‘Putting blinkers on a blind man’

Providing cognitive support for creative processes with environmental cues.

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Abstract

Random cues may be both beneficial and harmful to creativity. Theories of analogical transfer and association assume that cues are helpful in generating new ideas. However, theories of Path-of-least-resistance, fixation, and unconscious plagiarism say that cues can lead you into traps. Empirical research partly supports both theories. So what is a practitioner to do in selecting random cues for enhancing creativity? It is suggested that the answer is found in looking at the relationship between cues and the creative cognitive processes and their functions, and how this leads to creative outcome originality and usefulness. Two processes are examined: analogical transfer and mental simulation. It is recommended that random between-domain cues be used to increase between domain analogizing primarily with instruction to make connections, leading to product originality. Random within-domain cues should be used to increase within-domain analogizing. Due to property transfer, close analogies may have a negative impact on the originality of the outcome in problem solving instances, but a positive impact on usefulness in problem identifying and problem solving instances. Random end-user cues will lead to greater amounts of end-user simulations of usability and user preferences, and thus to higher levels of product usefulness.

1.Introduction

Are you stuck on a creative problem, and don't know where to go from here? Try this: In what ways might you use a stork to solve your problem? A key chain? A foreign country? Two friends? A pair of pliers? Have you solved the problem yet?

Random or blind input into the ideational stages has long been thought to be potentially beneficial for solving creative problems. Theoretically, this position was forcefully put forth by Campbell, who in his 1960 article argued that "a blind-variation-and-selective-retention process is fundamental to all inductive achievements, to all genuine increases in knowledge, to all increases in fit of system to environment" (Campbell, 1960, p. 380). In other words, in taking a blind dip into the infinite sea of ideas, you are better off generating more ideas than fewer, since it's not possible to know upfront which ideas are going make it into history rather than the recycle bin (see also Simonton, 2003). In that sense, producing more ideas will help your chances of getting a good idea, and input that helps you associate or relate to distant or novel areas in your thinking processes may help you along in getting more ideas. Several approaches have been developed to help the creative problem solver produce more ideas, the most well-known being brainstorming (Osborn, 1963). Brainstorming essentially uses a group-setting for striving for a multitude of novel ideas, where each idea acts as essentially random input to further idea-generation by the other group participants. Other practices that have attempted to use random stimuli to promote creativity include 'forced connections' (e.g., Firestien, 1996; MacCrimmon & Wagner, 1994; Terninko, Zusman, & Zlotin, 1998), where the problem solver attempts to relate to a random picture or other complex stimuli, and use that input in problem solving. De Bono (de Bono, 1975) developed the dictionary method, which is simply to introduce a random word by, say, selecting a random page and position of the word in the dictionary, and then use that word to solve your problem (see de Bono, 1992 for more methods involving random input). MacCrimmon & Wagner (1994) developed and tested software for support for a number of these random input techniques, and concluded that : "We feel confident in asserting that 'forced connections work' but have no detailed evidence on which ones work better under particular circumstances and, more importantly, cannot explain why they work." (p. 1531).

Some potential explanations for how forced connections might work have been put forth in the cognitive sciences. Notably, the literature on analogical transfer (Gick & Holyoak, 1980; Holyoak & Thagard, 1995; Forbus, Gentner, & Law, 1994) has dealt extensively with trying to understand how subjects retrieve and transfer elements from past examples to new problems. Using Duncker's (Duncker, 1945) radiation problem, Gick & Holyoak's (1980; 1983) classic study demonstrated how subjects transferred elements from the Attack-Dispersion problem to the help solve the radiation problem. The study also showed that, unless explicitly instructed to try to make a connection between the problems, subjects rarely noticed their similarity and failed to use it to solve the radiation problem. This lack of an automatic transfer has been repeated many times since (see e.g., Anolli, Antonietti, Crisafulli, & Cantoia, 2001). Some of the reasons for the lack of automatic transfer have been found to include the difference between superficial and structural similarity (Holyoak & Koh, 1987; Gentner, Rattermann, & Forbus, 1993), in that it has become evident that whereas structural similarities may ensure effective transfer, the superficial similarity between concepts is a powerful driver of noticing the connection between them in the first place. Without superficial similarity, spontaneous retrieval is rare. Furthermore, if people are instructed to actively look for connections between concepts or domains, they produce far more transfers than if no instructions are provided.

Associative theory provides another potential explanation for why forced connections with random input might improve creativity. Mednick (1962) was among the first to propose an associative theory of the creative process, in asserting that creative ideas tend to be remote. That is, original ideas usually only comes to you once the obvious ones are depleted. For example, in rating open-ended responses to questions such as 'name all of the uses of a brick you can think of ', the second half of ideas will tend to be more original responses than the first half (Mednick, 1962; Runco, 1985).

Empirical studies have tried to establish that exposures to *relevant* cues lead to increased performance on creative tasks, but they have received mixed results for both analogies and associates (see Christensen & Schunn, 2005 for a brief review), with some studies showing positive effects, and other studies showing null results. Empirical studies trying to establish that *random* stimuli lead to increased performance, however, seem to be almost none-existent. Insofar as random cues will tend to include at least some elements that can potentially help solve creative problems, the mixed findings from the relevant cuing conditions may generalize to random conditions.

So all in all, there appears to be some (although mixed) evidence that providing exposures to random cues can increase performance on creative problems, based on theories of analogical transfer and association. Many a practitioner may settle for this as evidence enough – random stimuli may enhance creativity, so let's try it – what harm could that do? Well, considering another classic line of creativity research, potentially quite a bit!

Gestalt and cognitive psychologists long have been interesting in the potential harmful effects on creativity and problem solving of past knowledge, strategies and behavioural tendencies. For example, Wertheimer (1959) used the term reproductive thinking to refer to problem solving in which one blindly carries out a previously learned procedure. Early gestalt studies by Maier (1931) and Duncker (1945) showed how the standard function of objects apparently restricted individuals ability to use them in novel ways in creative problem solving, a phenomenon termed functional fixedness. Luchins (1942) went on to demonstrate that having problem solving strategies may lead people to become unable to solve new problems that do not lend themselves to be solved with the standard strategy, despite the fact that the problems could be easily solved if no problem solving strategy had been established. This was termed a 'mental set'. Cognitive studies of fixation have looked along similar lines, showing how people can become fixated on certain solutions, leaving them unable to solve creative problems, or solving them less creatively than without such fixating elements. Such fixation may occur if a person is introduced to an element in the environment that will tend to lead his thinking in certain directions, for example by trapping his thinking in a 'mental rut' through providing enticing and well-known (but unsuitable) solution elements (e.g., Smith, 1995a; 1995b), similar to the experience of knowing the answer but being unable to currently produce it (aka. The Tip-of-the-Tongue phenomenon).

A number of studies have shown how providing (Jansson & Smith, 1991; Ward, 1994; Dahl & Moreau, 2002; Marsh, Ward, & Landau, 1999; Jaarsveld & van Leeuwen, 2005) or retrieving (Ward, 1994) existing examples may inhibit generative creative processes. Examples, in this sense, lead to a higher proportion of property transfers from the examples into the subject's own work (e.g., Marsh, Landau, & Hicks, 1996), and notably this also occurs even when subjects are explicitly instructed that they should try to avoid such transfer (e.g., Smith, Ward, & Schumacher, 1993). Extending these findings, it has been shown that especially in generative tasks, people are frequently incapable of monitoring this property transfer (e.g., Marsh, Landau, & Hicks, 1997). In such cases, unconscious influence of memory causes current thoughts to be (wrongly) experienced as novel or original inventions, which is also termed 'unconscous plagiarism' or 'cryptomnesia' (Brown & Murphy, 1989; Marsh & Bower, 1993; Marsh et al., 1999; Marsh & Landau, 1995).

Ward (1994; 1995; 1998) proposed a path-of-least-resistance model to account for some of these findings, which states that the default approach in tasks of imagination (especially when few constraints must be satisfied) is to access a specific known entity or category exemplar (gravitating towards basic level), and then pattern the new entity after it. In support of this model, Ward (1994; Ward, Patterson, Sifonis, Dodds, & Saunders, 2002) found that people who report basing their novel constructions on specific exemplars are less original than people who use other strategies. Property transfer in generative tasks has proven robust across a variety of settings, including engineering design tasks conducted in the lab (Jansson et al., 1991; Dahl et al., 2002; Christiaans & Andel, 1993). Jansson and Smith (1991) had people (either mechanical engineering students or professional designers) work on simple design problems (such as how to construct a car-mounted bicycle rack), with (the fixation group) or without (the no fixation group) a specific example provided by the experimenter. They found that the fixation group included more properties from the examples. However, it should be noted that a failure to replicate this finding has been reported (Purcell & Gero, 1992).

Reproductive thinking theories, such as these, are basically saying that if you use your past behavior, strategies and representations to solve novel or creative problems, then you may end up with a less than original solution. The theory aligns well with the frequently used search metaphor in creative problem solving, by showing how searching for creative solutions using past knowledge may lead you down the wrong path, into mental ruts (Smith, 1995a; 1995b), or to an oasis of false promise, that is hard to leave again (Perkins, 2000). Reproductive theories contrast with the classic problem solving literature, which has listed the use of past knowledge and heuristics as being useful to problem solving (e.g., Newell & Simon, 1972; see also Metcalfe & Wiebe, 1987). It seems that specifically in creativity, past strategies, exemplars or knowledge may in some (but not all, see Ward, Smith, & Vaid, 1997) cases be harmful.

So, this may all be quite confusing to the practitioner interested in using random stimuli. Will random stimuli enhance creativity – or does he risk jeopardizing the creativity of the outcome instead? A first step in resolving this dilemma obviously involves understanding that not all environmental cues are beneficial to a particular creative task – the environment is not always kind - and some environmental cues will have quite the opposite effect; they will be fixating or detrimental to problem solving. But which ones? It is not enough for the practitioner to 'avoid the fixating stimuli', since that would be impossible to know a priori. Put simply, part of the solution may lie in knowing whether the problem solver is expected to use a stimulus as a cue for past reproductive behaviour, or as a cue to generate new solution attempts. But it is still more complex than that: creativity is not a single process, but a host of processes, and pooling all creative processes provides an insufficient understanding of what creativity is about. At a general level, creative processes can be divided into generative and exploratory processes (Finke, Ward, & Smith, 1992). Generative processes are for example, analogical transfer, association, retrieval and synthesis, while the exploratory processes include for example, contextual shifting, functional inference and hypothesis testing.

So not all cognitive processes involved in creativity involves generative processes. A random cue may for example promote one type of generative creative process, while it limits another exploratory one. Cuing very distant domains may help your mind wander widely, but it is likely to detract attention from closely scrutinizing and testing the current idea. It is necessary to try to predict whether a cue may help or hinder depending on the expected function of the creative cognitive process. To this end, a more detailed understanding of the individual creative processes and their functions are needed.

If we are to help the practitioner in his creative process, it is necessary to dive deeper into the processes and functions in creativity, in order to further understand how and why some stimuli may start up creativity at certain points, while stopping it at others. Here we will limit ourselves to examine two creative processes: analogical transfer and mental simulation. By understanding how these processes work, which functions they serve, we aim to provide some guidelines for the practitioners in selecting and using somewhat random or blind stimuli to promote creative output. Rather than just looking at the connection between cue and creative outcome, we instead examine the intermediate factors of how environmental cues affect creative cognitive processes, showing that the cue effect depends on the functions served by the cognitive processes. And further we examine the link between the creative cognitive processes, and the creative products resulting. The hypothesis is that a strategic interaction between creative cognitive processes and environmental stimuli can lead to products that are more original, useful and thus creative (ref. the standard definition of creativity, Mayer, 1999).

We have studied both of these processes in real-world engineering design, using the in vivo method (Dunbar & Blanchette, 2001). Basically, in vivo research entails selecting a suitable object of study in the real-world, collecting data from these objects of study using video or audio recordings, transcribing the recorded data, and coding the data according to suitable coding schemes. Dunbar (1997; 1995; 2001b) has used this methodology to examine analogy in the domain of science (in particular microbiology), where he found that a suitable object of study for the study of scientific thinking and reasoning was the weekly lab meetings. In vivo methodology has the advantage of adding ecological validity to the typical lab experiments conducted in cognitive science, at the expense of having limited control over individual variables. As such, it is well-suited for exploring functions and mechanisms of real-world creative processes that can then later be examined further in lab studies. We used the methodology to examine functions of creative cognitive processes in engineering design conversations.

A number of terms will be used here to denote the objects presented during the creative process and their impact on subjects thinking. ‘Prime’ is used to denote objects where the subject is not consciously aware of the impact of the object on thinking or outcome. ‘Input/stimuli’ is used as a neutral demarker of the objects presented to the subject during creative processes, regardless of whether the subject uses this object in his thinking or creative solution. ‘Cues’ usually have positive connotations in that in order for something to be a cue, a third party (usually the experimenter) is assuming that the object should make a positive contribution to problem solving. However, here ‘cue’ is used in the sense ‘blind or random cue’, since here it is unbeknownst beforehand whether a given ‘cue’ object will have a positive or negative impact on creative problem solving. The term ‘relevant cue’ will be used in those instances where a third party has evaluated apriori that the cue ought to make a positive contribution to problem solving, and the term ‘fixating cue’ will be used where a third party has evaluated that the cue will be impacting in a negative way.

2 Analogical transfer and the relation to random cues

Analogy involves accessing and transferring elements from familiar categories (source) to use in constructing a novel idea, e.g., in an attempt to solve a problem or explain a concept (target) (Gentner, 1998). In design, as in other creative domains, analogy has been argued to be of special importance (e.g., Roozenburg & Eekels, 1996; Casakin & Goldschmidt, 1999b; Goldschmidt, 2001), as also evidenced by the many anecdotes of breakthrough inventions following distant analogies that exist in the design field. One of the most famous anecdotes is George de Mestral's development of Velcro after examining the seeds of the burdock root that had attached themselves to his dog. The sheer number of similar anecdotes of breakthroughs and inventions attest to the importance that is placed on analogy in domains of innovation (see e.g., Shepard, 1978; Ghiselin, 1954). Below we will look at analogical functions, analogical distance, and the automaticity of analogical retrieval in order to show how they relate to random stimuli influx.

2.1 Analogies serve other functions besides problem solving

Analogies are constructed for different purposes. While it is the problem solving or generative functions of analogies that have interested creativity scholars and cognitive scientists, analogies have been shown to have other functions in science and design. Notably, Dunbar's (1997; Dunbar, 2001a) in vivo studies of real-world analogizing in science distinguished 4 types of functions for analogies: forming hypotheses, designing experiments, fixing experiments, and explaining concepts to other scientists (see also Ward, 1998 for another classification of analogies in invention). Dunbar found that almost half of the analogies were explanatory.

These functions are, however, in part specific to science. In design, for example, other kinds of activity are more prevalent and important, such as the construction, modification and evaluation of novel and useful objects. In our own real-world studies of engineering design (Christensen & Schunn, 2007), we found that analogies served three different functions: explanation, problem solving, and problem identification. The first two are similar to analogy functions in science, while the last one has been uniquely identified in design. Engineering design is frequently conducted in teams, rather than individually, whereby communicating novel ideas to other members of a team becomes an important part of the process. Explanations through analogy can be a way of enhancing and ensuring comprehension, while avoiding misunderstanding when dealing with novelty. Particularly when novel ideas are discussed that are supported by diagrams or prototypes explanatory analogies serve an important purpose, as it is can be difficult for design team members to know whether they are referring to the same thing. Here analogies serve the purpose of communicative alignment in design conversations.

Yet another function analogy serves is that of problem solving. Indeed as noted above, this function is perhaps the primary reason researchers have focused on analogy in design and science. In addition to these two functions, problem identification is an important function, especially in the early conceptual stages of engineering design. When developing novel concepts, it is necessary to try to foresee whether a novel idea or concept would work under particular circumstances. In this case, analogy plays a part in evaluating novel concepts, in that it is possible to transfer not only solutions but also potential problems from sources with which the designer has past experience. Here the elements to be transferred from source to target involve potential design problems that the new concept may display. In engineering design, we found that the functions of analogies were distributed roughly evenly among these 3 categories, with 32% explanatory analogies, 40% problem solving analogies, and 28% problem identifying analogies.

These real-world findings lend support to the hypothesis that analogies do not serve a single purpose in science or design. Rather, in design, it seems that analogies are used for widely different cognitive functions, such as explanatory communicative support (e.g., using an analogy to a concept known by all participants, in order to promote comprehension of a new and unfamiliar concept), generative processes such as problem solving (e.g., transferring a structure from an exemplar into creating new solutions), and exploratory processes such as problem identification (e.g., transferring problems with a previous structure to a new structure in order to identify problems with the new structure). Since analogies do not serve a single function in design, it is necessary to identify which analogy function you wish to promote, before going to lengths in order to promote the use of analogies. For example, promoting the use of analogies may not help you in generating new ideas if the analogies are merely used for explanatory purposes. Further, this analogy function distinction suggests that analogies can be used in other aspects of creative work than to generate solutions and solve problems. In exploratory stages, where new ideas needs to be closely examined, tested and scrutinized, promoting analogy use may lead to identifying more design problems based on previous experience.

2.2 Within domain sources are easier to retrieve but may lead to less than original responses

In analogical transfer, the ’distance’ between source and target may be large or small. To cite examples from our own research, a designer trying to develop a new type of blood bag in medical plastics may for example make an analogy to other blood bag in medical plastics (within-domain, or local analogies), or make an analogy to Christmas decorations or shoes or credit cards in developing the design (between-domain, or distant analogies) (Christensen & Schunn, 2007, see also Dunbar, 1995; Dunbar et al., 2001; Vosniadou & Ortony, 1989). A consistent finding in the research literature is that transfer increases with similarity (e.g., Holyoak et al., 1987; Novick, 1988; Ross, 1987; 1989; Simon & Hayes, 1976). But whereas analogical transfer has been found to be closely related to structural similarity, analogical access often strongly depends on superficial similarity between source and target (Gentner et al., 1993; Holyoak et al., 1987; Ross, 1987; Novick, 1988). The distinction between local and distant analogies is related to differential amount of superficial similarity, with more superficial similarity for local analogies. This higher amount of superficial similarity may make local analogies easier to access (e.g., Gentner et al., 1993; Holyoak et al., 1987). Further, both local and distant analogies contain structural similarity, but since distant analogies connect two previously distinct concepts or domains, it may be more difficult to ensure successful transfer of solution elements in design problem solving from source to target because the domains may differ in multiple subtle but important ways (Johnson-Laird, 1989).

Few studies have looked at the use of distant analogies in design. In an experimental study of visual analogy in design, Casakin (2004) found that both novices and experts produced more between-domain than within-domain analogies. While these studies and the above mentioned design anecdotes suggest that between-domain analogizing may be common in design and science, naturalistic studies of analogy in science seem to question this conclusion. Dunbar (1995; 2001a) found that distant analogies did not play a significant part in discovery, but rather were very rare in comparison to local analogies. However, our real-world research in engineering design has shown that in design local and distant analogies are about equally prevalent (Christensen & Schunn, 2007), indicating both that between domain analogizing is common, and that within domain analogizing is also used heavily in design.

The research on fixation and exemplar influence in generative tasks described above supports the notion that having or making examples available will bias people's creations toward features in those examples. Objects from similar domains share more superficial similarity than objects from dissimilar domains, and since superficial similarity is one of the key driving forces of analogical access, this lead to the expectation that the presence or availability of within-domain exemplars increases the likelihood of within-domain analogizing (Ward, 1998). In other words, the presence of within domain examples may make it hard for creative problem solvers to break away from local analogies, since superficial similarity dominates access, and distant analogies will be less superficially similar than local analogies. Providing prior within-domain examples thus bias people's creations toward features contained in those examples (Marsh et al., 1996). This within-domain biasing could for example be the case when designers use external support of prototypes during the concept phases in engineering design, as compared to conditions without such support. We examined this issue in our real-world engineering design study (Christensen & Schunn, 2007), by comparing analogy frequency with or without the reference to sketches and prototypes. Here it was found that the prevalence of between-domain analogies in design conversations was reduced when referring to within domain prototypes as compared to unsupported cognition. This result suggests that in real-world design, the use of within-domain tools may in effect be limiting the use of generative between domain analogies, thus extending the unconscious plagiarism finding that making within-domain exemplars available during the creative constructive process tend to lead subjects to unconsciously plagiarize these exemplars, to include objects that are a natural part of the design space. If exemplars are present the designers are less likely to think about other domains than the present one.

These findings can be substantiated by Dahl & Moreau's (2002) study of analogy use in design. They had undergraduate engineering students design new products that would solve problems for the commuting diner (e.g., difficulties with spillage, consumption and storage of food during automotive driving). They found that exposing students to one or several within-domain examples (e.g., sketches of a drive-in window) led to a lower proportion of far analogies being used compared to subjects who saw no sketch. Further, the proportion of far analogies used was a strong indicator of the originality of the resulting design. Apparently, the presence of one or more within-domain exemplars hindered students in producing original responses.

More tentative support for the link between external within-domain sources to analogical use and outcome comes from experiments providing visual analogs as hints in problem solving (Beveridge & Parkins, 1987) and design (Bonnardel & Marmèche, 2004; Casakin et al., 1999b). These experiments indicate that providing visual information can lead to transfer of solution elements. These findings could have important implications for structuring innovation tools. If the designer's goal involves generating novel and original products seemingly unrelated to or inspired by previous products in the category, then a tentative recommendation would be to avoid using environmental cues that point towards within-domain exemplars. Apparently the tendency to access and transfer within-domain exemplars into novel work is quite potent, and even extends into the presence of typical design space objects (such as prototypes) not intended to lead design thinking along traditional (as opposed to original) paths.

We examined in vivo whether analogical distance would interact in certain ways with analogical functions. Based on past research, we expected that explanatory analogies would be primarily between-domain, since between-domain analogizing may be necessary in explaining novel design concepts precisely because they are new to the domain. Problem identification in evaluation was hypothesized to involve primarily within-domain analogies since within-domain analogies are more accessible due to superficial similarity, more available due to within-domain expertise and more appropriate for identifying problems because within-domain analogies may increase the chances of successful transfer. And finally, because engineering design involves the production of novel and useful solutions, solving problems by relating to past within-domain knowledge may frequently not be enough to construct an original product. Therefore, a mixture of within and between-domain analogies are expected when the function of the analogy is to solve a design problem. As expected, these three types of analogy functions in design had differential ratios of within to between domain analogies. Problem identification analogies were mainly within-domain, explanatory analogies were more frequently (and mainly) between-domain, while problem solving analogies concerned a mixture of within and between-domain analogies (see figure 1).

Insert figure 1 about here

These findings on analogical distance carry a number of consequences for tools supporting the use of analogies in innovation. As noted under analogical functions, when promoting the use of analogies it is important to take into considerations which analogy function to support. If the purpose is to support the problem solving or generative aspects of analogies, then both within domain and between-domain products may be used. However, in so far as close analogies are used, it can be expected that a fair amount of exemplar property transfer will take place, thereby making the resulting innovation structurally similar to previous exemplars. This similarity may in effect reduce the evaluated originality of the resulting product. This does, however, not mean that within-domain exemplars are useless in solving problems. Quite the contrary – within domain analogies may be quite effective in solving problems in design. In fact, it is quite possible that within domain analogies may be quite effective in making the resulting design solutions more useful, since the sources may be well-known sources or industry standards that are effective in securing transfer of proven and comprehensible solutions. But the resulting innovation may not be very original, so within-domain analogizing should perhaps primarily be used in cases where the resulting design is not required to be original or notably distinct or different from previous designs. So, while within-domain analogizing is effective at solving problems, property transfer from within-domain exemplars will tend to make the resulting solution less than original.

Further, as several theories have pointed out, within-domain analogies (sharing a greater amount of superficial similarity) will tend to be retrieved and used more easily. As such, it could be argued that within-domain analogies will be retrieved and used more frequently, be considered more relevant, interesting and examined more closely, when compared to between-domain sources. This tendency should tend to lead to an overshadowing effect of within-domain exemplars to between domain exemplars, in so far as they are both used as cues. A recent study tested this, and showed that within-domain exemplars drew more attention (were looked at longer), were considered to be much more inspiring to the designers, when compared to between-domain exemplars or other cue categories (Christensen, under review).

Additionally, analogy serves other functions than problem solving. It may be possible to promote in particular the problem identifying analogies by cuing within-domain products, in order to identify problems with these previous exemplars that newly generated solutions also possess. Such exploratory creative processes may lead to the identification of problems and issues that are in need of being addressed in the innovation process.

2.3 Spontaneous analogical transfer is rare for distant analogies, but instructions to make connections help

In analogical transfer, spontaneous access refers to accessing a source without receiving hints or instructions to use this source. Gick & Holyoak's (1980) classic study showed that, unless explicitly instructed to try to make a connection between the problems, subjects rarely discovered their similarity and used it to solve the radiation problem. This lack of an automatic transfer has been repeated many times since, leading some authors to argue that analogical access is not a spontaneous process (e.g., Anolli et al., 2001). However, as Ross, Ryan and Tenpenny (1989) noted, studies have generally not shown that people never spontaneously access relevant information – only that in cases where they were expected to do so, they often do not. As noted in the previous section, superficial similarity between source and target (as in within domain analogizing) is one way of ensuring spontaneous transfer. As such, spontaneous retrieval of between-domain sources is quite rare, although a few studies have attempted to document that it is not altogether absent (Ball, Ormerod, & Morley, 2004; Christensen & Schunn, 2005). One approach to increasing transfer between source and target in between domain analogizing involves bypassing the spontaneous access part of analogies, and simply instruct or hint subjects they should make connections between source and target (Gick et al., 1980; for a more recent study in design, see Casakin & Goldschmidt, 1999a). This approach increases transfer between even highly dissimilar domains. However, there is some evidence that presenting analogies in spoken form increases the chance of retrieval over the written format, particularly at longer lags between cue and recall (Markman, Taylor & Gentner, in press).

The lack of experimental evidence for spontaneous access is surprising when viewed in the light of in vivo research. Dunbar (Blanchette & Dunbar, 2000; 2001; Dunbar, 1995; 1997; 2001a) has conducted several studies of analogical transfer in real-world science and politics using the in vivo methodology (see Dunbar, 1995; 1997) and he has found that scientists and politicians frequently access analogues spontaneously (e.g., Dunbar, 2001a) – even for analogues sharing mainly deeper structural features (see also Bearman, Ball, & Ormerod, 2002 for similar results on a task in management decision making). Our own findings from engineering design show similar results (Christensen & Schunn, 2007). This research finding obviously stands in sharp contrast to the experimental findings; a contrast Dunbar called the analogical paradox. For some reason experimental research and real-world research seem to reach opposite conclusions concerning frequency of spontaneous access. Experiments on spontaneous access are supposed to be studying a simplified version of the real-world, but several differences exist between the two research strains that could potentially explain the paradox. One potentially important contrast highlighted by Blanchette & Dunbar (2000; 2001; Dunbar, 2001a) is that in the real-world experts generate their own analogies, while in the typical experimental laboratory subjects are provided with specific analogue sources. However, regardless of whether experimental studies using random cues may find some evidence of spontaneous between-domain analogizing in experimental research, there is no reason to think that instructing subjects to access random cues will not still lead to higher transfer rates. These findings have consequences for tools of innovations in that if a cuing tool (for example a random picture viewer) is showing between-domain sources meant to promote the use of problem solving analogies, it cannot be expected that designers will make use of the sources to any great degree, unless explicitly instructed to do so. The access path between distant analogues simply has too much resistance to lead to spontaneous use. This is not to say that an uninstructed or 'priming' version of a distant analogy generator may never work (as some research does show that in some cases transfer does occur even here)– but simply to say that the transfer between distant analogues is greatly enhanced by asking designers to actively think of connections between target and source. Further, if within-domain sources are used in combination with between-domain sources, it may be expected that within domain analogues are retrieved far more due to paths of less resistance in both the instructed and uninstructed cases.

3. Explorations using mental simulation of end users lead to more useful products.

Another frequently used creative process in design and science involves mentally simulating events and entities under changed circumstances in order to support reasoning, understanding and prediction (Gentner, 2002). In more popular terms, mental simulations have also been referred to as 'thought experiments', and one of the most famous examples is probably Einsteins anecdote of how imagining travelling trough space next to a beam of light helped him discover the special theory of relativity (Einstein, in Hadamard, 1945, p. 142). Although different and competing paradigms of mental models have been proposed (e.g., Johnson-Laird, 1983; Gentner & Stevens, 1983; Forbus & Gentner, 1997; Kuipers, 1994; Kahneman & Tversky, 1982), these theories are basically in agreement with a minimalist approach hypothesizing that in certain problem solving tasks humans reason by constructing a mental model of the situations, events and processes in WM that in dynamic cases can be manipulated through simulation (Nersessian, 2002; Christensen & Schunn, in press). An important feature of mental models is that they frequently permit mental simulation. A mental simulation refers to the sense of being able to dynamically 'run' a simulation internally to observe functioning and outcome of a system or device. 'Runability' implies a sense of being able to simulate system behavior and predict outcomes even for situations where the subject has no previous experience. In innovation, the potential advantage of using mental model runs include being able to reason about how physical systems will operate under changed circumstances/with altered features, without having to resort to physically constructing such a system or device. Mental model runs allow quick and cheap ways of exploring and testing possible alternatives. This ability is particularly useful in creative domains where uncertainty is an inescapable part of the problem space since the task involves constructing novelty. While a mental model is runnable, the mental simulation is the actual 'run' (Trickett & Trafton, 2002; Trickett, 2004; Trickett, Trafton, Saner, & Schunn, 2005), and these 'run' instances are detectable in verbal protocols. The different paradigms of mental models basically agree that mental models are run under situations of uncertainty, in order to turn that uncertainty into approximate or imprecise answers or solutions.

We tested this basic assumption in vivo by examining the mental simulations of engineering designers (Christensen & Schunn, in press). We found that mental simulations were very frequently employed in design, and that they primarily served the function of mentally exploring and testing ideas, concepts and prototypes that had been generated. We found support for the basic assumptions 1) that simulations are run in situations of increased uncertainty, 2) the running of mental simulations in effect reduces uncertainty, and 3) the resulting representations following mental simulations have increased approximation. Further, it was found that there were at least two different kinds of mental simulation in engineering design: simulations of technical or functions aspects, and simulations of end-user usability, preference, and product interaction.

It was found that the reference to prototypes had fewer technical or functional simulations compared to sketches or unsupported cognition, perhaps indicating the lower degree of technical uncertainty in prototypes. While both types of simulations (technical/functional and end-user) may reduce uncertainty, notably the latter has been linked to creative outcomes in the literature. Theories of user-centered design (e.g., Norman & Draper, 1986), user involvement in design (e.g., Kujala, 2003), usability (e.g., Rubin, 1994) and user driven innovation (e.g., von Hippel, 2005) all agree that considering or involving the end-user in design processes has the possibility of improving the usefulness of the resulting product. Usefulness is one of the defining characteristics of creative products (Mayer, 1999). In examining the impact of imagining end-users on the resulting design, Dahl, Chattopadhyay & Gorn (1999) found that instructing designers to include the customer in imagination visual imagery during the design process has a greater positive effect on the usefulness of the designs produced than including the customer in memory visual imagery, as evaluated by the target customers themselves. These findings point towards the theory that cuing random end-user information during innovative processes may lead designers to increasingly mentally simulate end-user preferences, usability and product interactions, in order to explore and test the usefulness of the current pre-inventive structure. Insofar as these simulations point towards problems and potentials in the product, such increased end-user simulations may in effect lead to more useful products as evaluated by both designers and the end-users themselves.

4. A model for blind cues, cognitive processes and functions, and creative outcome

The findings from studies of analogical transfer and mental simulation led us to develop the following model of the relationship between random environmental cue categories, the cognitive processes of analogy and simulations, and the hypothesized creative outcome in terms of expected changes in originality or usefulness of the resulting product (see figure 2). Currently the model consists of three categories of random cues: within-domain products, between-domain products, and end-users. As more creative cognitive processes and their functions are examined, we expect that more categories will be specified, and that further restrictions for the current categories will be put forth. First, random between-domain cues will lead to increased between-domain analogizing primarily if subjects are instructed to make connections. In so far as the analogies serve problem solving purposes, this should lead to increased product originality. Second, random within domain cues will lead to increased within-domain analogizing even when cues are presented without instructions. But higher levels of within-domain analogizing is expected with instruction to make connections. Due to property transfer, these close analogies will have a negative impact on the originality of the outcome in problem solving instances, although they may also increase usefulness at the same time. In problem identifying or exploratory instances, these close analogies should lead only to increased levels of outcome usefulness. Third, random end-user cues will lead to greater amounts of end-user simulations. The exploratory nature of end-user mental simulations will lead to considering usability and user preferences more, and thus to higher levels of product usefulness (as evaluated by the end-user).

Insert figure 2 about here

A recent test of aspects of this model related to outcome usefulness (Christensen, under review) asked design students to design a new product within medical plastics, while being exposed to random images from these cue categories. We collected about 1000 random pictures from both photo-databases with general content, and photo-databases with pictures from medical plastics, and coded each picture for category (within-domain; between-domain; end-users; other people; a control group viewed abstract art). Design students were then given 30 minutes to solve the design task, while being exposed to 60 random pictures from these cue categories. Following the experiment, design experts were asked to rate the usefulness of the solutions while blind to conditions. We also measured the design solutions for amount of within-domain property transfer and end-user inclusion. In support of the model, we found that pictures of end-users did lead to products that take the end-user more into consideration, and to improved ratings of usefulness in the resulting product as evaluated by design experts. Furthermore, cues of within-domain products lead to increased transfer of within domain properties, leading also to increased evaluations of usefulness. The experiment thus illustrated two different paths to increased outcome usefulness. Furthermore, support was found for the hypothesis that the within-domain cues were overshadowing the effect of end-user cues, when both categories were employed.

5. Practical implications

Random environmental cues can be used to support creative processes, but the particular processes and their functions need to be considered before it can be hypothesized what the resulting impact will be on creative outcomes. It is possible for the practitioner to pre-select random cues in certain categories, and expect them to lead to improved creativity. However, in some cases they may also harm creativity – especially the originality of the outcome, if proper cues categories are not selected for support of the right creative processes. Some of the categories to be used in innovation can be seen in table 1.

Insert table 1 about here

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6. Conclusion

Cues are inherently neither good or bad. But contextual information can be strategically selected and presented during creative processes to enhance the probability of ending up with an original and useful product. The problem is this: we want a random flux of information to inspire us and lead us along unexpected and potentially fruitful paths in creativity. But we do not want this flux to be misleading us along unfruitful paths. So, a restricted randomization seems in order. However, in blind creative processes we do not know beforehand where we will end up. We have no a priori insight into which are the fruitful paths and which are the unfruitful ones until we have actually walked along them. The proposal here is that it is possible, if we examine how creative cognition works, to restrict the pool of random stimuli to increase the opportunity for great novelty, and decrease the probability of misleading failures. We have looked at the potential impact of three broad categories of cues, their impact on creative cognitive processes, and the expected outcomes.

By setting limits to randomness, it is possible to exclude cues that would have promoted processes that may harm originality (such as property transfer effects, and other reproductive thinking processes), while at the same time enhance processes that may lead to original and useful products.

Restricted randomness is not the same as algorithmic searches or the 'working-out' of the typically well-defined problem, since, as noted by Cziko (1998, p. 207) "…any adaptive constraint put on the current generation of blind variations does not make the resulting variations 'sighted,' 'smart,' or any less blind." Rather, by analogy with the leather shields placed over horses' eyes in order to restrict their vision, we are "putting blinkers on a blind man", by asking him to generate new variations from the road ahead, rather than from the road behind. The blind man still needs to walk the walk – but hopefully it will carry him into original and uncharted territory. Once there, the blind man needs to use his yard-stick to scrutinize, test and select the best possible ideas he has generated. Categories of environmental cues may help provide both the blinkers, and the yard-stick, by strategically supporting creative cognitive processes.

As such, creative search is still done without knowing where precisely you will end up in the infinite land of new ideas, but wherever the process may take you, the blinkers will ensure that it will probably not be in the land of the well-knowns. And the yard-stick may ensure that the weird variations are quickly left behind, while the winning variations are selectively adopted.

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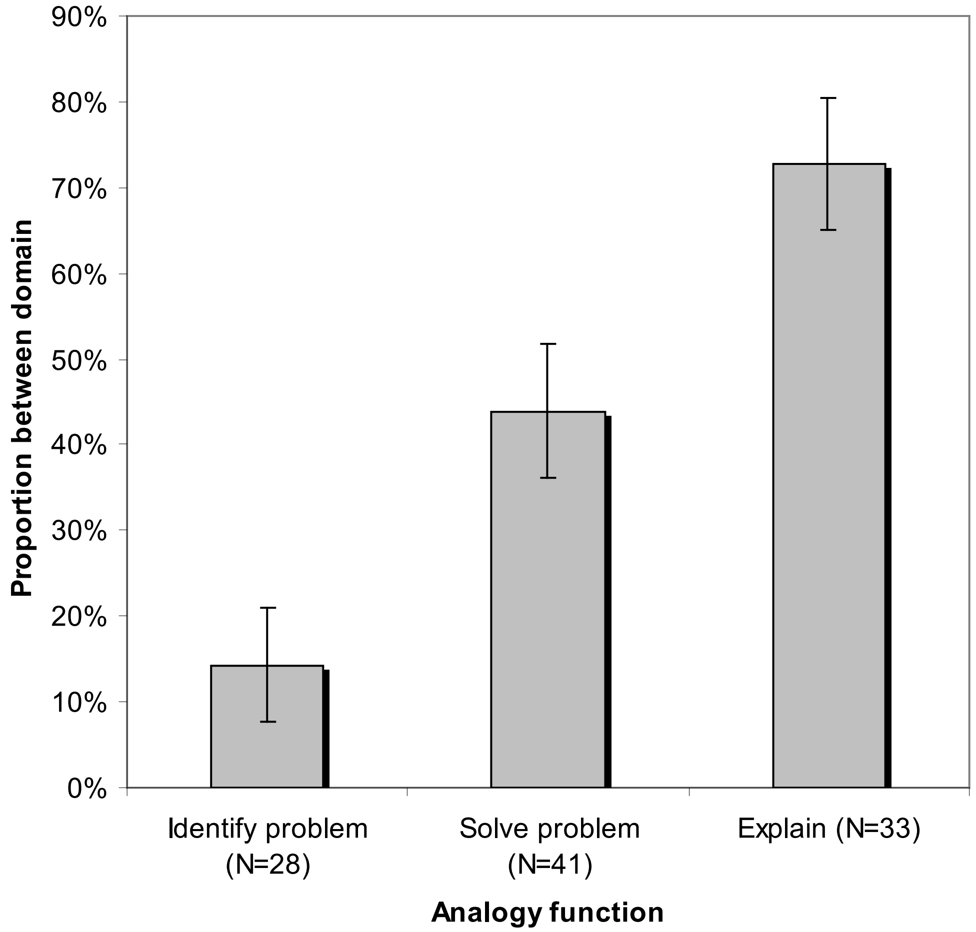

Figure 1: Proportion between domain analogies by analogical function (with SE bars).

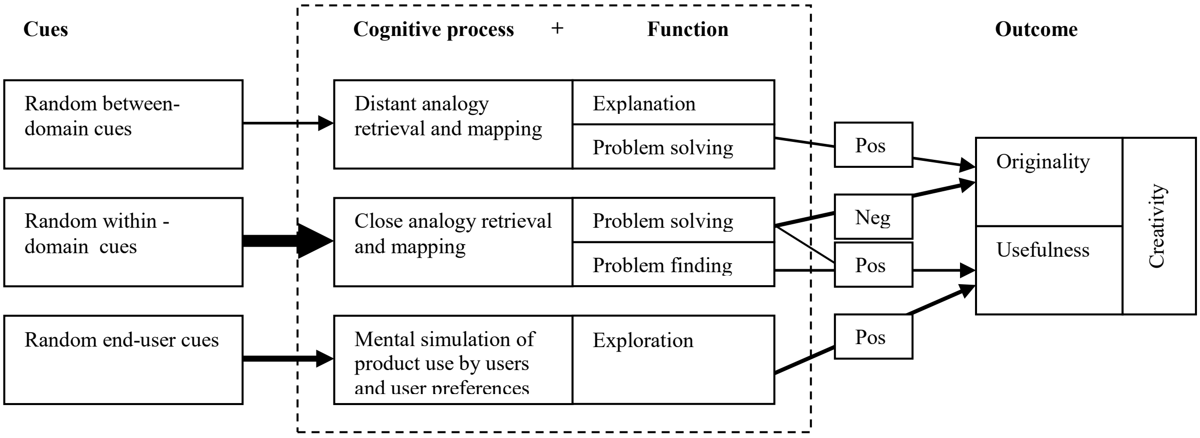

Figure 2: A model for the relation between random cue categories, creative cognitive processes and functions, and creative outcomes

Table 1. Recommendations for cue categories

Cue category	Sample pictures[1]	Recommendation
Within-domain products	  	This category will tend to lead designers to think in terms of close analogical solutions, and generate products that share a fair amount of elements with the past/cued solutions. In some cases this may affect the evaluated originality of the resulting product negatively. The effect of using this category seems to be rather potent, and tends to overshadow some of the other cuing categories below. It is thus recommended that this category is used in isolation, without cross-cuing with the other categories. It is tentatively suitable for coming up with (generating) less than original solutions to problems, or for supporting exploratory processes of already generated solutions by means of identifying problems with these solutions based on previous knowledge. Because of the potency, the cuing category may be used either actively (as in instructing participants to try to relate to the cues) or passively (as in presenting cues without instructions during regular innovation processes).
Between-domain products	  	This category may in some cases lead to more original products by means of between domain analogizing. Due to low levels of shared superficial similarity with the problem at hand, the cues will seem less interesting and less related to the designers, unless perhaps, explicitly instructed to make the connection. As such, the category should be used actively (i.e., instructed), although some research has shown that a small effect is also possible without instruction. Further, if within-domain cues are present, this effect will be diminished due to less resistance in accessing those cues. Cuing between-domain products should primarily be used for generative problem solving purposes, requiring greater originality in the solution. Further, distant analogies serve a natural explanatory purpose.
End-users	  	This category is notably useful in product design where there is an identifiable end-user. Cues of end-users may lead to greater amounts of mental simulation of end-users interacting with the innovation, potentially creating more useful products, as evaluated by design experts and the users themselves. Can be used either actively or passively, but should not be used in combination with the overshadowing 'within-domain product' category. Serves primarily exploratory functions of already generated designs. The use of this category does not limit the originality of the resulting design. On the contrary, the solution can be expected to be more useful and creative.

[1] Sample pictures taken from Christensen (under review), where the design domain concerned medical plastics, and the end-user in this case was a nurse working in an ICU. As such, random within domain products were from medical plastics, between-domain products were from other domains, and end-users were nurses at work.