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Context Effects on Problem Solving

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Abstract

Context effects on problem solving demonstrated so far in the literature are the result of systematic manipulation of some supposedly irrelevant to the solution *elements of the problem description*. Little attention has been paid to the role of *casual entities in the environment* which are not part of the problem description, but which might influence the problem solving process. The main purpose of the current paper is to avoid this limitation and to study the context effects (if any) caused by such accidental elements from the problem solver's environment and in this way to test the predictions made by the dynamic theory of context and its implementation in the DUAL cognitive architecture. Two experiments have been performed. In Experiment I the entities whose influence is being tested are part of the illustrations accompanying the target problem descriptions and therefore they belong to the core of the context, while in Experiment II the tested entities are part of the illustrations accompanying other problems' descriptions, they are accidental with respect to the target problem and therefore they possibly belong to the periphery of the context (if a context effect could be demonstrated at all). The results demonstrate both near and far context effects on problem solving caused by core (Experiment I) and peripheral elements (Experiment II) of the perception-induced context, respectively.

1. Motivation

Let us recall two famous stories where a particular accidental event or the presence of a particular casual object in the environment has reportedly played a crucial role in human problem solving: (1) Archimedes discovered his law in the bathtub seeing the water overflowing the bathtub when he entered it; (2) seeing an apple falling from a tree gave Newton inspiration for his theory of gravity. Most people will claim they have analogous experience. Surprisingly enough these claims have never been tested in controlled experiments. The current research focuses on exploring whether such accidental objects or events in the problem solvers' environment can influence their reasoning process and on explaining how this could possibly happen.

Although problem solving has always been in the focus of research in Cognitive Science the issues of context influence on problem solving have largely been ignored. Gestalt psychologists initiated the study of context effects on perception and problem solving. However, while in perception they have focused on questions like the figure and background interaction, in problem solving they typically take it as granted that subjects start with a clear problem description (the figure) and the rest of the world is ignored during the problem solving process (the background). Being interested in how the problem representation is being constructed, they have restricted their investigations to cases where all the needed elements are given by the experimenter and the task of the subject is to arrange them in an appropriate way. They have studied some of the obstacles in building correct representations like functional fixedness (Maier, 1931, Dunker, 1945) and set effects (Luchins, 1942), which can be called context effects. Recently Tversky and Kahneman (1981) and Shafir, Simonson and Tversky (1993) have demonstrated context effects on decision making; Johnson-Laird, Legrenzi and Legrenzi (1972), Gick and Holyoak (1980, 1983), McAfee and Proffitt (1991), Cooke and Breedin (1994) have demonstrated context effects on problem solving. However, the context effects demonstrated in the above research are the result of systematic manipulation of some supposedly irrelevant to the solution elements of the problem description. Little attention has been paid to the role of casual entities in the environment which are not part of the problem description, but which might influence the problem solving process.

The main purpose of the current paper is to avoid this limitation and to study the context effects (if any) caused by such accidental elements from the problem solver's environment.

2. A Dynamic Theory of Context

Recently a dynamic theory of context has been proposed (Kokinov, 1995) where context is considered as the set of *all* entities which influence human cognitive behavior on a particular occasion. All these context elements are elements of human working memory. Various entities influence the cognitive process to different degrees, e.g. usually, the goal influences the problem solving process much deeper than a casual object in the problem solver's environment. That is why instead of defining clear-cut boundaries of context it would be better to consider context as a fuzzy set of elements which gradually diminish their influence on human behavior. As a consequence, *context is considered as the dynamic fuzzy set of all associatively relevant memory elements (mental representations or operations) at a particular instant of time*.

There are various sources of context elements: reasoning mechanisms (the set of elements produced and manipulated by them is called *reasoning-induced context*), perceptual mechanisms (the set of elements produced by the perception process and representing entities from the environment is called *perception-induced context*), and memory mechanisms (the set of all elements retrieved/activated by memory processes or being a residue from a previous context is called *memory-induced context*).

The effects of the memory-induced context are usually describedas set effects and priming effects while the effects caused by the perception-induced context are usually called simply context effects. There are many experiments on priming effects on perception, categorization, language comprehension, sentence completion, etc. Some experiments performed by the first author have demonstrated priming effects on problem solving (Kokinov, 1990, 1994a) with very clear dynamic properties: the priming effects disappear in the course of time according to an exponential law. Complementary, in the current work we are interested in *context effects* on problem solving.

A cognitive architecture DUAL has been proposed with a special emphasis on the context-sensitive nature of human cognitive processes (Kokinov, 1994b,c). A context-sensitive model of analogical reasoning, AMBR, has been developed on the basis of this architecture (Kokinov, 1994a). The performed simulation experiments with AMBR have replicated the priming effects obtained in the psychological experiments and in addition they made a prediction about context effects on problem solving. Part of the motivation of the current work is to test these predictions.

The DUAL architecture explains context effects in the following way. The perceptual mechanisms build up representations of the objects in the environment and their properties and relations in the Working Memory (WM) or just reactivate existing representations in Long-Term Memory (LTM) and bring them into the WM. During the period of fixation on a particular object its representation becomes a source of activation, i.e. it continuously emits activation to its neighbors for that period. Moreover, depending on the location of the object in the visual field (center/periphery) and the amount of attention devoted to it, the amount of emitted activation will vary. The basic memory process in DUAL is a process of spreading activation where each WM element continuously spreads its activation to its neighbors. The resulting activation levels of the LTM elements determine their availability (accessibility for the declarative elements and speed of running for the procedural elements). The general predictions that this architecture makes are that (1) every element (be it part of the problem description or not) which is being perceived (and therefore activated in WM) can potentially influence the reasoning process if it happens that it is somehow linked (directly or via a chain of links) to a concept which can play a key role in the solution of the problem, (2) the more the element is attended to the higher its potential influence (if the distance between the element and the key concept is the same), i.e. generally the elements of the core of the contexts (e.g. the elements of the problem description) will have greater impact than the elements of the periphery of the context, (3) for a large number of elements that are not intentionally perceived their influence will be at the subconscious level and could not be reported by the subjects.

Two experiments have been performed. In Experiment I the entities whose influence is being tested are part of the illustrations accompanying the target problem descriptions and are supposed to be attended to even if later on they can be considered as irrelevant, therefore they (rather) belong to the core of the context, while in Experiment II the tested entities are part of the illustrations accompanying other problems' descriptions, they are casual with respect to the target problem and might not be attended to at all, therefore they (possibly) belong to the periphery of the context (if a context effect could be demonstrated at all).

3. Experiment I: Near Context Effects

This experiment investigates the influence that some elements of the environment related to the problem description (without being an explicit part of it) can have on the problem solving process. Similar experiments have been performed by Maier (1931) accidentally bumping against a string to get it swinging providing a hint for the solution of the two-string problem and by Cooke and Breedin (1994) studying effects of irrelevant shapes of objects on naive reasoning about motion and trajectories. In this sense this experiment can be considered as a replication of existing experiments in the case of changing the illustrations accompanying some insight problems. However, instead of exploring whether the illustration can play the role of a hint (e.g. it will raise the number of subjects correctly solving the problem) this study focuses on whether the elements of the illustration can change the way in which the problem is being solved.

3.1. Method

3.1.1. Subjects. 257 subjects (high school students and undergraduate students in psychology, law, drama, journalism and economics at NBU) participated in the experiment.

3.1.2. Design. There were two experimental conditions for each target problem – two different contexts in which it was presented and each subject received one of these two versions (i.e. the experiment had a between-subjects design). Subjects were randomly assigned to the two experimental conditions.

For each target problem the variety of solutions was clustered in several categories and each particular solution proposed by a subject was classified as belonging to one of them by two experts. The number of categories differed from problem to problem depending on the richness of the target domain. The measured variable was the type of the solution proposed by the subject.

There were *control* and *context conditions*. In the control condition subjects received just the standard target problem description which does not include a drawing. In the context condition subjects received an additional picture (Figure 1).

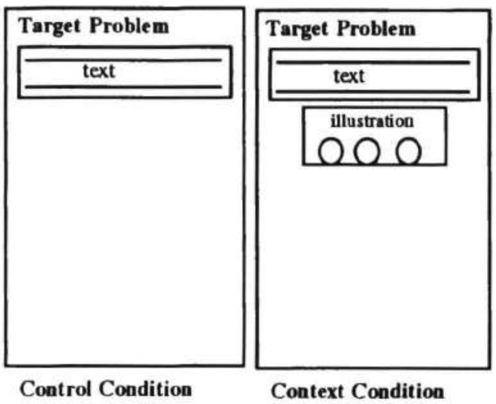

Figure 1. Control and Context Conditions.

3.1.3. Materials. Four target problems were used in the experiment. They can be classified as various insight problems. Because of space limitations only one example target problem will be described.

Target problem (Heating Problem): Imagine you are in a forest by a river and you want to heat up some water. You have only a knife, an axe and a match-box. You have no containers of any kind. You could cut a vessel of wood but it would burn up if placed above the fire. How would you boil your egg using <u>this</u> wooden vessel?

Originally presented in (Kokinov, 1990)

This problem was presented in the following experimental conditions. In the *control condition* subjects received only the textual description of the problem, while in the *context condition* they received a color picture in addition (Figure 2 presents a gray scale copy of it). There are many stones in the picture and the intention was to check whether this would increase the number of subjects using stones in the solution of the problem (as predicted by the simulation experiment).

Figure 2. Picture used as illustration of the target problem in the Context condition.

3.1.4. Procedure. Each subject received sheets of paper each presenting one target problem. They had to solve the problems one by one and for a fixed period of time varying for the different problems (from 1 to 4 minutes). They were not allowed to browse the sheets of papers and look at previous or following problems, or to come later back to previous problems. Subjects were asked to report in case they were familiar with a particular problem and in such cases their results were discarded.

3.2. Results

The solutions produced by the subjects were classified in the corresponding number of categories. Table 1 presents the percentage of generated solutions in each category in each experimental condition for the target problem. The results show that in the presence of the picture significantly more subjects (χ^2=37.89, df=4, p<0.001) produce solutions involving stones (14% produced a solution involving immersing heated stones in the water vs. 5% in the control condition, and 22% produced other solutions involving stones vs. 2% in the control group). This corresponds to the simulation results obtained in (Kokinov, 1994a) and so meets the predictions of the theory.

Similar context effects were demonstrated with the other 3 target problems. Thus our hypothesis about the presence of context effects when manipulating elements of the problem illustration was supported.

	Control	Context
immersing a knife	23	16
immersing an axe	11	10
immersing a stone	5	14
other usage of stones	2	22
other solutions failures	59	37

Table 1. Percentage of answers which fall into the category corresponding to each cell in the Experiment on the Heating Problem.

4. Experiment II: Far Context Effects

This experiment investigates the influence that some marginal elements of the environment (without being part of the description of the problem) can have on the problem solving process. We are not aware of analogous experiments in the literature.

4.1. Method

4.1.1. Subjects. The same subjects who participated in Experiment I participated also in Experiment II.

4.1.2. Design. Experiment II had a similar between-subject design as Experiment I and the same measured variable (type of generated solution). However, on each sheet of paper two problems were presented to the subjects: the first one is the target problem and the second one is the context one.

For each target problem several experimental conditions were designed: a control condition and two or more context conditions differing in the illustration accompanying the second problem on the sheet (Figure 3).

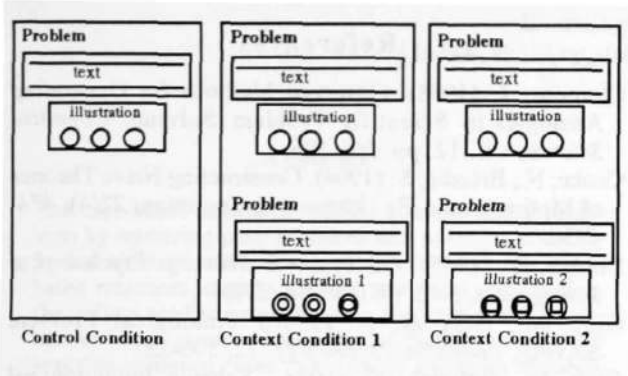

Figure 3. Control and Two Context Conditions.

4.1.3. Materials. Again four insight problems were used in the experiment. The context problems were designed so that the problems themselves and their solutions could not help in the solution of the target problem, but only their illustrations could be found relevant.

Because of space limitations only one such target problem together with the corresponding context problems and their illustrations will be described. Three *different context conditions* were used, i.e. three different context problems were presented in the *different* experimental conditions.

Target Problem 2 (The Spring Problem): Two springs are made of the same steel wire and have the same number of coils. They differ only in the diameters of the coils. Which spring would stretch further down if we hang the same weights on both of them?

Adapted from (Clement, 1988)

Comb Context Problem: From which part of the comb would you produce a higher-pitched sound?

Bent Comb Context Problem: From which part of the comb would you produce a higher-pitched sound?

Beam Context Problem: On a 7 meter long lever two weights are hanging as shown in the picture. If one of the weights is 10 kg, what should the other one be so that the lever remains in balance?

The comb with bent tines in the second illustration (Figure 4) was supposed to activate the concepts of bending and different thickness and consequently the concept of stronger (more robust) material associated with massive (solid) objects and therefore to mislead subjects that the wider spring will stretch less. The lever in the third illustration was supposed to activate the concept of equilibrium and therefore suggests equal stretching of both springs.

The comb in the first illustration was initially designed with the intention to activate bending and different thickness. However, results show that the concept of bending is not activated by this picture (that is why we designed the second picture) and it seems that the fingers pointing to the thicker tines of the comb are associated with the wider spring which will stretch more (which happened to be the right answer).

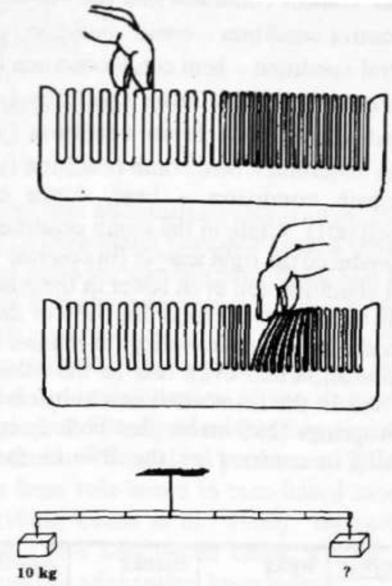

Figure 4. Drawings used for the comb, bent comb and beam context problems.

4.1.4. Procedure. The same procedure as in Experiment I was used, however, the subjects received sheets of paper each containing two problems. There was the following addition to the instruction:

"These sheets of papers were also used in another experiment where the subjects had to solve twice as many problems than in the present experiment. So, when you encounter two problems on the same sheet of paper, please, solve only the first one and skip the second one. In this experiment we are interested only in the first problems."

The reason for instructing subjects to skip the second problem on each sheet (the context one) is that we would like to isolate the context effects from the priming effects, i.e. if the subjects were solving the context problem first or in parallel with the target one then all the concepts used in it would be activated prior to the target problem solving process and would have caused a priming effect, i.e. we would test the influence of the memory-induced context instead of the perception-induced context.

After having finished with the problems the subjects were told the aim of the experiment and its hypothesis and were asked to write down an introspective report on whether they were influenced by the second problems while solving the first ones.

4.2. Results

The solutions produced by the subjects were classified in the corresponding number of categories. Table 2 presents the percentage of generated solutions in each category in each experimental condition.

The results obtained for the spring problem were found to differ significantly in the different context conditions as well as between the control condition and the various context conditions: control condition – comb condition (χ^2=13.07, p<0.01), control condition – bent comb condition (χ^2=6.17, p<0.05), control condition – beam condition (χ^2=10.63, p<0.01), comb condition – beam condition (χ^2=10.83, p<0.01), beam condition – bent comb condition (χ^2=15.55, p<0.001), comb condition – bent comb condition (χ^2=31.99, p<0.001). While in the comb condition 65% of the subjects produced the right answer (in contrast with 46% in the control condition and even fewer in the other context conditions), in the bent comb condition 59% of the subjects gave a preference to the slender spring (in contrast to 45% in the control condition and even less in the other context conditions), and in the lever condition subjects tended to equalize both springs (26% wrote that both springs would stretch equally in contrast to the 9% in the control condition).

answer / condition	wider spring	slender spring	equally
control	46	45	9
comb	65	21	14
bent comb	29	59	12
beam	42	32	26

Table 2. Percentage of answers which fall into the category corresponding to each cell in the experiment on the target problem.

Many subjects reported in their protocols that they were not aware of any relation between the problems (the target and the context ones) and that (as a result of the instruction and time pressure) they have completely ignored the second problem while solving the first one. (Moreover, some of them (fortunately, not many) have unconsciously covered the second half of the sheet with their hands while solving the target problems). However, the results described above provide evidence that these problems have actually influenced subjects' behavior at the unconscious level.

5. General Discussion

The performed experiments have demonstrated both near and far context effects on problem solving caused by core (Experiment I) and peripheral elements (Experiment II) of the perception-induced context, respectively.

The results obtained from the experiment with the Heating Problem are coherent with the simulation results obtained earlier on the same problem (Kokinov, 1994a).

There are many directions for future work as the current work marks only the beginning of more extensive study of context effects on problem solving. Emphasis will be put on far context effects and an attempt will be made to measure context effect as a function of the physical, conceptual and pragmatic distance between the target and the context problem descriptions.

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