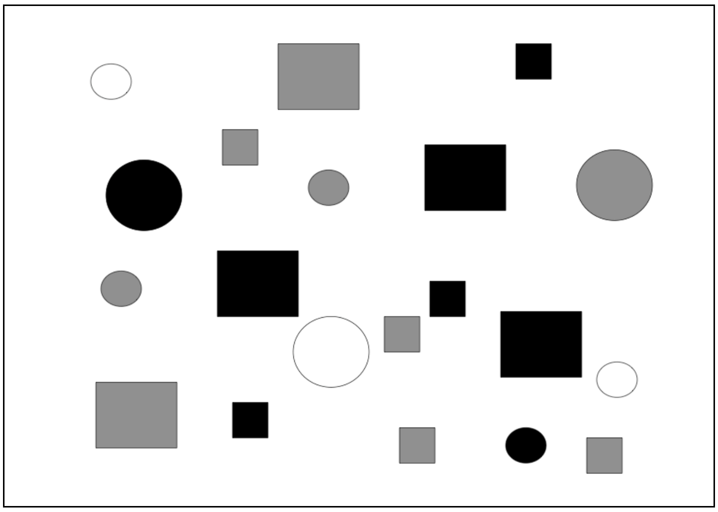

Figure 1. The problem at its initial state

Pupils had to click on a button to eliminate it. Children were presented three consecutive tests, and each test was guided since the experimenter rekindles told it involved an aspect of the buttons it has not eliminated, so that each of the three testing was ultimately be successful. After the three tests, a post-test was presented under similar conditions, but without guidance.

One of the most interesting results was that participants used two types of strategies. One strategy, called "by parts" (Figure 2a), analysed characteristics of the buttons. For example, first, children eliminated all small, grey and round buttons, then small, white round buttons, etc., until the only buttons remaining were large, square and black buttons. This strategy required them to search for all small, grey, round buttons over the entire screen before searching for small, white, round buttons etc. Another strategy was called a “space” strategy (Figure 2b), It consisted of starting from one side of the screen and eliminating all buttons except the big black squares and then repeating the process on the other side of the screen. In other words, children would start on the left of the screen and eliminate all buttons that were not large, square, black buttons. They would continue this process moving from left to right rather than searching for a particular type of “negative” button to eliminate throughout the whole screen.

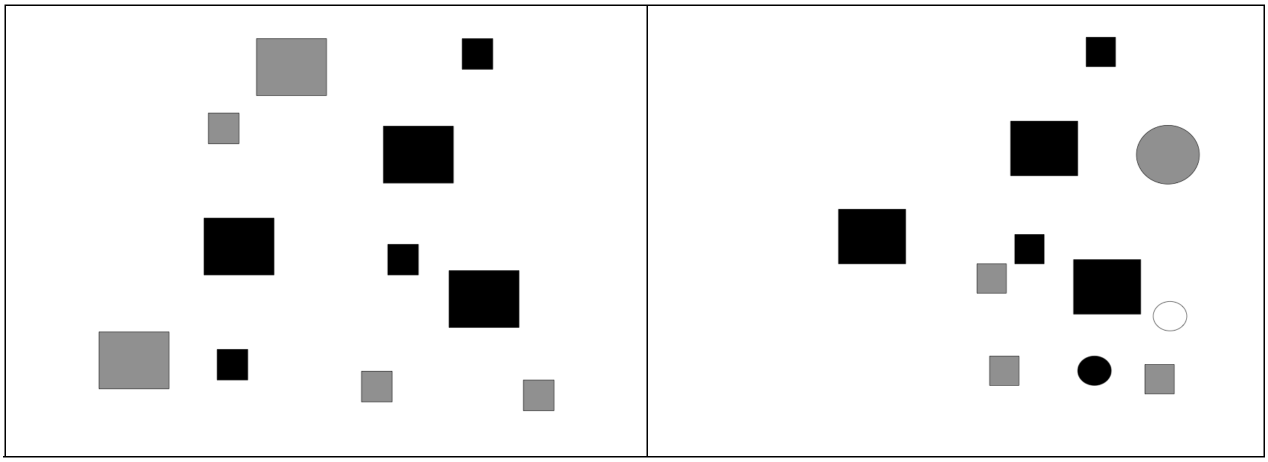

Figure 2b. The problem state after 9 clicks, “by parts” strategy

Figure 2a. The problem state after 9 clicks, “space” strategy

One third of children who used the “by parts” strategy and two-thirds of the children who used the “space” strategy succeed on the post-test. It is interesting to note that some children used the “by parts"strategy in the first test then gradually adopted a “space” strategy on subsequent tests. Compared to the “by parts” strategy, the “space” strategy can be seen as a simplification of the problem. It is a strategy that eliminates a considerable amount of information that needs to be processed. Each button is either "a large black square" or "not a large black square". Using this strategy, it does not matter whether a button is medium or small, grey or white, so long as it is not a large, black square. Using working memory resources to unnecessarily search for a particular type of non large, black, square button imposes an extraneous cognitive load. Both strategies can equally lead to solution but the space strategy will eliminate the working memory load associated with an extraneous search for particular types of buttons.
The “space” strategy is implemented by very young children aged 6, 7 and 8 years, a task with which they are unfamiliar. It is a task not linked to expertise.

These examples of problem solving among children show that the strategies used by individuals, either by choice or due to the way the task is presented, have a direct effect on cognitive load. The first example shows an effect of intrinsic cognitive load: some task presentations lead participants to implement cognitive load reducing strategies in which they exclude essential information and instead devote working memory resources to non relevant information, while other strategies encourage participants to focus on relevant information despite an increase in intrinsic cognitive load. The second example shows the effect of extraneous cognitive load: some strategies allow problem solvers to limit the amount of information to be processed, while other strategies unnecessarily increase the amount of information.

The following examples further illustrate the extent to which strategies are used by learners to manage their own cognitive load during problem solving.

Beilock and DeCaro (2007) investigated the effect of WM capacity and levels of pressure on strategies in mathematics problem solving, like judging the truth value of equations such as 34 - 18 (mod 4). The participants were undergraduate students who were asked to solve problems under low or high levels of pressure. In the high pressure condition, several sources of pressure commonly experienced in real-world testing situations were used: Monetary incentives (e.g., future scholarships, educational opportunities), peer pressure, and social evaluation (e.g., admissions committees, parents, teachers, and peers). The results showed that under low-pressure conditions, the higher individuals' WM, the more likely they were to use computationally demanding algorithms (vs. simpler shortcuts) to solve the problems, and the more accurate their mathematics performance. Under high-pressure conditions, higher WM individuals used simpler (and less efficacious) problem-solving strategies, and their performance accuracy suffered.

Cary and Carlson (1999) designed 2 experiments. They asked the participants to solve complex arithmetic problems with or without an external memory aid (paper and pencil). For the authors, an external memory aid is a way to reduce working memory load. The authors distinguished two different strategies to solve the problem. Concept-based strategies are focused on the problem structure. They imply a deep comprehension of the problem structure and represent a high cognitive load. A demand-based strategy is is used to solve the problem by processing the different steps in the order in which they are presented. The results showed that participants with the memory aid more often developed strategies that corresponded to the conceptual structure of the task. In Experiment 2, the availability both of an external memory aid and of a worked example varied between participants. Examples had the greatest influence on initial problem-solving strategies but did not override the effects of the memory aid. The results provide evidence about the roles of situational and cognitive constraints in shaping problem-solving strategies.

These various experiments demonstrate the extent to which problem solvers alter their problem solving strategies to reduce their cognitive load. Frequently, that reduction in cognitive load benefits performance providing it is extraneous cognitive load that is reduced.

If it is intrinsic cognitive load that is reduced, the reduction may be associated with a reduction in performance.

2. Strategies at work

Sperandio's (1971) work on air traffic controllers provides an excellent illustration of the role of strategies in the management of the cognitive load. Air traffic controllers perform complex tasks in which they must take into account multiple criteria (security, wind speed, fuel consumption, passenger comfort, workload of the crew, and so on). They regularly find themselves in situations where they simultaneously must manage the approach (*i.e*. the stage before landing) of several planes. Of course, the more numerous are the planes, the more complex is the task. Cognitive load may therefore increase in a more or less linear manner, depending on the number of airplanes. It is easy to assume that there is a threshold number of aircraft that reflects cognitive overload and leads to a deterioration of the quality of the work and consequently, an increase in accidents). In fact, Sperandio observed that:

- As long as the number of aircraft is low (between1 and 3), the controllers use sophisticated strategies, taking into account all relevant criteria to realize optimal control. Each criterion is taken into account in the most efficient way.
- When the number of aircraft is intermediate (between 4 and 8), the controllers use less sophisticated but equally effective strategies. They favor certain criteria (security, possibly wind speed…) and eliminate other information that is complex but which yields less useful information.
- When the number of aircraft is important (more than 8), the controllers use rudimentary but very effective strategies, considering only a single criterion: security. Sperandio (1980, p. 99) indicated: "It is ironic to note that for each aircraft, the average time of treatment accorded to information is minimal though it is obviously where the traffic density is high that the problems solved are the largest and most difficult. From the strategic viewpoint, the most frequently used procedures are stereotypical, standard. The flexibility of the system is then low."
- Finally, when the number of aircraft is above the amount that a controller can handle, the workstation is split: two controllers support the relevant space.

3. Conclusion

When children or adults solve problems, the same dual phenomenon is observed: (a) different strategies implemented to achieve the same task can be more or less cognitively costly, based on the quantity of information to be processed to perform the task, (b) to perform the task, individuals can choose, in a more or less deliberate way, less costly strategies. They can reduce the amount of information they process without eliminating the most relevant information and without diminishing their probability of success. The reduction in cognitive load is extraneous to effective performance. Nevertheless, under some conditions, when humans are not able to effectively manage their own cognitive load, the consequences can be negative. If a strategy is employed that reduces intrinsic cognitive load by eliminating essential, interacting elements, performance will suffer.

The version of CLT proposed by Gerjets and Scheiter (2003) introduces the effects of moderator variables in the mapping between instruction design and resulting pattern of cognitive load forms. As configuration of learner goals, learner's activities (processing strategies) may be a moderator variable. The used strategies by learners in an instructional environment may support germane cognitive load and may also trigger extraneous cognitive load. Whereas strategies can imply information processing not effective for learning, other strategies can reduce extraneous cognitive load driving the learner to avoid ineffective processes for learning. Hence, the relations between the instructional design and the cognitive load have to be investigated through the study of the used strategies to reduce cognitive load. Accurately, our proposal leads to consider the strategies that the learners use to regulate their mental effort. The complex task would entail suitable behaviours to reach the task goals, however learner have to maintain acceptable mental effort to perform the task. Hence, learners have to choose and run strategies supporting a decrease of cognitive load (i.e. extraneous and intrinsic load). In learning hypertext environments, Gerjets and Scheiter (2003) suggest that high time pressure would entail strategies leading to process more relevant information (increase germane cognitive load) and to avoid processing of irrelevant information (reduce extraneous cognitive load).

The fact that these strategy changes seem to occur easily and automatically amongst both children and adults without explicit training suggests that the phenomenon is an aspect of biologically primary knowledge. To this point, there seems to be no data suggesting that cognitive load reducing strategy changes can be explicitly taught in the manner of biologically secondary knowledge.

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