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OVERCOMING BLOCKS IN CONCEPTUAL DESIGN: THE EFFECTS OF OPEN GOALS AND ANALOGICAL SIMILARITY ON IDEA GENERATION

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ABSTRACT

Designers have been known to seek analogical inspiration during design ideation. This paper presents an experiment that studies the types of analogies that most impact design creativity, as well as the time during problem solving when it is most effective to seek such analogical stimulation. This experiment showed that new information that was highly similar to the problem affected problem solving even if the information was given before problem solving began. On the other hand, new information that was distantly related to the problem only affected problem solving when it was presented during a break after problem solving had already begun. These results support the idea that open goals increase the likelihood that distantly related information become incorporated into problem solving. Functional principles found in the problem-relevant information given were also found to prime solutions in corresponding categories.

1 INTRODUCTION

Researchers have long studied the complicated mental processes used in problem solving. One commonly examined phenomenon, which can inhibit problem solving, is fixation. Fixation was first introduced by the Gestalt psychologists [5] as an often self-imposed obstacle that blocks successful completion of a problem. Fixation can come from any number of sources, and often comes from the mindsets of previously attempted solutions or precedents in how things are usually done.

In design, it has been shown that designers are particularly susceptible to information from example solutions such as existing products that are similar to what is being designed [4][9][14][15]. It is even the case that designers incorporate poor aspects of existing solutions into their own solution [9]. One possible explanation for this is that designers become fixated on these existing design solutions to the extent that they are not able to think of any other ways to solve the current problem. This situation would then lead to a situation where the designer is unable to come up with a new innovative approach to solving the problem.

These experiments show evidence for fixation caused by pictorial examples given with the design problem. While these findings can be useful in the practice of design education as well as for professionals designing in markets where similar products already exist, most real world design problems do not come with example solutions. Instead, designers often look to other devices, whether consciously or subconsciously, that they may have encountered before for inspiration. These devices may often fulfill tasks that are seemingly unrelated to the design problem, but they can contain subsystems and functional principles that may be borrowed to solve the problem at hand. Usually this knowledge comes from life experiences that occurred before problem solving, thus it is important to understand how people in a problem solving task can be reminded of prior information or experiences.

It is also possible that people could encounter relevant information during a break in problem solving, which may lead to a higher rate of analogical mapping [3]. It has been shown that having an open goal to solve a problem, a goal which has been set but one for which the associated task has not been completed, leads to the implicit acquisition of relevant information even while not working on a problem, and that people may be most sensitive to new information around the time where they reach an impasse on a problem [12][13]. In particular, seeing the same problem relevant information before working on the problem is not as effective as seeing the same information during a break from problem solving [12].

In research on analogy, a distinction is often made between surface similarity and structural or deep similarity (e.g.,

[1][6][8]). Surface similarity is similarity in appearance or attributes. For example, two math word problems may both involve similar objects like apples and oranges. However, structural similarity means that two things involve similar relationships. For example, the atom and the solar system involve a similar configuration of objects, but they are not similar in appearance.

A designer may find it difficult to recognize analogically useful information from their past for problem solving if the relationships between the information and problem bear structural similarity but little or no surface similarity. In the case where the problem solver has the goal to solve a problem but has not yet completed the solution, the problem solver has an open problem-solving goal. Having an open goal actually makes it more likely that relevant information is incorporated into problem solving even when the person is not actively engaged in solving the problem [12]. Because of the effects of open goals, designers may be better able to make the connection between this same information and the problem if they see the information after problem solving has begun.

For this reason, one of the main goals of this experiment was to examine whether people are able to better recognize and use relevant principles from sources that are not obviously related to the problem (i.e., items that share functional characteristics but not purpose or appearance) when they have an open goal. To achieve this, surface dissimilar information that is structurally similar is presented to problem solvers either before problem solving or during a break in problem solving. Another goal was to assess whether principles from surface similar sources presented before problem solving affect problem solving more than from surface dissimilar sources. Lastly this experiment examined whether this information could prime similar solution types.

2 HYPOTHESIS

Three hypotheses were examined in this experiment: 1) information that is more distantly related to the problem would impact idea generation more when there was an open goal to solve the problem than without, 2) information that is more obviously similar to the problem would impact idea generation more than distantly related information when seen before problem solving has begun, and 3) functional principles of the presented designs would appear more frequently in the solutions of the participants who saw those designs than in those participants in the control condition who received no problem-relevant material.

3 METHODS

The problem used in this experiment was an open-ended design problem where participants were asked to generate conceptual designs for as many time-keeping devices as possible using only a provided list of household objects. There are two key comparisons for our hypotheses: 1) comparing highly related and distantly related information before problem solving has begun and 2) comparing distantly related information given before problem solving to when the same information is given during a break in problem solving. Three conditions were designed which allowed us to assess these comparisons, and in these conditions we manipulated the timing of when problem-relevant information is given (before problem solving or during a break in problem solving) and whether the presented problem relevant information contains surface similarities or structural similarities. In addition, a control condition was included as a baseline in which participants saw only information irrelevant to the problem solving task. The problem relevant information that was presented was one of two sets of device descriptions. One set consisted of a description of three clocks, and this set was highly similar to the presented problem in function, purpose, and possibly appearance. The other set consisted of descriptions of three distant devices that were not similar to the design problem in appearance or purpose, but in which some of the functional information could be used to solve the design problem. Further details of the experiment and the results can be found in [18].

3.1 Participants

Seventy-one Carnegie Mellon University undergraduate seniors in the Department of Mechanical Engineering were recruited from two senior courses and voluntarily participated in this experiment.

3.2 Design and Materials

All participants solved the same design idea generation problem. The timing and type of problem relevant information given to the participants was manipulated. There were two times when information was presented: before the problem solving began, labeled “pre-problem”; and during a break that occurred five minutes after problem solving began, labeled “during-break”. Each participant was presented with information at these times. The information could either be irrelevant to the problem, a description of three clocks (the surface similar information), or a description of three distant devices (the surface dissimilar information). The three distant devices used were a water meter, a heart rate monitor, and a cassette tape recorder. The irrelevant information, or filler task, consisted of three short summaries of current news stories. The design of all four conditions is shown in Figure 1. Participants were randomly assigned to one of these four conditions.

Participants in the control condition (N=18) were presented with the filler task for both the pre-problem and during-break reading tasks. In the clocks-before condition (N=17) participants were given the clock descriptions for the pre-problem reading task, and the filler task for the during-break reading task. In the devices-before condition (N=18) participants were given the descriptions of distant devices for the pre-problem reading task, and the filler task for the during-break reading task. In the devices-during condition (N=18) participants were given the filler task for the pre-problem reading task, and the descriptions of the three distant devices for the during-break reading task. The filler task used for the clocks-before condition, devices-before condition, devices-during condition, and for one of the control condition breaks was the same.

3.3 Procedure

The experiment was run in groups in two consecutive class times, with 41 participants in the first class and 30 in the second. Participants received visibly identical packets that contained all materials. Each task was contained in a separate envelope within the packet labeled A, B, C, and D to be used in sequence. The participants were verbally instructed between tasks to advance from envelope to envelope, and were only allowed to view the materials in the current envelope at any one time.

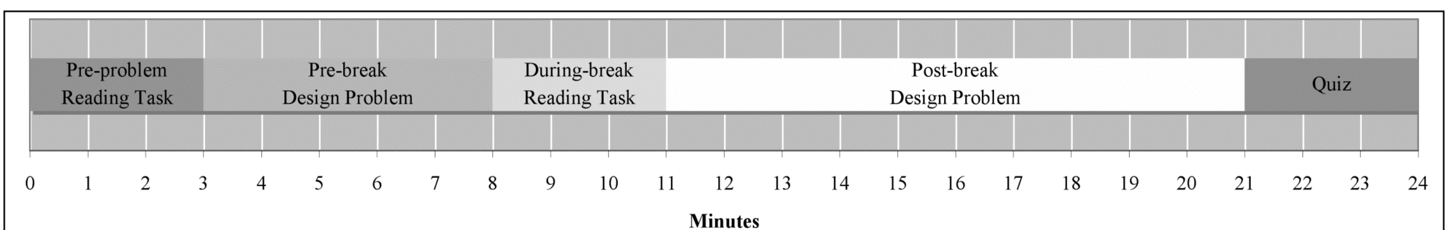
Each participant began with the three-minute reading task, which was specific to his or her randomly assigned condition. Next, all participants were given five minutes to work on the design problem. All participants were instructed to draw or describe their solutions consecutively in the boxes provided and to label each box with the time they finished the solution in hh:mm:ss format, as projected in the front of the classroom. Fourteen boxes were provided for each problem solving session, and no participant reached this limit. The participants were encouraged to generate as many solutions as possible. After the five minutes, the participants were given a break from problem solving during which they were given three minutes for the second reading task. After the break, all participants were given an additional ten minutes to continue work on the design problem in the same format as before. The participants were verbally instructed not to write down the same answers as before but told that these solutions should be in addition to the previous solutions from the first 5 minutes. The participants were not allowed to look back at their previous solutions. At the end, all participants were given a previously announced quiz to assess whether they retained the information from the two reading tasks to ensure that they read the material and that any failure to use the material in problem solving was not due to an inability to remember the information.

3.4 Data Analysis

All solutions were analyzed from the drawings and descriptions, resulting in fifteen functional categories that were found to fit 97% of all solutions generated. The remaining three percent were lumped into a sixteenth category of "other" solutions. Solutions that simultaneously included principles from multiple functional categories were placed in all relevant categories in fraction. For instance, a solution that uses the sink to fill a container in a see-saw arrangement to offset the 3 kg weight on the other side would be placed half in the "rate of flow/fill" category and half in the "weight equilibrium" category. Solutions that spanned multiple categories were only included in the tabulation for repeated functional category if both solutions were categorized in exactly the same categories. Solutions that were incomplete, implausible, or nonsensical were not included in the data evaluation and represented less than 4% of the total solutions.

One researcher first coded all data, and then the designs generated by five participants from each condition (28% of the data) were randomly selected and were coded by another researcher. The two researchers showed 89% agreement and a Cohen's Kappa of 0.87, which supports the use of this coding system as a reliable way to categorize the data.

Using this categorization, four dependent measures were defined. 1) The total number of designs is the number of solutions generated by each participant in both the five minute pre-break and ten-minute post-break time periods. 2) The number of functional repeats is the number of times a participant generated a solution in a functional category in which they had already generated a solution. Solutions that spanned multiple categories were only counted as a repeated design if both solutions were categorized in exactly the same set of categories. 3) The number of functionally distinct designs is the number of different categories a particular subject generated at least one design in. 4) The novelty of each solution is a measure of its uniqueness across all participants' solutions and was measured by adapting an originality metric defined in [9]. The novelty of a particular design is found as the sum of the 'n' scores for an individual's ideas divided by the number of ideas generated for that participant. The 'n' score for each item was calculated across all conditions as:



	Pre-problem Reading Task	Pre-break Design Problem	During-break Reading Task	Post-break Design Problem	Quiz
Devices-during	Filler 1 →	Design Problem →	Devices →	Design Problem →	Quiz
Devices-before	Devices →	Design Problem →	Filler 1 →	Design Problem →	Quiz
Clocks-before	Clocks →	Design Problem →	Filler 1 →	Design Problem →	Quiz
Control	Filler 1 →	Design Problem →	Filler 2 →	Design Problem →	Quiz

Figure 1: Experiment design for all four conditions.

$$n = 1 - \frac{\#\ \text{of functionally similar designs generated by other subjects}}{\text{total}\ \#\ \text{of designs for all subjects}}.$$

Two designs were considered functionally similar designs if they were both assigned to the same functional category.

4 RESULTS

The average total number of designs, number of functional repeats, and the number of functionally distinct solutions for each condition is shown in Figure 2, and the average novelty of the designs for each condition is shown in Figure 3. Participants in all conditions answered an average of 88% of the post-experiment quiz questions correctly and this percentage did not differ significantly between conditions; thus any observed differences were not due to a failure to encode and access the presented information. For all statistical tests an alpha level of .05 was used ($\alpha = .05$).

4.1 Open goals and distantly related devices

The first hypothesis was that devices which are more distantly related to the problem would impact idea generation only when there was an open goal to solve the problem. This hypothesis was examined by comparing the devices-before condition to the devices-during condition.

Participants in the devices-before condition produced more total designs, $t(34) = 2.28$, $p = .03$, than participants in the control condition, but with more functional repeats, $t(34) = 2.92$, $p = .006$. The devices-before condition did not differ significantly from control in the number of functionally distinct designs or novelty. This suggests that some of the information was recognized and applied, although with only an increase to the quantity of solutions and not to the variety. Participants in the devices-during condition produced solutions that were marginally more novel, $t(34) = 1.92$, $p = .06$, as well as more total designs, $t(34) = 2.11$, $p = .04$, without the added functional repeats, resulting in more functionally distinct designs, $t(34) = 2.50$, $p = .02$, when compared to the participants in the control condition.

Participants in the devices-during condition generated fewer functionally repeated solutions, $t(34) = 2.03$, $p = .05$, solutions that scored higher in novelty, $t(34) = 2.63$, $p = .01$, and marginally more functionally distinct solutions, $t(34) = 1.87$, $p = .07$, than participants in the devices-before condition. To investigate the timing issue in more detail, the number of functionally distinct solutions in the pre-break period and the post-break period were examined for these two conditions. Participants in both conditions produced a similar number of functionally distinct solutions in pre-break problem solving, $t(34) = 0.14$, $p = .89$, but in post-break problem solving, participants in the devices-during condition produced significantly more functionally distinct solutions than participants in the devices-before condition, $t(34) = 2.54$, $p = .02$. In other words, the distantly related set of three distant device descriptions presented before the problem did not give the devices-before condition any advantage in the pre-break period, but the distant device descriptions did give the devices-during condition a significant advantage in the post-break period.

While there was some effect on the devices-before condition relative to control, comparing the devices-before and devices-during conditions clearly shows that the device descriptions affected problem solving significantly more when there was an open problem solving goal. These results support the first hypothesis that having an open goal increases the positive effect of distantly related information.

4.2 Surface similarity

The second hypothesis was that information that is more closely related to the problem would impact idea generation more than distantly related information when both were given before the problem began. This hypothesis was evaluated by comparing the clocks-before and devices-before conditions.

These two conditions did not differ significantly in terms of the total number of solutions generated, the number of functionally repeated solutions, or the number of functionally distinct solutions. The level of surface similarity of the material did affect the novelty of the solutions generated as participants in the clocks-before condition scored significantly

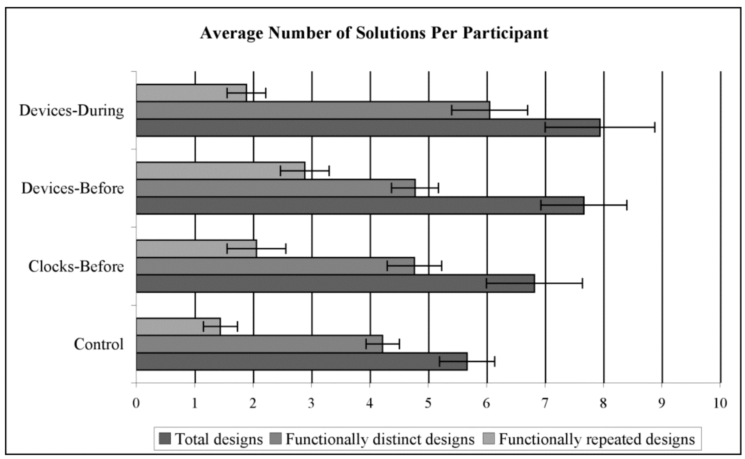


Figure 2: Average number of solutions per participant

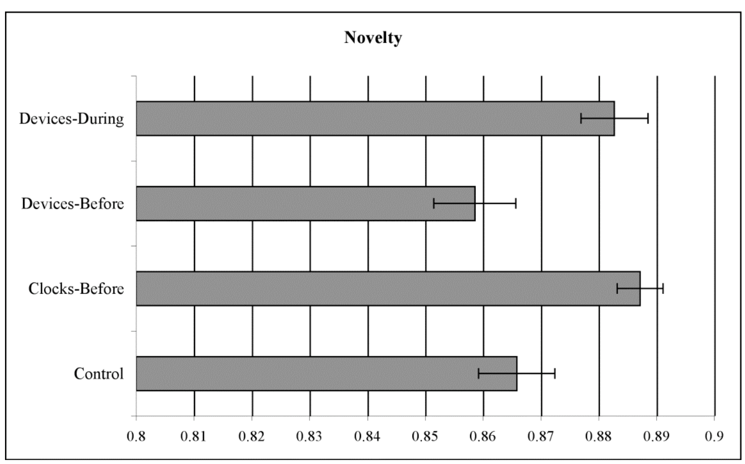


Figure 3: Average novelty per condition

higher in novelty than participants in the devices-before condition, $t(34) = 3.46$, $p = .002$. Participants in the clocks-before condition also scored significantly higher in novelty than participants in the control condition, $t(33) = 2.73$, $p = .01$. As stated earlier, the participants in the devices-before condition generated more solutions in total, but failed to generate more functionally distinct solutions or solutions high in novelty than the control condition. These results support the second hypothesis that information that is more obviously similar to the problem impacts idea generation more than distantly related information when seen before problem solving has begun. However, this highly related information only impacted the novelty of the solutions and none of the other measures. The analyses in the next section shed some light onto why the novelty of the solutions increased in the clocks condition relative to the control and devices-before conditions.

4.3 Priming of design solutions

The third hypothesis was that the information provided to participants was expected to prime specific functional principles to be used in solving the problem. The three clock descriptions were expected to prime pendulum based solutions, and the three distant device descriptions, a heart rate monitor, a water flow meter, and a cassette tape deck, were expected to prime solutions in the heart rate, rate of flow/fill, and unwinding and pulling of tape categories respectively. All four primed functional principles did appear more frequently in the solutions generated by participants in corresponding conditions than solutions generated by participants in the control condition.

Since many of the participants did not produce designs in a particular category, a non-parametric test, the Wilcoxon rank sum test, was used to assess the priming effects rather than a t-test. Participants in the devices-during condition generated marginally more rate of unwinding and pulling of tape solutions than the participants in the control condition, $W=125.5$, $p = .078$. The three obtained heart-rate solutions only occurred in conditions where participants were presented with the distant device descriptions. It is difficult to measure the statistical significance of this result due to the low frequency with which it occurred. The devices conditions generated more rate of flow/fill solutions than the control condition, and the clocks condition generated more pendulum solutions than the control condition, although these expected priming effects did not approach or reach statistical significance.

5 DISCUSSION

The results support all three hypotheses. There was strong support for the hypothesis that open problem solving goals influence the acquisition and use of distantly related information. The results also agree with prior work on analogical transfer showing that distantly related information is often not recognized as relevant, but that information that shares surface similarity with the problem is recognized as relevant. There was also some evidence that the functional principles in the presented devices were primed and used in the solutions.

Open problem solving goals have been shown to influence information acquisition in problem solving even when people are not working on a problem [12]. However, this initial work on open goals used simple problems. The results presented here extend this work to a more complex problem and suggest how open goals may interact with analogical transfer by allowing for the recognition and use of distantly related analogies.

When devices that were functionally related to the problem but not related in purpose or appearance were presented before participants had a chance to attempt the problem, it was indeed difficult for participants to recognize and apply the information, resulting in no more functionally distinct solutions than from participants who received no relevant information. This same distantly related information, presented after the participants were given five minutes to work on the problem, resulted in a significant increase in both the number of functionally distinct solutions and the novelty of the solutions.

Participants who received the priming examples generated more solutions in all primed solution categories than participants in the control condition. Although this effect did not always reach statistical significance, all four primed examples saw shifts in the number of solutions in the expected direction when compared to the control case. The incorporation of aspects of example solutions has been shown to occur in design (e.g., [9][15]), and so it is not surprising that we found them as well. What is interesting is the extent to which distantly related devices primed solution concepts. Most prior work on design idea generation has focused on presenting examples that are actually solutions to the problem at hand (e.g., [9][14]). Our results therefore extend this prior work by showing that distantly related information can actually prime solution concepts when presented during a break in problem solving. The optimal timing of such information is left for future work.

The clock descriptions bear more surface similarity to the problem since they are literally time keeping devices, so analogies from them can be more easily applied to problem solving. Because of this, participants who received the clock descriptions before starting the problem scored significantly higher in novelty when compared to the participants who received device descriptions before starting the problem. This change in the distribution of solutions and the lack of differences between control and the devices-before condition is evidence that in the absence of open goals, surface similar information is more readily applied to problem solving than surface dissimilar information.

Our results have a number of implications for improving design methodology. Analogical inspiration in design can clearly be a powerful way to increase the number and variety of solutions generated in problem solving leading to better and more novel designs. From the results of this experiment and from prior research, the best time to seek analogical inspiration for maximum effect is after work on the problem has begun. In fact, the point at which the designer reaches an impasse in problem solving, namely when no new significant design concepts are being generated, may be the best time to take a break [13]. When searching for analogical inspiration, both information that is surface similar and dissimilar to the problem solving task at hand can be considered, resulting in the possibility of wide variation in potentially inspirational information, but the dissimilar information is the most influential and effective when received after problem solving has begun. Given that it has been found that it is not necessary for the problem solver to even be aware of encountering the relevant information for it to have an impact on problem solving, it may be best to engage in a variety of tasks where exposure to disparate information is encountered. One possible application to design practice would be to improve existing design ideation methods (e.g., [10][17]) to take advantage of this cognitive process. In fact, prior research has suggested that expert design engineers readily use analogies based on both structural cues and surface cues when designing, while novice design engineers frequently only use analogies based on surface cues [1]. The results of our experiment suggest that open goals can help even novice designers to apply analogies garnered from structural similarities. Further work can help to develop design tools that can better stimulate distant analogies for novices and experts alike, resulting in better and more novel designs.

6 CONCLUSIONS

There is an interesting relationship between the nature of analogies in newly given information and when this information is given that determines whether the information is effectively utilized in problem solving. It was found that new information that was highly similar to the problem affected problem solving even if the information was given before problem solving began. On the other hand, new information that was distantly related to the problem only affected problem solving when it was presented during a break after problem solving already began. These results support the idea that open goals increase the likelihood that distantly related information become incorporated into problem solving. These distantly related ideas may spur innovative or creative solutions to design problems. Functional principles found in the problem-relevant information given were found to prime solutions in corresponding categories.

As a result of these findings, the best time to intentionally seek and introduce problem relevant information may be after problem solving has begun. At this point the problem solver has open goals, which can help the problem solver to make connections between the information and the problem, especially when the information is not obviously similar to the problem being solved. The positive effects of open goals on the ability for a designer to successfully apply distant information to problem solving are significant and need to be examined further in more complex problems. There are also a number of potential applications for this work including possible improvements to design methods and the creation of computational design aids.

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