The role of timing and analogical similarity in the stimulation of idea generation in design

Ian Tseng[1], Jarrod Moss[2], Jonathan Cagan[1], Kenneth Kotovsky[1]

[1]Carnegie Mellon University, [2]University of Pittsburgh

Abstract

An experiment was conducted to gain an understanding of how people assimilate and apply newly acquired information when ideating solutions to a design problem by studying how the nature of problem-relevant information and timing of when it is given can affect idea generation in an open-ended design problem. More specifically, the effects of presenting surface similar information before design conceptualization, or surface dissimilar information before and during design conceptualization on the quantity, breadth, and novelty of solutions generated were analyzed. The effects of open goals, fixation, and priming, as well as their implications in design problem solving are examined. It was found that information that is more distantly related to the design problem impacted idea generation more when there was an open goal to solve the problem, while information that is more obviously similar to the problem impacted idea generation more than distantly related information when seen before problem solving has begun. Evidence of induced design fixation and priming were also observed.

Keywords: problem solving, design cognition, creativity, conceptual design

We have observed professional designers breaking from the conceptualization process at points of frustration or impasse to browse magazines or surf the web, seemingly with no specific purpose. When returning to the ideation process, new concepts begin to emerge. This paper contributes to the literature of foundational cognitive principles that inform the design process. In particular, this work studies the types of analogies that most impact design creativity, as well as the timing when it is most effective to seek such analogical stimulation.

The initial stages of design often consist of generating ideas for a conceptual solution to the design problem. There have been many attempts to formalize this ideation process beginning with the initial proposal for brainstorming (Osborn, 1957) to more recent attempts to experimentally compare different ideation methods (Linsey, et al., 2005; Shah, 1998). During these initial conceptual stages, 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 (Chrysikou & Weisberg, 2005; Jansson & Smith, 1991; Perttula & Liikkanen, 2006; Purcell & Gero, 1996). Designers have even been observed to incorporate poor aspects of existing solutions into their own solution (Jansson & Smith, 1991). One possible explanation for this is that designers become fixated on existing design solutions to the extent that they are not able to think of any other ways to solve the current problem. In this situation, fixation on existing solutions could prevent the designer from being able to come up with an innovative solution to the problem. While these findings may be useful in routine design when similar products already exist, new design problems seldom come with example solutions. Instead, designers often subconsciously look to other devices that they have encountered or may encounter while working on the problem.

Some theories of creativity posit that the source of creative ideas is the combination of distantly related concepts (Campbell, 1960; Simonton, 1999). Perhaps if designers were able to think of distant but relevant ideas, they could avoid becoming fixated on existing solutions. However, research has shown that people are not very good at retrieving and using information that is analogically related to the problem they are trying to solve (e.g., Forbus, Gentner, & Law, 1995; Gick & Holyoak, 1980). These findings lead to the conclusion that people only rarely make use of distantly related information when they are trying to solve a problem.

However, it has been noted that much of this work on analogical transfer has made use of an experimental design where people learn about some material and then later attempt to solve a problem where the learned material could be analogically mapped on to the problem to help solve it. Alternatively, people could encounter relevant information during a break in problem solving that may lead to a higher rate of analogical mapping (Christensen & Schunn, 2005). People who encounter information after work on a problem has begun have an open problem-solving goal. An open goal has been defined as a goal which has been set but one for which the associated task has not been completed. In fact, it has been shown that having an open goal to solve a problem leads to the implicit acquisition of relevant information even while not working on a problem (Moss, Kotovsky, & Cagan, 2007a). Additionally, people may be most sensitive to new information around the time when they reach an impasse on a problem (Moss, Kotovsky, & Cagan, 2007b).

In research on analogy, a distinction is often made between surface similarity and structural or deep similarity (e.g., Forbus et al., 1995; Holyoak & Koh, 1987). Surface similarity is similarity in appearance or attributes. For example, a bicycle may bear some resemblance to a pair of glasses when viewed from the side or two math word problems may both involve similar objects like apples and oranges. Structural similarity, however, 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. Two math problems may be similar on the surface as noted, but when one involves calculating the total amount of fruit and the other involves calculating the probability of picking an apple out of a bin of apples and oranges, then the two problems are structurally different.

In design, devices can be similar in appearance, purpose, or function. Here, purpose is defined as the main way in which the device is used while function involves a more abstract view of what the device is doing. Two different types of clocks may be highly similar in function, purpose, and appearance. A clock and a watch may be similar in function and purpose but less similar in appearance. However, a bathroom scale and a pressure gauge may be similar in function (i.e., measuring a force, or force per unit area), but not at all similar in appearance or purpose.

Based on the results in the analogy literature described above, designers may find it difficult to recognize analogically useful information from past design experiences if the relationships between the experiences and problem bear structural similarity (i.e., functional similarity) but little or no surface similarity (i.e., appearance or purpose). 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. Since having an open goal makes it more likely that relevant information is incorporated into problem solving even when the person is not actively engaged in solving the problem, 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.

It has also been found that general representations of analogous information are more likely to be applied to cross-domain design problems than domain specific representations (Linsey et al., 2007). For instance, framing an air mattress as “a device that uses a substance from the environment it is used in”, rather than “a device that is filled with air” makes it more likely to be used later in relevant design problems. So, encountering information that leads to a more general framing or representation of the information may make it more likely to be used while solving a design problem.

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 examine this, surface dissimilar information that was structurally similar was presented to problem solvers (designers) either before conceptualization (problem solving) or during a break in conceptualization. In addition, this surface dissimilar information was presented as a group of different devices to encourage a more general representation of the information. Another goal was to assess whether principles from surface similar sources presented before problem solving affect problem solving more than from surface dissimilar sources, and so a condition where surface similar information was presented before problem solving was compared to the case where surface dissimilar information was presented before problem solving.

1. Hypothesis

Three hypotheses were examined in this experiment: 1) devices which are more distantly related to the problem would impact idea generation more when there was an open goal to solve the problem, 2) information which 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.

2. 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. The open-ended nature of the design problem meant that there would be a large number of possible solutions. 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 only saw irrelevant information. 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.

2.1 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.

2.2 Design and Materials

All participants solved the same design idea generation problem, which is shown in Figure 1. 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 device descriptions are shown in the Appendix. The design of all four conditions is shown in Figure 2. 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.

2.3 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. The format with two sample solutions can be seen in Figure 3. 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.

2.4 Data Analysis

All solutions were analyzed using the participants' drawings and descriptions. Each solution was categorized inductively according to the function(s) used to tell time in the design. For example, the solution shown in Figure 3(a) was categorized as a "Rate of

Heating/Cooling" solution. Any functional category used by more than one participant was added to the list. This categorization resulted in fifteen functional categories that were found to fit 97% of all solutions generated. The remaining singular solutions were lumped into a sixteenth category of "other" solutions (3% of the solutions). Solutions that included principles from multiple functional categories were placed in all relevant categories in fraction (4% of the solutions). 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, as seen in Figure 3(b), would be placed half in the "rate of flow/fill" category and half in the "weight equilibrium" category. Some solutions were deemed invalid when a design used a component not given in the problem statement, or where the description of the device was incomplete or abandoned. These invalid solutions, which made up less than 4% of the data, were excluded from analysis. The resulting average number of designs per participant in each category can be found in Table 1. All data was first coded by one researcher as described above, 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 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. Note that the sum of a participant's functionally distinct designs and repeated designs is equal to the total number of designs generated by that participant. 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 by Jansson & Smith (1991). 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:

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

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

3. 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 4, and the average novelty of the designs for each condition is shown in Figure 5. 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 ($\alpha = .05$).

3.1 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 shows 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 during-devices 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.

3.2 Surface similarity

The second hypothesis was that information which 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 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.

3.3 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. As can be seen in Table 1, 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.

An unexpected finding that was noticed while examining the distribution of solutions across categories was that there was an inverse relationship between two functional categories. The clocks-before condition produced fewer rate of flow/fill solutions than were produced by the participants in the other conditions while producing more drip solutions than the other conditions. This is interesting because both types of solutions involve measuring a quantity of liquid as it leaves a container. In the flow/fill solutions the amount of liquid flowing into or out of a container is used to measure time while in the drip solutions the number of drips as the liquid flows is counted.

To test whether this tradeoff between the two categories was significant, a preference score was created for each participant in the clocks-before and control conditions by subtracting the number of drip solutions from the number of flow/fill solutions. Participants in the clocks condition had a higher preference score for drip solutions more than flow/fill solutions, $W = 91.5$, $p = .04$. Individual analysis of the participants shows that generating a solution in either the rate-of-drip or rate-of-flow/fill categories seems to prevent the participant from generating any solutions in the other category. Out of 71 participants only 12 generated both rate-of-flow/fill solutions and rate-of-drip solutions. Of those 12, eight of them switched from one to the other at the break, and only four switched during a problem solving session. The participants that first generated a rate-of-flow/fill solution later generated a total of 82 rate-of-flow/fill solutions and only 4 rate-of-drip solutions. Similarly of the participants that first generated a rate-of-drip solution would go on to generate a total of 22 rate-of-drip solutions and 12 rate-of-flow/fill solutions. This is evidence that the participants may have been fixated on one problem solution category, which then prevented them from generating solutions in the other category. One possible explanation for this fixation was that the tick-tock noise described in one of the clock descriptions primed the rate-of-drip solutions. Another possibility is that the clocks descriptions primed measuring a liquid in a discrete counting drips way, which then inhibited thinking about measuring the liquid in the continuous flow/fill way.

4. 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 (Moss et al., 2007a). However, this initial work on open goals used simple problems. The results presented here extend this work to a more complex problem and indicate 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 correct direction when compared to the control case. The incorporation of aspects of example solutions has been shown to occur in design (e.g., Jansson & Smith, 1991; Purcell & Gero, 1996), 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., Jansson & Smith, 1991; Perttula & Liikkanen, 2006). 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. The clocks conditions apparently primed the creation of drip counting solutions which were less frequent in the other three conditions, and therefore these solutions increased the novelty of the clocks-before condition because the solutions generated by participants in the clocks-before condition were appreciably different from the solutions generated by participants in the other conditions. This priming could have occurred because the clocks primed thinking about measuring time discretely as counting the number of drips or because the tick-tock in the clocks primed the sound of dripping. 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.

The inhibition of one or more solutions caused by a block or fixation on prior ideas is a common theme in the problem solving literature (e.g., Duncker 1935/1945; Janson & Smith, 1991; Smith & Blankenship, 1991). When a problem solver starts a problem, it may initially be easy to generate different ideas, but after generating a few ideas it becomes harder to generate new ideas because the previously generated ideas interfere with the ability to generate future ideas. This kind of fixation has been shown in simple problems (Moss et al., 2007b). In computational models of human memory such as ACT-R (Anderson et al., 2004) an item's probability of retrieval is based on how well a person's current context primes the item as well as how recently and frequently the item has been retrieved in the past. So, the first few ideas that a person generates in a design problem may be continuously retrieved both because these were the ideas that were best primed by the given problem and because they have recently been retrieved. In design, fixation is likely to occur over both short and long time periods. Short-term fixation is likely due to the recency and frequency with which some idea or object is encountered or recalled. One approach to overcoming this fixation is to take a break from the problem. This helps to overcome short-term fixation due to frequency and recency of retrieval, but it does not change the long-term associations that led to the initial solution concepts in the first place (Wiley, 1998). Fixation due to long-term associations between the design problem and other concepts is therefore unlikely to be overcome by just taking a break from the problem. However, exposure to new information after there is an open problem solving goal may allow new ideas to enter the problem solving process and help to overcome fixation due to long-term associations as one proposed model of the open goal effect states that open goals lead to the formation or strengthening of associations between the problem and relevant information that is encountered after a problem solving goal has been established (Moss, 2007a).

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 (Moss et al., 2007b). 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 application to design practice would be to improve existing design ideation methods (e.g., Linsey, et al., 2005; Shah, 1998) to take advantage of this cognitive process. There are even opportunities for design tools that aid idea generation by presenting a wide variety of design stimuli since people are generally not very good at coming up with distant analogies on their own.

5. Conclusions

The timing and analogical similarity of newly acquired information plays a role in generating ideas and solving problems in design. By manipulating the type and timing of relevant information, it was found that highly similar information impacted problem solving even before problem solving began, but distantly related information only affected problem solving when it was presented during a break. 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. Evidence of induced design fixation was observed as participants exhibited an interesting tradeoff behavior when thinking about two distinct solution approaches (liquid flowing versus counting the number of drips). This relationship suggests that the participants became fixated from a priming hint, and were unable to generate solutions from the other similar solution category.

Analogical inspiration is not only a powerful tool in design, but it is also one that could show much greater potential with further research. 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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Appendix

Three-clocks description:

Please read and study this information until we tell you to stop. You have three minutes. There will be a quiz on this material at the end.

Grandfather Clock

A grandfather clock uses the constant period of a swinging pendulum to provide a continuous and stable reference frequency. This pendulum in turn drives the escapement, which is generally a gear and a pair of stops, which are actuated by the pendulum, that allow one tooth of the escapement's gear to "escape" after each full swing of the pendulum. The engagement of the two stops results in the characteristic "tick" and "tock" sounds of a clock. The escapement's gear is connected to a series of gears that control the relative speed of rotation between the escapement and the hands of the clock, the bells, and other elements of the clock. The energy to drive the hands is provided by a set of dropping weights that drop a small amount per cycle. These weights also provide just enough energy to the pendulum to overcome friction via the escapement.

Windup Clock

A windup clock uses the constant period of a spring powered rotating mass or flywheel, which works much like a pendulum in providing a continuous and stable reference frequency. This flywheel drives an escapement much like as used in a grandfather clock, which in turn drives the hands and other functions of the clock. The flywheel is generally small and turns at a much higher frequency than a pendulum, which results in the ability to drive a second hand. The power to drive the flywheel and the hands is provided by a spring, which is tensioned by winding.

Quartz Wristwatch

A quartz wristwatch uses an electronic quartz crystal oscillator to provide a constant period. Most battery-powered crystal clocks use a 32.768 kHz oscillator. Using the piezoelectric effect, an excited crystal generates voltage pulses, which are then divided down using a frequency divider or counter and used to drive a tiny electric motor, which in turn drives the hands and other functions of the wristwatch.

Three distant devices description:

Please read and study this information until we tell you to stop. You have three minutes. There will be a quiz on this material at the end.

Heart Rate Monitor

A heart rate monitor is a device that allows a user to measure his or her heart rate in real time. It usually consists of two elements: a chest strap transmitter and a wrist receiver (which usually doubles as a watch). Strapless heart rate monitors are available as well, but lack some of the functionality of the original design. Advanced models additionally measure heart rate variability to assess a user's fitness.

The chest strap has electrodes in contact with the skin to monitor the electrical voltages in the heart. When a heartbeat is detected a radio signal is sent out which the receiver uses to determine the current heart rate.

Cassette Tape Deck

A tape recorder, tape deck, reel-to-reel tape deck, cassette deck or tape machine is an audio storage device that records and plays back sound using magnetic tape, either wound on a reel or in a cassette, for storage. It records a fluctuating signal by moving the tape across a tape head that polarizes the magnetic domains in the tape in proportion to the audio signal.

Professional recorders usually use a simple three-motor scheme. One motor with a constant rotation speed provides traction for the leading wheel that is usually combined with a capstan and flywheel to ensure that the tape speed does not fluctuate. The other two motors apply constant torque to maintain the tape's tension or wind the tape quickly. Cheaper models use a single motor for all required functions. There are also variants with two motors, in which one motor is used for rewinding only.

Water Meter

A water meter is a device used to measure water usage. Water meters are normally used at every residence and commercial building in a public water system. Water meters can also be used at the water source, well, or throughout a water system to determine flow through that portion of the system. Water meters typically measure and display total usage in US gallons, cubic feet, or cubic meters on a mechanical or electronic register.

Water meters typically fall into two categories. A displacement type water meters relies on the water to physically displace the moving measuring element in direct relation to the amount of water that passes through the meter. The piston or disk moves a magnet that drives the register. A velocity type water meter measures the velocity of flow though a meter of a known internal capacity. The speed of the flow can then be converted into volume of flow for usage.

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Figure 1: Idea generation problem.

The clock is one of the oldest human inventions, requiring a physical process that will proceed at a known rate and a way to gauge how long that process has run. As the seasons and the phases of the moon can be used to measure the passage of longer periods of time, shorter processes had to be used to measure off hours, minutes, and seconds.

You need to come up with as many of these shorter processes to measure the passage of hours, minutes, and seconds as you can in ten minutes. The time measurement does not have to be in any known unit so long as it is repeatable so that you can repeat it with a clock at a later time.

You are alone in a large featureless room with no windows, a door with doorknob, a hanging light fixture on the 10-foot ceiling, and a sink and drain with working tap.

The only other items in the room are:

Three rolls of adhesive tape a roll of twine a 1 qt Tupperware container with lid a gallon metal can of black latex paint with lid a 2” wide paint brush with wooden handle a 7 foot aluminum ladder a 6” serrated hunting knife	a blue click-type ballpoint pen a 12” wooden ruler a 3 kg lead weight with hook a 8” tall candlestick with holder a box of matches a thermometer a handle (large bottle)of vodka

Please draw or describe the concept of your solutions in order in the boxes provided and mark the time as projected by the laptop in the front of the classroom to the second (hh:mm:ss) in the space provided when you finish each solution. More pages are attached as needed.

Figure 2: Experiment design for all four conditions.

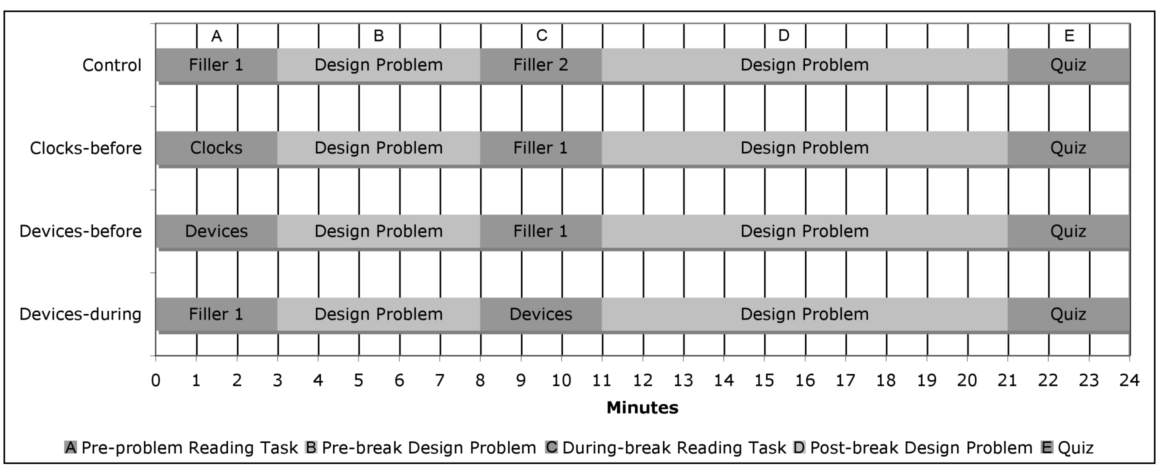

Figure 3: Example solutions - (a) Rate of heating/cooling solution (b) Multi-category solution.

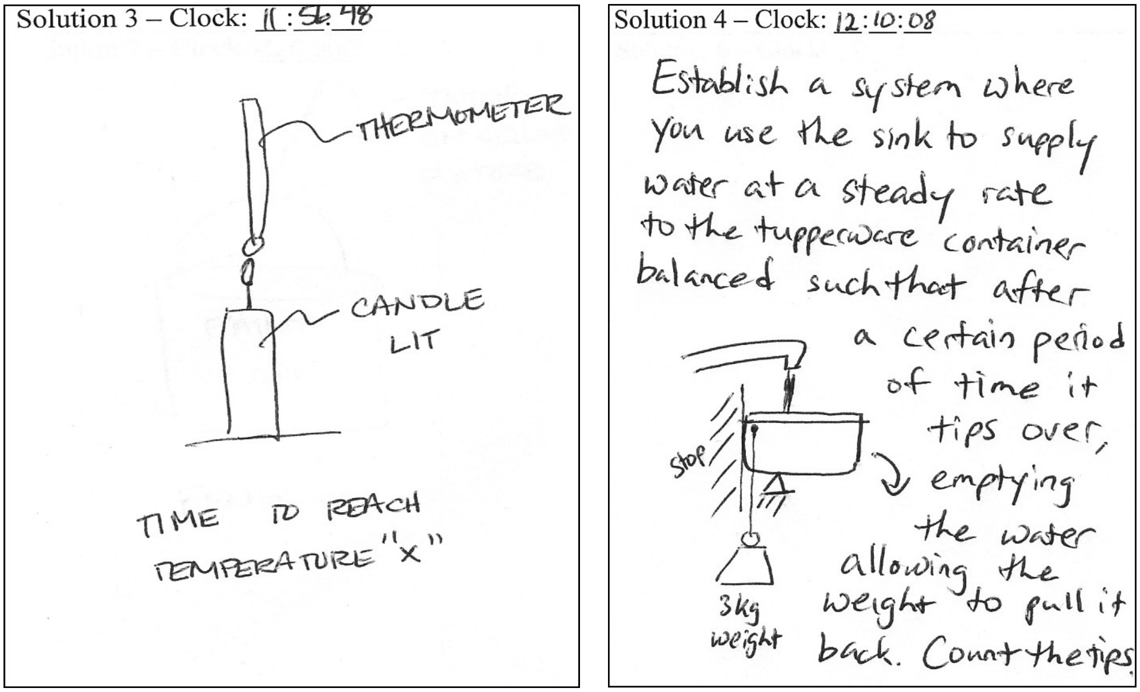

Figure 4: Average number of solutions per participant.

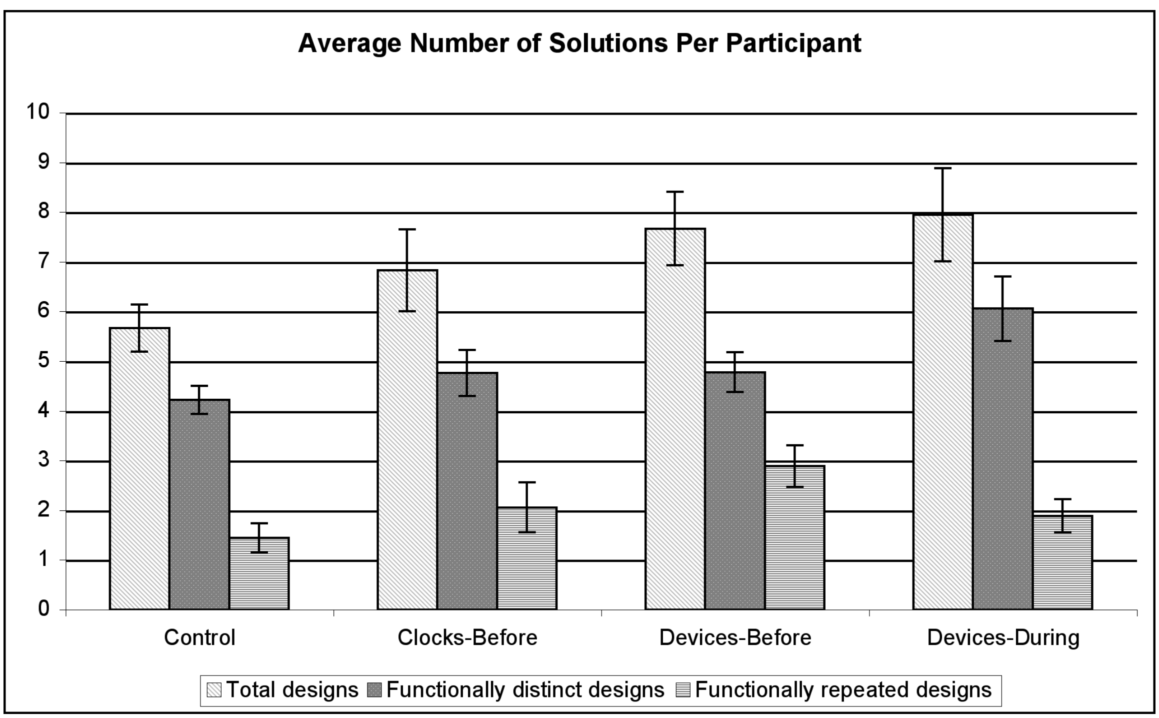

Figure 5: Average novelty per condition.

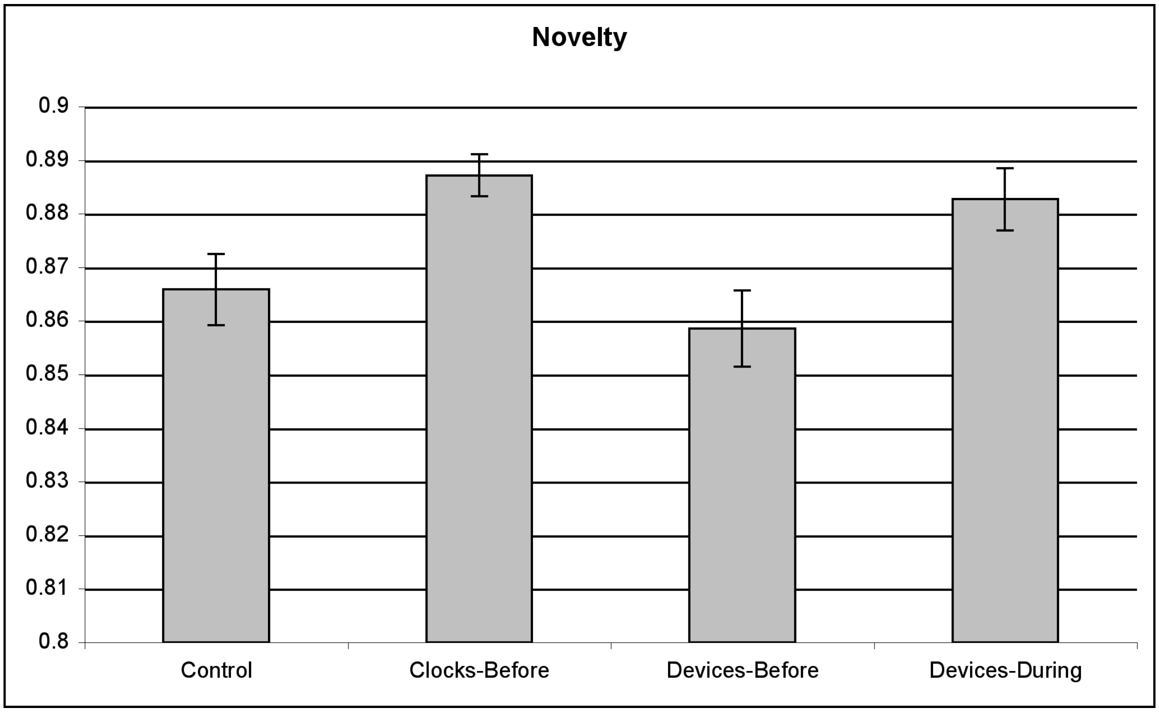

Table 1: Average number of ideas per participant in each category.

	Pendulum Period	Swinging Rate of Decay	Rate of Drip (Counting Drip Sounds)	Rate of Flow/Fill (Amount of Liquid)	Rate of Burn	Unwinding or Pulling of Tape	Rate of Heating/Cooling	Rate of Paint Drying	Rate of Free Fall or Inclined Rolling (Gravity)	Repetitious Conscious Behavior	Heart Rate	Drink the Vodka	Weight Equilibrium	Rate of Evaporation	Rate of Spring Release	Other
Control	0.44	0.11	0.26	1.20	1.50	0.06	0.67	0.11	0.28	0.50	0.00	0.17	0.20	0.11	0.00	0.06
Clocks-before	0.74	0.06	0.71	0.71	1.62	0.24	0.74	0.12	0.56	0.44	0.00	0.12	0.03	0.29	0.18	0.29
Devices-before	0.94	0.00	0.22	1.61	2.03	0.17	0.89	0.28	0.78	0.06	0.11	0.06	0.00	0.22	0.11	0.19
Devices-during	0.61	0.06	0.25	1.67	1.44	0.33	0.89	0.33	0.42	0.56	0.06	0.33	0.14	0.36	0.14	0.36
Average	0.68	0.06	0.36	1.30	1.65	0.20	0.79	0.21	0.51	0.39	0.04	0.17	0.09	0.25	0.11	0.23