Investigating Visual Analogies for Visual Insight Problems

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ABSTRACT

Much research has focused on the impact of analogies in insight problem solving, but less work has investigated how the visual analogies for insight are actually constructed. Thus, it appears that in the search for their facilitative impact on the incubation effect, the understanding of what makes good visual analogies has somehow been lost. This paper presents preliminary work of constructing a set of 6 visual analogies and evaluating their impact on solving the visual problem of eight coins. Findings suggest that in visual analogies, the insight cues are the most beneficial ones, especially when integrated, and that depth cues are important surface aspects in facilitating incubation effect. Our findings support the facilitative cue theory and replicate previous outcomes on the importance of impasse experience as a prerequisite for analogical transfer.

Keywords:
Visual insight problem, visual analogies, incubation effect

INTRODUCTION

Analogies are powerful cognitive tools supporting perception, decision making, problem solving, and creativity. While the construction of visual analogies has been extensively investigated in creative design studies, research focusing on insight problems was restricted mostly to their facilitative role. Such limited focus could be counterproductive, as shown by a wealth of studies and their contrasting outcomes supporting both the facilitative [16] and detrimental roles of visual analogies [14].

We argue that research on insight problems could greatly benefit from extending its focus to include not only studies on whether the analogies work but also on what types of visual cues are facilitative and why. An investigation into how the visual cues are constructed can offer a different perspective into the visual insight problem solving. However, this benefit comes with a caveat because constructing a potent visual analogy is by far a trivial task. In fact it is in itself a visual insight problem and thus an additional argument for engaging and investigating it.

In order to address this research gap, the work presented in this paper offers a novel approach to the study of visual analogies which brings under the scrutiny the process of developing visual analogies, identifying their relevant aspects for the incubation effect, and varying such aspects to test their impact. We argue that systematic construction and rigorous evaluation of a series of visual analogies within the same experimental design can offer a different perspective to the study of visual insight. The paper presents a preliminary experimental study aiming to address the following research questions:

- What aspects of the visual analogies are most relevant for incubation effect in visual insight problems?
- How can the surface and structural aspects be represented in visual analogies?

The paper starts by reviewing relevant work and continues with a reflection on the construction of the visual analogies. The experimental study is a partial replication of an experiment using the eight coins problem, and the findings are further reported and discussed.

RELATED WORK

In creativity research, there has been a long standing debate regarding the role of incubation in solving insight problems, i.e. incubation effect. Much research and contrasting findings suggest that solution rate could either increase [1] or decrease [37] after the problem is left unattended. However, in a recent meta-analysis of 29

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studies, Sio and Ormerod [49] identified a positive incubation effect for both creative and insight problems.

Contrasting perspectives have also arisen with respect to the nature of insight and what constitutes an insight problem. Proponents of insight have argued for its distinct characteristics such as cognitive restructuring and sudden awareness [33], conceptual changes [26], insight-specific processes [29] and the absence of incremental feeling of warmth [35, 40]. In contrast, its opponents view insight as an ordinary, incremental approach to problem solving [47] or a hill-climbing heuristics [10]. Despite their contrasting positions, the state-of-the art research in incubation effect often employs similar insight problems, mainly because of the difficulties associated with developing new and particularly visual ones.

Indeed, insight problems could be broadly grouped into verbal and visual problems which involve processing of linguistic and visual-spatial information respectively, and which appear to benefit from different cognitive skills [24].

Much research has focused on verbal insight problems such as remote associates tests [34], anagrams, rebuses and riddles. In contrast, visual insight problems appear to be much fewer and subsequently to receive less experimental attention. Examples of such problems are the farm problem requiring the division of an L shaped farm in four parts that have the same size and shape [16], the tree problem requiring to plant 10 trees in five rows with four trees in each row [16], the nine dots problems requiring to connect all nine equidistant dots arranged in a grid with four straight lines [11], and the coin problem requiring the alteration of an array of x coins by moving y coins only, to create a final array in which each coin touches exactly z others [40].

Analogy in Insight Problems

Analogies are cognitive processes with significant impact on perception, decision making, problem solving, and creativity. They involve transfer of information from a known situation (source) to a new one (target) which subsequently can be better understood [51]. The process of transfer involves mapping the corresponding relationships which have been abstracted from the source to the target [44].

The facilitative cues theories relate to the theory of cognitive preparedness and argue that information from the environment is the cause of incubation effect and successful insight problem solving [9]. These theories are partially supported by empirical findings. On the one hand, some findings argue against the facilitative cues suggesting that these could lead to either insignificant results [15] or worse results than the condition in which participants received the answer [14]. One the other hand, other findings show that cues during incubation can in fact lead to better performance [16, 34, 22, 4, 38, 8, 40].

The proponents of the facilitative cues theories argue that analogical transfer is supported by the retrieval of previously un-retrieved relevant information or schemas [52, 28, 16, 39, 22], and that their spreading activation can sensitize the problem solver to chance encounters with related stimuli [48].

Despite the important role of analogies in problem solving, findings suggest that people rarely employ them spontaneously [17, 20]. Hence, the increased interest in developing cues for supporting the ability to use analogies in problem solving [5]. However, the development of successful cues is by far a trivial task because people tend (i) to miss the connection both in terms of correspondences between objects in the source and target, and between relations among objects [25, 7]; and (ii) to focus on the surface attributes of the analogy while failing to extract the deep or structural ones [23, 37].

The relevance of the latter aspect has led to the distinction between surface and structural analogies [20]. Whereas the surface analogies relate to the easily accessible aspects of object properties, structural analogies relate to the higher order relations that are based on the most relevant, albeit less accessible properties. Surface analogies are easier to produce but they could not guarantee the transfer of structural relations between the source and the target. Structural analogies are difficult to produce but they could have a strong influence on supporting this transfer [21].

Structure mapping theory [20] identifies two principles for the transfer of relevant information from the source to the target. *Systematicity principle* states that connected knowledge is preferred over independent facts; and *structural consistency principle* suggests one-to-one mapping between each part of the target and each part of the source, as well as between each of the attributes of these two parts. The system of matching objects, their attributes and relations is what Gentner called aligned structure [20]. Interesting in this structure is the distinction between *alignable differences* and *non alignable differences*. The former involve correspondence between non-identical objects [32], while the latter refer to the lack of, or wrong correspondence between non-identical objects from the source and the target.

Structure mapping theory argues that when the target and the source are compared, the commonalities and alignable differences become more salient and are better remembered [19]. In addition, new information about the base or the target could be considered and the existing mapping, further extended to include them, i.e. extended mapping.

Another important distinction is the one between within-domain and between-domain analogies. The former capture the similarities between the surface aspects of the source and target which belong to the same domain, while the latter capture similarities between the structural aspects of the source and target, each belonging to two different domains [9].

Findings suggest that in contrast with within-domain analogies, between-domain ones are more difficult to construct and understand but they can lead to better transfer [50].

The research on the role of analogy in insight problems is directly relevant to the work presented in this paper. The above findings and in particular the structure mapping theory are subsequently applied in the construction and evaluation of our visual analogies. In return, our work aims to provide additional empirical support for the facilitative cue theories.

Visual Analogy for Visual Insight Problems

Whereas much work has focused on investigating performance in verbal insight problems (as opposed to visual problems), or the role of verbal cues in both verbal and visual insight problems (as opposed to visual cues), fewer efforts have focused on investigating the role of visual insight in visual insight problems. But why would visual insight problems benefit from visual cues?

We argue that they would and offer a twofold rationale for this. Firstly, the dual code theory [41] states that visual and verbal information are processed along distinct channels and represented in distinct memory systems with the verbal system dealing with linguistic information while the non-verbal one stores perceptual information. This theory offers a compelling account for the superiority of memory for images, because images engage multiple representations and associations with external knowledge thus encouraging a more elaborate encoding than words [41, 42].

Secondly, research into child psychology on learning and memory for pictorial and verbal information successfully replicate findings suggesting the superiority of memory for pictures over words [43, 45] a superiority which is also maintained in adulthood [27].

We argue that it would be valuable to investigate whether the picture-over-word superiority generalizes to the domain of analogical transfer, because the information provided through visual analogies can engage more associations in processing visual insight problems, than counterpart verbal cues.

A number of researchers have investigated the role of visual analogies in visual insight problems [29]. For instance, in a well cited work Dreistadt [16] showed large incubation effect of visual analogies provided during solving the farm problem (70% success rate). However, attempts to replicate these findings were less successful with Olton and Johnson's [38] findings showing a lower success rate of 38%.

Chronicle, Ormerod and MacGregor [11] investigated the use of visual analogy for the nine dots problem which is a notorious difficult visual task. The findings suggest that a perceptual cue to the shape of the solution gave rise to only minimal improvements in performance (24%), while exposure to correct solution in problem variants lead to a floor performance. These data suggest that visual constraint relaxation is probably not the only condition for reaching insight [11].

An interesting set of visual insight problems are the coin problems. *The eight-coin problem* requires arranging an array of eight coins by moving only two of them to create a final array in which each coin touches exactly 3 others [40]. Like other similar visual insight problems [36, 46], its primary insight requires a shift from moving the elements of the problem in three rather than two dimensions [40].

Ormerod et al [40] used the eight-coin problem for investigating the effect of the two dimensional constraints. In an experimental study, they manipulated move availability and chunk decomposition (tight-loose) through 4 different configurations. Figure 1 shows a particularly challenging initial configuration with multiple available two-dimensional moves and strong figural integrity.

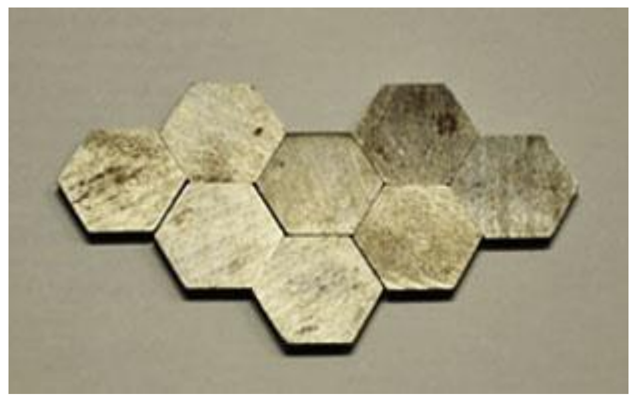


Figure 1: One initial configuration for the eight coins problem

The first experiment in Ormerod's et al paper [40] is further detailed. In order to avoid the floor effect, the experimental procedure included two verbal cues [40] provided after 2 minutes: "*the coins can end up in two separate groups*" (grouping cue) and after another 2 minutes respectively: "*a coin can come to rest on top of other coins*" (stacking cue). The findings suggest that the impact of move-availability and figural integrity with 79% of participants in "no move available" condition solving the problem as opposed to only 50% in "move available condition". The second experiment investigated the impact of an additional nonverbal cue consisting of one of the coins being placed directly on top of another in the initial configuration (non verbal stacking cue). Findings show no impact of nonverbal cue on success rate (33%), suggesting that its effectiveness is influenced by the availability of the moves.

This is an important outcome and yet it sheds little light into how the cues themselves, rather than the problem configuration, can be designed to facilitate incubation effect. Indeed, the verbal cues were directly communicating the primary insight (stacking) and the secondary insight (grouping), and hence their facilitative roles in finding the solution. In addition, the non-verbal stacking cue was physical rather than pictorial.

The state of the art research on the role of visual cues in visual insight problems does not offer conclusive results and follows a similar pattern with the findings on the impact of verbal cues. In both cases, conflicting outcomes suggest that the impact of cues on incubation effect is likely to be mediated by other factors such as the experience of impasse [11], the level of cue processing [38], the problem difficulty or domain [9], and pre-incubation period [49].

However, research on the role of visual cues in visual insight problems has three additional limitations. Firstly, most of the studies reviewed above use a single visual cue, whose impact is usually compared with no cue condition or with verbal cues. Secondly, when the cues are in pictorial forms they usually consist of two dimensional black and white images which might fail to reap the benefits that richer pictorial representation could provide. Thirdly, the construction of a particular visual cue is seldom scrutinized. This is surprising, given the role of surface and structural aspects in visual analogies and the difficulties of integrating them in one visual analogy.

We argue for a shift of emphasis towards extending the current investigation paradigm: rather than focusing only on *if* the visual cues are facilitative, it will be more beneficial to focus also on *what* types of visual cues are facilitative and *why*. A systematic construction and rigorous evaluation of a series of visual analogies within the same experimental design can offer a better understanding into visual insight. And this is our methodological approach.

METHODOLOGY

This section offers a description of the construction of the visual analogies together with a reflection on that process. The following subsection focuses on the experimental study for comparing and evaluating the visual analogies.

Construction of the Visual Analogies

The process of constructing the visual analogies has been a lengthy iterative one involving over 10 families of cues, and an important aspect in developing them was identifying the relevant features which could be manipulated and subsequently expected to impact on the success rate of solving the problem. These features pertaining to the set of cues used in our experiment are further detailed but the discussion of the previous set of cues leading to the final ones is not the focus of this paper.

In the construction of the analogies we employed the distinction between their surface and structural aspects, as well as the two principles of the Structure mapping theory [20]. Figure 2 captures the unique problem solution, while Table 1 presents an overview of the created visual analogies, which are further discussed.

The *surface aspects* of the problem relevant for pictorial representation include the physical artifacts (coins) and their attributes such as number (eight), shape (hexagonal) and color (grey); their spatial organization (topology), and the perspective from which they can be seen (above). Among these aspects, we decided to discard the less important ones such as shape and color while including in the analogy the number of objects and their spatial relationships.

With respect to the artifact representation, we introduced an additional surface aspect, i.e. depth. The rationale for this choice is twofold: (i) findings suggest that depth cues can improve object recognition within pictures [2], and (ii) solving the eight-coin problem involves physical manipulations of coins and therefore their pictorial abstract representations may be better recognized when offered in three dimensions rather than two dimensions.

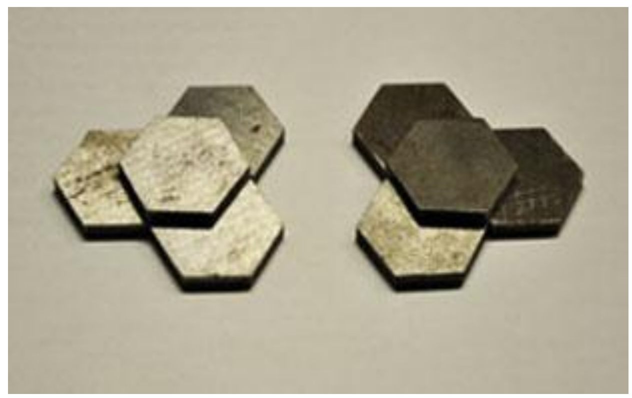
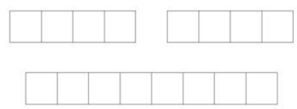
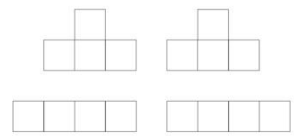
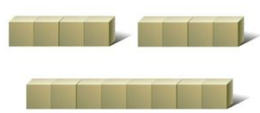
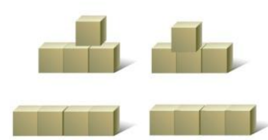


Figure 2: The configuration for the problem solution

In addition, although designers appear to often draw three dimensional sketches [13] and arguably may benefit from three dimensional cues, there has been limited work on the role of depth in visual analogies. For example, in a study focused on the role of visual analogies on creative design problems, Casakin and Goldschmidt [5] use both two dimensional and three dimensional representational images as visual cues. Unfortunately, the findings do not report the different impact these two sets of cues have on the performance scores.

In order to account for the considered surface aspects, we constructed three types of analogies: abstract two dimensional (2D), abstract three dimensional (3D) and representational three dimensional (representational 3D).

At this stage it is important to disambiguate the meaning of three dimensional cues. Throughout the paper the three dimensional cues are the one which involve cast shadows and perspective, as opposed to those which suggest stacking, and which in Ormerod’s et al paper [40] were referred to as 3D cue. The latter cues were aimed to support the solver in moving from the unsuccessful attempts to solve the problem in two dimensions, towards considering the problem in three dimensions by placing one coin on top of others. In our paper, these cues are called stacking cues.

Visual Analogies (cues)		Structural aspects: Insight	
Surface aspects: Depth	Structural aspects: Process	1. Grouping	2. Stacking + Grouping
Abstract Two dimensional (A-2D)	No process	 A	 B
	Process	 C	 D
Abstract Three dimensional (A-3D)	No process	 E	 F
	Process	 G	 H
Representational Three dimensional (R-3D)	No process	 I	 J

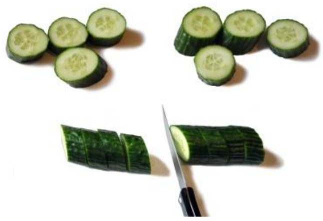
Process	 K	 L

Table 1: The constructed visual analogies vary with respect to both surface and structural aspects

The 2D analogies have surface similarities with the problem such as identical elements (squares), identical number of elements (two groups of 4 elements each), and their spatial organization (elements in an array on a flat surface). The different shape of the element (square rather than hexagon) and their placement in a straight line position are alignable differences.

The 3D analogies have the same surface similarities with the problem as the 2D ones expect that the elements are cubes. The different shape and color of the elements as well as their placement in a straight line position are alignable differences.

Representational 3D analogies are pictorial representations of everyday objects which share the same surface similarities with the problem as the abstract analogies. Slices of cut cucumber, which are similar to the shape and form of the coins, placed in groups and stacked on each other, offer stronger surface similarities than the abstract analogies. The different color is an alignable difference. For both abstract and representational 3D cues, the depth was suggested through cast shadows and perspective.

In order to test the role of depth in visual analogies we formulated the *depth hypothesis*: the three dimensional representations support better incubation effect than two dimensional ones.

The developed analogies are consistent with the *structural consistency principle* involving one-to-one mapping between each part of the target an each part of the source, as well as between each of these parts' attributes.

The *structural aspects* of the problem include the primary and secondary insights, i.e. the verbal cues in Ormerod's experiments [40]. Thus, the concepts of grouping and stacking were visually represented through spatial configurations such as two groups of 4 items each (for grouping cue), and groups of four elements with three on a base and one on top (for stacking cue).

There appears to be a temporal dependency between these structural aspects, so that one has to perform grouping before the primary insight of stacking can be reached. This interdependency is captured in Ormerod's et al experiment through the order in which cues are provided, i.e. grouping cue followed by the stacking cue.

We kept the same order of cues but the stacking cue was provided together with the grouping one. This decision ensured that *systematicity principle* [20] was respected, so that the stacking cue involves two groups of four items each of them with 3 items as a base and one item on top (rather than one group only). In this way, the stacking is actually a stacking plus grouping cue representing thus an extended mapping [19].

In order to test the role of these two structural aspects, we formulated the *extended cue hypothesis*: the stacking plus grouping cues support better incubation effect than grouping only ones.

The analogies discussed so far have one limitation: they capture the similarities with the problem solution (Figure 1) but not the ones in the problem initial state, which in turn could prevent recognition (Figure 2). Therefore, we decided to embed another structural aspect in the analogies, i.e. transformation or process. Thus we have developed analogies with and without information about the process. In the case of 2D and 3D abstract analogies, the information about the process is represented through elements of both the problem initial state (array of eight elements in a straight line) and its solution. In the case of representational 3D analogies, the process has a more explicit representation including also information pertaining to operation: the knife cuts the slices of cucumber grouping them, and stacking them respectively.

To test the role of this structural aspect, we formulated the *process hypothesis*: the visual analogies with process representations support better incubation effect than those without.

According to the systematicity principle, both surface and structural aspects were consistently carried across from the problem representation to each of the developed visual analogies and subsequently in each experimental condition.

To summarize, we have three hypotheses exploring the impact on incubation effect of visual analogies and their various aspects manipulated during the construction of such cues. Two of these hypotheses investigate the impact of changes in structural aspects, while the third one refers to changes in surface aspects.

H1 Extended cue hypothesis: visual analogies capturing structural aspects of insight such as both stacking and grouping support better incubation effect than those capturing grouping only.

H2 Process hypothesis: visual analogies capturing structural aspects such as process or transformational representations support better incubation effect than those without.

H3 Depth hypothesis: visual analogies capturing surface aspects such as three dimensional representations support better incubation effect than those capturing two dimensional ones.

EXPERIMENT

This experiment is a partial replication of the Experiment 1 described in [40] and we used the same eight coin problem, the most difficult stimulus configuration which is shown in Figure 1, and the same procedure both as instruction and timing. The difference is that we replaced the verbal cues for grouping and stacking with the visual cues described in previous section. The reasons for the replication are twofold: no image based visual cues have been used for this problem, and it involves a small set of identical items, i.e. coins which can be consistently mapped.

Participants

Fifty students from Lancaster University were randomly assigned to one of the six experimental conditions and were paid £7. Of these, 2 solved the problem in the first 2 minutes so that they were not given the cues and were excluded from further analyses. This left 8 participants per condition for each of the six between conditions. The overall sample consisted of 60% male and 40% female, and over 75% were between 21 and 30 years of age.

Design

The Independent Variables (IV) for our experimental design have been already introduced in the description of the visual analogies, since they were purposely manipulated during the analogy construction. Thus, we have three independent variables. The first IV relates to the structural aspect of insight and has two levels: grouping only, and grouping plus stacking.

The second IV relates to the structural aspects of process or transformation and has two levels: no process, and process. The third IV relates to the surface aspects of depth and has three levels: abstract 2D, abstract 3D and representational 3D.

Thus, the experiment involves a mix factorial design with two between factors and one within factor. Between factors are surface and process aspects, and within factor is the insight or structural aspect, i.e. 3 x 2 x 2. Each visual cue was presented as an image on a printed 8 x 10 inches paper in the order shown in Table 1.

The Dependent Variables (DV) were the success or failure in solving the problem. The participants were video recorded during the task completion and from the visual analysis we extracted an additional measurement for reaching impasse.

In order to assess if participants have reached impasse, we counted the length of time when they had standstill either staring silently at the coins or playing with a coin without placing it down. If such a length exceeded 5 seconds, we considered that the participants reached impasse. Then we computed for each participant the number of times they reached impasse and the total duration of experiencing impasse.

Procedure

Participants were randomly assigned to one of the six conditions and were provided with two visual cues, one every 2 minutes (Table 1). They were instructed to rearrange the eight coins by moving two coins only so that the correct solution would result in each coin touching exactly two others. In the initial condition (no cues) no further information was provided and participants were allowed to work for 2 minutes and to make as many solution attempts as they wished.

Participants were given a total of 6 minutes to work on the problem and were allowed to make as many solution attempts as they wish with the condition that for each new attempt they must start with the original arrangement. Participants who solved the problem at any time scored as successful and excluded from further participation in the study.

Materials

Each participant was initially provided with a single sheet with the study instructions. In addition, participants received 8 coins positioned in the initial configuration (Figure 1) and a sheet of paper with an image of the initial configuration for prompting them to reposition the coins in after every two moves. As suggested by Ormerod et al [40], we used steel regular hexagons, with length of side of 15 mm and thickness of 3 mm, to make it easier for participants to assess the number of mutual contacts between them. Participants also received two additional sheets, each with a different printed cue-image provided after 2 and 4 minutes respectively.

For the entire set of visual cues see Table 1. In the end, participants were asked some demographic questions and about familiarity with the problem. With the consent of participants the sessions were video recorded.

FINDINGS

All participants were naïve to the problem and we had 8 participants per condition. The main results are illustrated in Table 2, which shows the percentage of participants producing correct solutions for each of the 6 conditions.

Condition	Structural cues	Grouping cue	Stacking cue

Surface cues			
Abstract 2D cue			
	No process cue	0	0
	Process cue	0	0
Abstract 3D cue			
	No process cue	0	4 (50)
	Process cue	2 (25)	0
Representational 3D cue			
	No process cue	0	1 (12.5)
	Process cue	0	4 (50)
Total		2 (4.16)	9 (18.75)

Note: Number in parentheses are percentages, n = 8 in each condition

Table 2: Number of problem solvers in each condition after the visual cues

The numbers of times that each participant produced correct solutions were processed with an analysis of variance, with surface cues and structural process cues as between factors, and structural insight cues as within factor.

Although the use of ANOVA for binary data has been previously criticized [18], ANOVA analysis used by Ormerod [40] has led to almost identical patterns of results to the ones employing the recommended factorial design for binary data [12].

Our findings suggest two significant main effects and an interaction effect. There appears to be a main effect of structural insight cues with grouping plus stacking cues leading to significantly more correct solutions (mean = 0.19) than grouping only cues (mean = 0.04) ($F(1, 42) = 6.72$, $MSE=0.51$, $p < 0.05$).

The other main effect regards the surface cues ($F(1, 42) = 4{,}26$, $MSE = 0.32$, $p < 0.05$) and the post-hoc Tukey's HSD tests showed that abstract 3D cues lead to significantly more correct solutions (mean = 0.19) than abstract 2D cues (mean = 0.0) at 0.05 level of significance Without being significant, post-hoc Tukey's HSD tests suggest that the representational 3D cues also lead to more correct solutions (mean = 0.16) than abstract 2D cues (mean = 0.07). The other comparison was not significant.

There also appears to be an interaction effect between all three factors: surface cue and both structural cues ($F(2, 42) = 8.65$, $MSE = 0.66$, $p < 0.05$). Thus the most successful cues, both with a success rate of 50% are stacking cues without process information and in abstract 3D representational format, together with stacking cues with process informational and in representational 3D format. Furthermore, representational 3D cues only work, and work well, together with stacking insight cues rather than grouping ones. On the other hand, abstract 3D cues work with grouping cues with process information.

DISCUSSION

Whereas, the overall success rate for all the visual cues is about 23% (11 participants out of 48), an in-depth analysis shows that different features of the visual cues can in fact considerably improve this result.

When comparing this overall finding with outcomes on the impact of visual cues from previous studies (Table 3), two things emerge. Firstly, the success of visual cues appears to relate to task difficulty. Indeed, both our eight coins problem and the nine 9 dots problem are particularly difficult and they lead to similarly low success rates (above 20%). Secondly, when compared with the original experiment in the same initial spatial configuration [40], there appears that the verbal cues support insights better than our visual cues.

As previously suggested this may be due to moderator variables such the experience of impasse [11, 49] the level of cue processing [38], the problem difficulty or domain [9], and pre-incubation period [49]. While the level of difficulty has been addressed, and the pre-incubation period has not been manipulated, we will further discuss the experience of impasse.

Study findings suggest a significant impact of impasse on the success rate. We run independent t-tests and findings suggest that over the duration of 4 minutes when cues were provided, the solvers experienced impasse for significantly longer periods of time (mean = 59 sec) than non-solvers (mean = 20 sec) ($t(46) = 3.83$, $p < 0.05$), as well as significantly more moments of impasse (mean = 4 times) then non-solvers (mean = 1 time) ($t(46) = 4.97$, $p < 0.05$). In addition, the mean impasse duration for the entire sample was 30 sec and findings suggest that over 52% of those experiencing impasse for at least 30 sec, have succeed in solving the problem, whereas only 3.4% of those experiencing impasse for less than 30 sec solved the problem. Sadly, almost 69% of participants did experience less than 30 sec of impasse, and 74% of non-solvers have had not a single moment of impasse.

Problem	Sample size	Success rate (%)	Incubation time (min)
Farm [16]	40	70	20
Farm [39]	160	38	20
Nine dots [11]	58	24	3
Nine dots [11]	110	24	3
Eight coin Exp1 [40]	56	42	6
Eight coin Exp2 [40]	52	33	8

Table 3: Success rates of using cues to facilitate incubation effect in visual insight problems

These outcomes are particularly relevant in supporting the importance of reaching impasse before the visual cues are processed and could prove useful. These findings support the facilitative cue theories, while emphasizing the prerequisite conditions of reaching impasse.

A significant contribution of this paper is based on the findings which show that in fact some of the employed visual cues did work, and we will turn our attention to them while revisiting the study hypotheses.

H1 Extended cue hypothesis is validated by the main effect of structural insight cues, with the grouping plus stacking cues leading to significantly more correct solutions than grouping only cues.

This is a particularly important outcome for the construction of visual analogies and we argue that seamless *integration* of distinct insight cues and their parallel processing can be better achieved through pictures than words. This is supported by findings in brain science on hemisphere specialization, with the left one superior at language processing and sequential organization and the right one superior at perceiving relationships, the whole configuration and performing spatial visual transformations [3].

H2 Process hypothesis is refuted by the failure to identify a main effect of structural process aspects. However, structural process cues have a significant impact when they are integrated together with surface cues and structural insights cues (see the interaction effect in the Findings section). Findings suggest that the most successful cues are a mix of 3D cues, stacking cues and no process cues; and a mix of representational 3D cues, stacking cues and process cues.

What is interesting is the fact that process cues do not appear to work in the case of abstract 3D cues (H cell Table 1), albeit they work for representational 3D cues (L cell in Table 1). Process cues were designed to provide information about the initial problem state and about the transformation process from that to the solution state. The major distinction between the cues in the cell H and L in Table 1, is that the transformation process is tacit in the former and explicit in the latter, i.e. from each of the bottom arrays one element is supposed to be moved on top of the array. In other words, without being explicit about the transformation process, the process cues can be detrimental for problem solving, probably because of failure of mapping. The transformation process can be made explicit by providing means to extract the operation needed to move from the initial to the final state of the problem.

H3 Depth hypothesis is validated by the main effect of surface cues, with three dimensional representations supporting better incubation effect than those capturing two dimensional ones.

This is another significant outcome for constructing visual analogies, especially since most of the previously employed visual cues are two dimensional. It is possible that three dimensional cues are particularly suitable for the eight-coin problem, and future work could explore if their impact on the success rate of solving other visual insight problems which require manipulations of physical artifacts can be replicated. If that is the case, then three dimensional visual analogies may be particularly beneficial for design practices involving manipulation and production of physical artifacts. Future work could further explore this research question.

CONCLUSION

This paper presented the reflection on, and the construction of a set of visual analogies, together with their empirical evaluation.

In the reflective practice of constructing the analogies, we draw support from the structural mapping theory. We made use of the constructs of surface and structural aspects, alignable and non alignable differences, as well as of the principles of structural consistency and systematicity.

The experimental findings suggest that in visual analogies insight cues are the most beneficial ones, especially when integrated, and that depth cues are important surface aspects in facilitating incubation effect. Our findings support the facilitative cue theory and replicate previous outcomes on the importance of impasse as prerequisite for analogical transfer.

Our work can make important theoretical contributions to the understanding of visual analogies and insight problem solving. In addition, the visual cues that we constructed could also be extended to other visual insight problems that share similar insight, i.e. three trees or six matches.

Finally, our findings support the benefit of our novel methodological approach consisting in the systematic construction and evaluation of a set of visual analogies within the same experimental design. The long term benefits of such an approach is that it allows for a shift of emphasis from exploring not only if the cues work but also which ones and more importantly why.

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