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.
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
described as set effects and priming effects while the effects
carried by the memory-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

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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).

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 this 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).

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 ($\chi^2=37.89$, 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.

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Control</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>immersing a knife</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>immersing an axe</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>immersing a stone</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>other usage of stones</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>other solutions failures</td>
<td>59</td>
<td>37</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Problem</th>
<th>Problem</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>text</td>
<td>illustration</td>
<td>text</td>
</tr>
<tr>
<td>OO</td>
<td>0</td>
<td>OO</td>
</tr>
<tr>
<td>text</td>
<td>illustration</td>
<td>illustration</td>
</tr>
<tr>
<td>000</td>
<td>1</td>
<td>000</td>
</tr>
</tbody>
</table>

Control Condition | Context Condition 1 | Context Condition 2

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?

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 ($\chi^2=13.07$, $p<0.01$), control condition - bent comb condition ($\chi^2=6.17$, $p<0.05$), control condition - beam condition ($\chi^2=10.63$, $p<0.01$), comb condition - beam condition ($\chi^2=10.83$, $p<0.01$), beam condition - bent comb condition ($\chi^2=15.55$, $p<0.001$), comb condition - bent comb condition ($\chi^2=31.99$, $p<0.001$). 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).

<table>
<thead>
<tr>
<th>answer</th>
<th>wider spring</th>
<th>slender spring</th>
<th>equally</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>46</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>comb</td>
<td>65</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>bent comb</td>
<td>29</td>
<td>59</td>
<td>12</td>
</tr>
<tr>
<td>beam</td>
<td>42</td>
<td>32</td>
<td>26</td>
</tr>
</tbody>
</table>

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.

Acknowledgements

This research has been partially supported by the Bulgarian National Science Fund under contract OHN406/94.

References


