Draft - CREATIVITY PREDICTORS: FINDINGS FROM DESIGN-BY-ANALOGY METHODS

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ABSTRACT

The mechanisms and interactions by which psychological and cognitive factors influence creative performance in design, explicitly in design's ideation stage have not been fully explored and understood. The present study aims to explore such influences for Design by Analogy (DbA) ideation methods. 69 participants from 52 companies in Mexico and Singapore executed two ideation sessions (phase I and phase II) to generate solution ideas for a service design problem (same design problem was used for both phases). Between the two phases participants were assigned and trained with one of three selected ideation conditions: Control, WordTree and SCAMPER. At the end of each phase, they were asked to self-evaluate 11 factors that may influence their creative performance. The explored factors comprised individual, performance self-perception and contextual factors. Individual factors are considered with respect to the ideation activity and the design problem. In the case of the ideation activity evaluated factors are: entertainment (boring-fun), motivation, inspiration and easiness (difficult-easy). For the design problem, interest, easiness and inspiration are considered. Performance self-perception factors are: commitment (minimal effort-hard work), concentration (unfocused-focused) and level of success (unsuccessful-successful). Lastly, the Contextual factor considered is the self-perceived relation of time with respect to ideas. Three analyses are presented and discussed in this article: the effect of learning and applying DbA ideation methods on participants' factor self-evaluation, the relationship between the 11 self-evaluated factors and creative performance using the metrics of Fluency, Novelty and Fixation, and; the correlations between creativity factors and metrics.

1. INTRODUCTION

Creativity has been defined as the ability to develop ideas or produce work (solutions) that are both novel and valuable [1, 2]. The use of idea generation (ideation) methods determines in part the creative performance. However, it has also been shown

that the creative performance of an individual or a group depends on the interaction of factors at the individual and contextual levels [3, 4] involving emotional, motivational, and behavioral influences [5].

2. CREATIVITY FACTORS

There is extensive research from the cognitive psychology field about creativity and the factors that may influence it. For instance, creativity has been associated with: intrinsic motivation [6], with individual attributes and attitudes, such as personality characteristics and cognitive style [7]; and with incubation [8, 9, 10].

According to the investment theory, creativity requires six types of resources: intellectual abilities, knowledge, cognitive style, personality, motivation, and environment (context) [11, 12]. Incubation may also play a role when the creativity capabilities have been exhausted and frustration emerges [11].

In [13] it is stated that intensity (commitment) and persistence to perform an assigned activity are amplified when motivation is high.

Table 1 presents a summary of the aforementioned factors that may influence creativity extracted from literature with a short description and -where applicable- their components.

3. CREATIVITY FACTORS IN DESIGN

Despite the extensive studies into creativity and its enablers, predictors and factors as well as a growing interest from diverse disciplines to identify and understand the cognitive components that are relevant for design activities [14] its exploration in the context of design has been less prevalent [15].

In design, it has been found that motivation and reward (promotion) are associated with the capability of generating more solutions [16]. In [17], it is found that personality type did not influence creativity metrics (quantity, variety, novelty and quality) when using visual stimuli or SCAMPER ideation methods. In contrast, in [18] it was found that MBTI personality type and “six thinking hats” modes of thinking do present statistically significant differences in the results of ideation metrics (quality, novelty, variety and quantity) when employing several ideation methods (brainstorming, mind-mapping and the C-Sketch method) [18]. In [19] it was found that for design platforms, motivation and interaction significantly influenced the perceived usefulness and perceived ease of use [19], which may imply that motivation influences the perceived usefulness and easiness of supporting design methodologies and tools as well.

4. DESIGN-BY-ANALOGY (DbA)

DbA believes that the solution to a given design problem may already exist (or partially exist) in an analogous domain or solution. Therefore, it can be extracted once the analogous associations between characteristics, attributes, properties, functions, or purposes are made [15, 20, 21, 22, 23]. Once association(s) between the design problem

and an existing solution in another domain is established, the design problem may potentially be solved.

4.1 Scamper

This is a DbA method that extends brainstorming recommendations in [24]. SCAMPER is an acronym of seven operator categories. Each category makes the designer change the viewpoint when developing solutions to a design problem: (S) Substitute, (C) Combine, (A) Adapt, (M) Modify/Magnify/Minimize, (P) Put to other uses, (E) Eliminate, and (R) Reverse/Rearrange [25]. Within each operator category there is a set of questions that directs and redirects the analogical search when solving the design problem.

4.2 WordTree

WordTree is a DbA method that enables the design problem re-representation, and the detection of potential analogies and analogous domains [26, 21, 27]. The method requires the identification of “key problem descriptors (KPDs)” which can be functional requirements, customer needs, or clarifying descriptions of the design problem. The next step consist on semantically re-represented in a diagram (known as WordTree) the identified KPDs by adding related terms in the form of hyperonymy (more general) and troponyms (more specific) extracted from Princeton’s WordNet or related tools such as Visual Thesaurus™. Then, the developed diagram is used to identify potential analogies and analogous domains to discover solutions. The next step consists of developing alternative problem statements or problem representations and repeating previously

mentioned steps. The method ends with an idea generation session, where the results from all previous steps are used to both refine and develop additional concept solutions.

5. AIM AND RESEARCH QUESTIONS

Considering that the influence of psychological and cognitive factors on creative performance in design has not been fully explored and understood -specifically, during the early stages of design- the present study aims to explore the effects of a selected set of such factors when learning and applying two Design-by-Analogy ideation methods (SCAMPER and Wordtree) to a service design problem. This study will expand not only our understanding of factors interactions and influences in creativity, but will also support designers when ideas are generated.

Therefore, the present study addresses the following research questions:

- What is the effect that learning and applying DbA ideation methods have in designers’ self-perception of the factors that may influence creative performance?
- Do the 11 self-evaluated factors predict creative performance (metrics of fluency, novelty and fixation)?
- What type of relations exist within the factors that may influence creative performance as well as the creativity metrics when ideating without the support of a specific method and when ideating using DbA methods?

6. STUDY DESIGN

The experiment developed in [28] involving domain knowledge participants (based on professional background and work role) is used to address the posed research questions. The experiment consisted of providing a service design problem to a group of 97 domain expert participants who had to develop ideas to solve the problem during two separate phases (see Figure 1).

During phase I, participants were asked to generate solutions over a 15 minute period without the support of a specific ideation method (NT-No Tool). Subsequently, they were asked to complete a questionnaire that requested their perception of the selected creativity related factors (see Figure 2). 28 participants of the study conducted in [28] were not requested to complete the questionnaire

Phase II took place two days later. Participants were assigned and trained with one of three selected ideation conditions: Control (NT, as in phase I), WordTree (WT) and SCAMPER (SCA). The latter two received 15 minute training in their assigned method. In phase II, participants were given the same service design problem used in phase I and were asked again to generate solutions over a 15 minute period, but this time –for the WT and SCA participants- with the assistance of the assigned method. After the ideation period, the participants were asked to complete the same questionnaire as the one they completed in phase I.

The performance of the ideation conditions in [28] was evaluated through creativity metrics: fluency, quality, novelty, design fixation and analogical semantic transfer. The detailed creativity metrics definitions, equations and results can be found

in [29, 28]. For current paper, the questionnaires results (factor evaluation) are contrasted to three creativity metrics of the study in [28]: fluency, novel and fixation.

The questionnaire asked the participants to judge themselves on 11 factors (see Figure 2) that, according to literature appear to have an influence in creative performance. In addition, participants were asked to provide some demographic information and had the possibility to record additional comments.

The selected factors comprised: individual, performance self-perception and contextual components (see Table 2).

Individual factors are presented in the first two sections of the questionnaire. In the case of ideation activity, which refers to the assigned ideation technique, the evaluated factors are: *entertainment, motivation, inspiration* and *easiness*. For the design problem, which refers to the perception of the provided service design problem when working with the assigned ideation condition, the factors are: *interest, easiness* and *inspiration*.

Performance self-perception factors are presented in the third section of the questionnaire. These factors are: *commitment, concentration* and *level of success*. The performance self-perception during the activity refers to the intensity, persistence and perceived level of success experienced with the assigned ideation condition.

The final section of the questionnaire contains the selected contextual component: *time*. The factor *time* refers to the perception of having been limited by the allotted time (15 minutes) in the generation of possible ideas (solutions).

Participants were asked to read each sentence and place an "X" mark in the box nearest to the factor that described best their perception.

A total of 69 complete sets of evaluations were collected and analyzed. A complete set contains one phase I and one phase II questionnaires per participant. The total sample size of questionnaires corresponded to 45 male and 24 female participants.

7. ANALYSIS

The total 138 questionnaires (one for each phase of the 69 participants) were coded using a Likert Scale. The position of each “X” along the 5 segments was assigned a value of -2,-1, 0, 1, 2 (see Figure 3), where a value of zero denotes indifference (or neutrality), and the other values a level of preference towards one of the two possible extreme attributes.

With the codded data three sets of analysis were preformed to address the research questions, and are presented in detail below.

7.1 First research question analysis

Average perceptions

The average perception values for each factor during phases I and II were calculated and are shown in Appendix A. Despite all of the 69 participants in phase I were working without the support of a specific ideation method (NT), to be able to contrast the pre- and post- training conditions, the results reported for phase I present the participants

grouped according to their assigned phase II ideation condition. The average results provide directions of findings, i.e. where significant differences may be found.

Comparison within and between phases

Mann-Whitney and Kruskal-Wallis tests were used to statistically evaluate the effect that learning and application of DbA ideation methods have in participants' self-perceived factor evaluation (see Table 4). The Mann-Whitney test was used to compare the participants' results between phases and the Kruskal-Wallis test for the participant's results within a given phase.

7.2 Second research question analysis

Multiple regression analyses were conducted for each of the two phases (see Appendix B) to identify the ability that the selected 11 factors (independent variables) may have to predict the creative metrics: Fluency, Novelty and Fixation (dependent variables).

In Appendix B, the regression coefficients are listed and the p-values highlighted (shaded). The coefficients indicate the nature (direct or inverse) and magnitude of the relation between the evaluated factor and the specific metric. The p-values indicate when the evaluated factor is statistically significantly related to the metric.

Fluency results are displayed disaggregated, i.e. the total quantity of developed ideas correspond to "quantity raw", and the net quantity of developed ideas after

excluding all repeated ideas correspond to “quantity filtered”. For completeness the amount of repeated ideas are also presented under “repeated”.

Novelty results are only presented in phase II due to its definition in the study “Novelty is defined as the design space composed of all ideas generated by a participant in phase II that were not generated by any participant in phase I, over the participant’s total phase II ideas” [28].

7.3 Third research question analysis

Correlations were calculated for all the selected 11 factors and the three creative metrics to identify statistically significant relations in the following two scenarios: when ideating without the support of a specific method and when ideating with the support of DbA methods. This enables the development of models to identify the influences that factors and metrics may have on each other.

Full correlation matrixes were developed for the two scenarios along with their correspondent significant test (see Appendix C). The reason for including the significant test result is to determine the probability that the observed correlation coefficients are real and not found by chance. The significance level used for the test is $\alpha=0.05$.

From the matrixes, only “strong” correlations, i.e. the ones with an absolute value of Pearson coefficient equal or greater than 0.5 were used to model the relationship between factors and metrics for the two scenarios: when ideating without the support of a specific method and when ideating with the support of DbA methods.

8. RESULTS

8.1 Average perception

The average results shows found that in phase I, 29 of the total 33 possible results (11 factors, 3 conditions to be assigned) were greater than zero, which means that participants' initial self-perception tended to be closer to the positive attributes of each evaluated factor. The results obtained for phase II showed a similar picture: one indifferent average result (zero), 29 positive average values and three negative average values. The indifferent and negative average results from tables in Appendix A are shown in Table 3 and discussed below.

One of the negative average results and the indifferent result concern factor: *easiness of the ideation activity*, i.e. of the method used. Compared to phase I, the ideation activity was considered less easy. For the NT participants, the average was still positive (towards easy) but reduced from 0.39 to 0.22. The average perception of WT participants' reduced from 0.93 to 0.00, and for the SCA participants from 0.38 to -0.38.

One of the four negative values obtained in phase I concerns factor *easiness of the problem* and involved those participants that were assigned to the scamper condition in phase II. This means that, on average, they considered the problem more difficult than easy. It can also be observed that this trend did not change in phase II, but increased (from -0.13 to -0.42), despite the fact that the problem was the same. The other three negative values correspond to factor *time*, the perception of all participants of having more time than ideas in phase I, i.e. when working without the support of a

specific ideation method. In phase II, only control group showed a negative average, which is consistent with their phase I results considering that they continued working without the support of a specific ideation method. It seems that both DbA ideation methods made the participants feel that they had more ideas than time.

Only seven results increased their magnitude in phase II respect to the one obtained in phase I: NT for *motivation, easiness* and *level of success*, WT for *time*, and SCA for *interest, commitment* and *time*.

8.2 Comparison within and between phases

The Mann-Whitney tests show statistically significant differences in four factors: *motivation, easiness, concentration* and *level of success*.

For *motivation*, participants assigned to the WT ideation condition showed a statistical significant reduction of motivation from phase I to phase II, while participants assigned to the NT ideation condition had a statistical significant increment.

For *easiness*, participants of both DbA ideation methods WT and SCA had statistical significant reductions in their easiness perception of the ideation activity.

For *concentration*, participants of WT had statistical significant reductions in their focus perceptions of their performance on the activity.

For *level of success*, participants of WT and SCA had statistical significant reductions on their perceived level of success while performing the activity.

The Kruskal-Wallis tests show that in the phase I, two factors, *motivation* and *level of success* show statistically significant differences, even though the condition for

all participants was the same. For *motivation*, the average results of participants that were assigned to the NT condition in phase II are lower than the ones of the other participants. For *level of success*, the average results of the participants that were assigned to NT condition in phase II are lower than the ones from the other participants.

In phase II, the Kruskal-Wallis tests show that *easiness of activity* and *easiness of problem* have statistically significant differences. In the case of the ideation activity, the average result of the NT participants is statistically higher than those of SCA participants (verified with Tukey's pairwise comparisons). For the design problem, the average result of the SCA participants is statistically lower than the ones obtained by the other participants (verified with Tukey's pairwise comparisons). The average results plotted in Appendix A complements these statistical findings, allowing to graphically verify this differences.

8.3 Creativity metrics prediction

Phase I regression results

All metrics had at least one factor with statistical significance. Interestingly, this depends on the assigned condition in phase II, even though the condition was the same for all participants in phase I.

For those who were assigned the NT ideation condition in phase II, it is found that *entertainment* and *commitment* are good predictors for Fluency (quantity raw), but for Fluency (quantity filtered) only *entertainment* seems to be a good predictor.

For those that were assigned the WT ideation condition in phase II, it was found that factors *motivation, inspiration of the activity, easiness of the activity, easiness of*

the problem, inspiration of the problem, commitment and *concentration* are good predictors for Fluency (quantity raw).

For those who were assigned the SCA ideation condition in phase II, it was found that *commitment* is a good predictor of Fixation, and that *inspiration of the problem* is a good predictor for Repeated ideas.

Phase II regression results

Entertainment was found a good predictor for Novelty in all the ideation conditions. In the case of NT and WT, the nature of the relation is direct, and inverse in the case of SCA.

For the participants assigned the NT ideation condition, it was found that factors *entertainment* and *motivation* are good predictors for Novelty. For Fluency (quantity raw) only *commitment* appears to be a good predictor, but for Fluency (quantity filtered) both, *level of success* and *time* were found good predictors. Lastly, for Repeated ideas *motivation* and *commitment* are good predictors.

For the participants assigned the WT ideation condition, it was found that *entertainment, motivation, interest, easiness of the problem, concentration* and *level of success* are good predictors for Novelty.

For the participants assigned the SCA ideation condition, it was found that *entertainment* and *level of success* are good predictors for Novelty.

None of the 11 evaluated factors was found a good predictor for Fixation.

Aggregating the results obtained in both phases, the overall influencing factors for the evaluated creativity related metrics are: *entertainment, motivation, easiness of the problem, inspiration of the problem, commitment, concentration* and *level of success*.

8.4 Correlations with and without the support of DbA methods

Since inspiration and easiness are factors that were evaluated with respect to the ideation activity and the design problem, in the model plots of Figures 4 and 5 they have an "A" when they refer to the ideation activity and a "P" when they refer to the design problem.

Correlations for No Tool ideation condition

From the correlation matrix in Appendix C, it was found that 8 factors (*entertainment, motivation, inspiration* of the activity, *interest, concentration, level of success*, *inspiration* of the design problem, and *time*) and 4 metrics (quantity raw, quantity filtered, repeated ideas and fixation) had strong and statistically significant correlations between them.

With the set of correlated and statistically significant of factors and metrics a relationship model was developed (Figure 4). All the found correlations on the plot are positive, i.e. increments in one of the correlated pair of variables correspond to increments in the other. No strong and statistically significant correlations among the factors and the creativity metrics were found.

Motivation and *level of success* are the factors with the largest amount of correlations. *Motivation* correlates with 6 factors while *level of success* with 4 factors.

The aggregated model for the factors in the No Tool scenario presented in Figure 4 shows that *motivation* appear to be the most influential factor correlating with all the factors with a positive relationship. This means that the more motivated the participants are, the more positive their perceptions of the other factors are. In addition, *entertainment* positively correlates with *level of success* and *time*, meaning that the more fun the participants feel they are having, the higher their perception of having more ideas than time and the more successful their performance is perceived. Lastly, the correlation between *inspiration* of the activity and the *inspiration* of the design problem appear to indicate the importance that the design problem being perceived as inspiring has with the perception of inspiration given by the activity.

The aggregated model for creativity metrics aligns with creativity literature where fluency expressed in the total amount of ideas generated (quantity raw) correlates with both, the amount of non-repeated ideas (quantity filtered) and the amount of repeated ideas; this last one less strongly than the first. The total amount of repeated ideas correlates and provides an indication of the amount of design fixation.

Correlations for DbA ideation conditions

From the second correlation matrix in Appendix C, it is found that 9 factors (*entertainment, motivation, inspiration* of the activity, *easiness* of the design problem*, interest, concentration, level of success*, *inspiration* of the design problem and *easiness*

of the design problem) and 4 metrics (quantity raw, quantity filtered, repeated ideas and fixation) had strong and statistically significant correlations between them.

The relationship model developed in Figure 5 shows that all the found correlations on the plot are positive and no strong and statistically significant correlations among the factors and the creativity metrics were found, just as it was in the case of the "No Tool" ideation condition.

Level of success, entertainment, motivation, inspiration of the activity, and *concentration* are the factors with the largest amount of correlations; *level of success* with 5 factors and the rest with 4 factors.

Unlike "No Tool" scenario, the most influential factor for the DbA scenario is *level of success* followed by *motivation* and *entertainment* with a positive relationship. This means that the more successful the perception performance of the participants is, the more positive their perceptions of the other factors are. In addition, *inspiration* of the design problem positively correlates with *interest* and *easiness* of the activity, meaning that the more inspired by the design problem the participants feel, the easiest the activity is perceived and the more interesting the design problem is perceived. In the DbA scenario the inspiration of the activity and the inspiration of the design problem are not directly correlated which may mean that the introduction of DbA ideation methods de-couples this correlation. The correlation between *easiness* of the activity and the *easiness* of the design problem appear to indicate the importance that the design problem being perceived as easy has with the perception of the easiness of the activity. Lastly, unlike "No Tool" scenario where *motivation* factor had the second place in

number of correlations and *entertainment* the third; in the case of DbA, both factors appear tied in the second place.

The factor *time* and the metric novelty have statistically significant correlations, but Pearson coefficients lower than 0.5 and that is why they do not appear in the model. In the case of *time*, it correlates with *entertainment*, *inspiration* of the design activity, *easiness* of the design activity, and *concentration*. In the case of novelty, it correlates with *easiness* of the activity, *inspiration* of the design problem, *easiness* of the design problem, and level of success.

The aggregated model for creativity metrics had the same number and type of correlations than the one of "No Tool" scenario.

9. DISCUSSION AND CONCLUSIONS

The results obtained in Section 8 confirm that creative performance is the result of a complex interaction of factors and has intriguing results about the changes of factors associated to creativity.

9.1 Motivation

Motivation -which was explicitly asked in the questionnaire- appears to be a significant factor (see Table 4).

The change in *motivation* before and after learning and applying the assigned ideation condition tested with Mann-Whitney showed that all participants felt initially

motivated in phase I, and then, in phase II, the self-perceived motivation level reduced significantly for the participants assigned in the WordTree ideation condition. Considering that the results in Appendix A show that the task was perceived as more difficult in phase II, the change in *motivation* for WordTree may imply that the method demands more cognitive investment, interpretations and proficiency that may reduce participants' self-perceived motivation. Although participants that were assigned to control ideation condition in phase II exhibited a significant magnitude difference in phase I with respect to their WordTree and SCAMPER counterparts, this result is believed to be an outlier, especially considering that the results for same control group in phase II show no statistical difference when compared with the results that WordTree and SCAMPER had in phase I (Kruskal-Wallis Test with p-value=0.560), and they were working under the same paradigm of not been assisted by an specific ideation method.

Motivation is a predictor for Novelty for both, control and WordTree conditions in phase II, however, the type of relation between *motivation* and novelty is inverse, i.e. the higher the self-perceived *motivation*, the lower the novelty result. It is interesting to notice that motivation also predicts in phase II the amount of repeated ideas for participants in control condition, and that their relation is inverse i.e. the higher the self-perceived *motivation*, the lower the amount of repeated ideas. This may imply a self-regulation mechanism in non-assisted scenarios, where a self-triggered motivation may alleviate the tendency to repeat ideas.

Inspiration and *Easiness of the activity* did not have a statistically significant change before and after learning and applying the assigned ideation condition, they also

do not appear be good predictors for any of the evaluated creativity metrics. Therefore, the incubation emergence after becoming frustrated due to exhaustion of creativity capabilities stated by [11] could not be verified or may have been mitigated with the ideation conditions.

Lastly, *motivation* appears to be one of the most influential factors when designers work without the support of a specific ideation method in the sense that it correlates with a considerable number of self-perceived factors, however, it does not correlate with the explored creativity metrics.

9.2 Performance factors

With respect to the evaluated performance factors *commitment, concentration* and *level of success*, their change before and after learning and applying the assigned ideation condition showed that in phase I all participants felt their performance to be focused (*concentration*), and in phase II that perception was reduced significantly for WordTree participants. This may be attributed to the same reasons proposed for the change in *motivation*. In addition, the perception about performing successfully became significantly reduced in phase II for the participants assigned to the DbA ideation methods, which may imply that performing new unfamiliar processes can increase the self-perception of being underperforming (unsuccessful). Nonetheless, even though there is a perception of reduced success level, the analysis of novelty and quality across this ideation condition of the studies carried in [28, 29] demonstrated significant improved performance, which implies that designers shouldn't worry too much about

feeling unsuccessful during idea generation sessions applying DbA methods, because this does not appear to influence their creativity outcome.

The performance factors were found good predictors of the evaluated creativity metrics.

Commitment, was found a good predictor of Fluency and repeated ideas for control condition. Specifically, *commitment* predicts the total amount of ideas generated (quantity raw). The more committed the participants felt, the higher the quantity of total ideas developed (quantity raw) and the more ideas they repeated. This dual effect is very important, because it reflects that even non-useful work, like the one participants do in repeating or developing slight variations of an idea, can be perceived as productive because participants were engaged in the activity and perceived themselves close to the "Worked hard" description of the *commitment* factor.

In the case of *concentration*, which refers to how focused participants felt they performed, the results show that this factor is a good predictor of Novelty for WordTree condition. Considering that their type of relation is direct, this may indicate that WordTree enables a more focused work that translates in novelty.

In the case of *level of success*, which refers to how successful participants felt their performance was, it was found that this factor is a good predictor of Novelty for participants assigned to both DbA ideation methods. This factor is a good predictor - with an inverse type of relation- of quantity filtered (net quantity of ideas generated) by participants in the control condition. Both results confirm that supporting designers

with ideation tools has a positive impact on their perceived successful performance and also translates in a larger amount of novel ideas developed.

From the results obtained for *motivation* and performance factors (*commitment, concentration, level of success*), it appears that the direct relation between motivation and commitment/intensity/persistence presented by [13] was not confirmed, because in the case of novelty, the effect is inverse to *motivation* and direct with respect to participants' focused and successful performance.

Lastly, *Level of success* appears to be one of the most influential factors when designers work with the support of DbA ideation methods since it correlates with a considerable number of self-perceived factors, however, as in the case for "No Tool" scenario, it does not correlate with the explored creativity metrics.

9.3 Easiness of the activity and the design problem

A set of related factors are *easiness of activity* and *easiness of the design problem*. For the first one, the perceived *easiness of the activity* increased significantly after learning and applying both DbA ideation methods, even though all considered the activity relatively easy when it was first introduced at the beginning of the study. The *easiness* perception became neutral for WordTree participants and shifted towards difficult for SCAMPER participants, and –as mentioned earlier- their perceived *level of success* reduced too. The application of new supporting tools during ideation seems to affect the perceived easiness with which the activity can be performed, at least for the first time. Although this may improve over time, such initial experience may result in a

rejection of new, potentially successful methods. Interestingly, what the designers did not seem to be aware of, is that their creative performance is not affected by this; in fact, the results show that none of the evaluated metrics can be predicted by this factor.

In the case of the perceived *easiness of the design problem*, there was no statistically significant change between phases, i.e., before and after learning and applying the assigned ideation condition. However, participants in the SCAMPER condition in phase II distinctively felt the problem was more difficult, but *easiness* was not found to be a good predictor of any of the evaluated creativity metrics for SCAMPER condition, which allow us to make the inference that there are improvement opportunities for the SCAMPER method, perhaps participants felt that not all of SCAMPER's operator categories were applicable or related to the design problem, and therefore, the perception of the design problem shifted and became difficult.

Easiness of the design problem was found to be a good predictor of Novelty for WordTree with a direct type of relation, i.e. the more "easy" the problem is perceived, the more novel ideas were generated. Which may indicate that the WordTree method may enable a smoother exploration of the design problem as well as an effective solution development.

As found by [19], the self-perceived *easiness* of ideation tools could be influenced by motivation. In our study, this can only be observed for the novelty metric of the WordTree condition, where *motivation* and *easiness of the design problem* are found to be good predictors of Novelty. The effects however are inverse to *motivation* and direct to *easiness*.

9.4 Time constraint

The contextual component *time* was found to be a good predictor of Fluency (quantity filtered) when the ideation is carried out without the support of a DbA method (control condition in phase II). The type of relation between the two is direct, i.e. the more limited by time rather than lack of ideas they felt, the more non-repeated ideas they develop.

The experiment design also included a period of two days in between phases where incubation could emerge and may support overcoming fixation (repeating ideas). However, none of the evaluated factors had a significant influence on the Fixation metric.

Despite being left out of the DbA relationship model, *time* is statistically significant in both scenarios, and the perception of having more ideas than time correlates with how entertained the participants feel.

9.5 Research question

In summary, and returning to the research questions formulated for present study:

What is the effect that learning and applying DbA ideation methods have in designers' self-perception of the factors that may influence creative performance?

The effect manifests in the perceptual changes in the factors *motivation, easiness of the activity, concentration,* and *level of success*.

Do the 11 self-evaluated factors predict creative performance (metrics of fluency, novelty and fixation)?

From the evaluated metrics, only for fixation none of the 11 evaluated factors was found to be a good predictor. Predictors for Fluency appear to be *commitment, level of success* and *time*. Predictors for Novelty appear to be *entertainment, motivation, easiness* of the problem*, concentration* and *level of success*.

What type of relations exists within the factors that may influence creative performance as well as the creativity metrics when ideating without the support of a specific method and when ideating using DbA methods?

From the explored set of factors and metrics, it was found that there are no statistically significant Pearson's correlations which absolute value was greater than 0.5 among the factors and the metrics. The first most correlated factor when ideating without the support of a specific method is *motivation* and the second is *level of success*; and when ideating using DbA methods the ranks of these two factors inverts.

9.6 Conclusion

There is still much that can be learned about the mechanisms and interactions by which psychological and cognitive factors influence creative performance in design, especially considering that present study considers only a set of possible factors that may influence creativity outcome; and that creativity outcome may be assessed though additional metrics than the ones used in this study.

The present study aims to explore the influences of a reduced set of factors on the creative performance of designers using different Design by Analogy (DbA) ideation methods. The results presented here are only preliminary and further research is required to expand our understanding of design creativity, in order to better support designers during early design stages.

ACKNOWLEDGMENT

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FUNDING

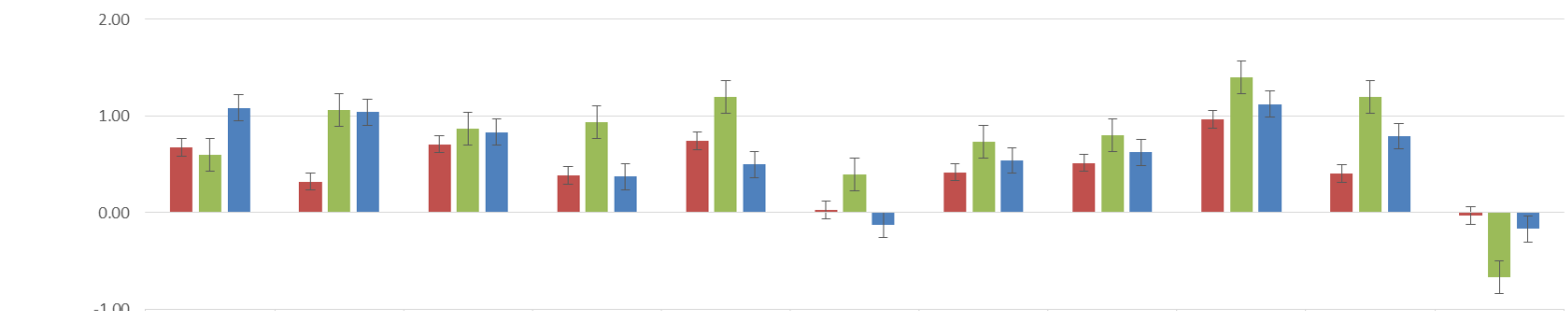
A separate section listing funding sources should be included. The full names along with their abbreviation should be included, e.g., U.S. Department of Energy (DOE).

NOMENCLATURE

α	Confidence level
ρ	Pearson’s coefficient

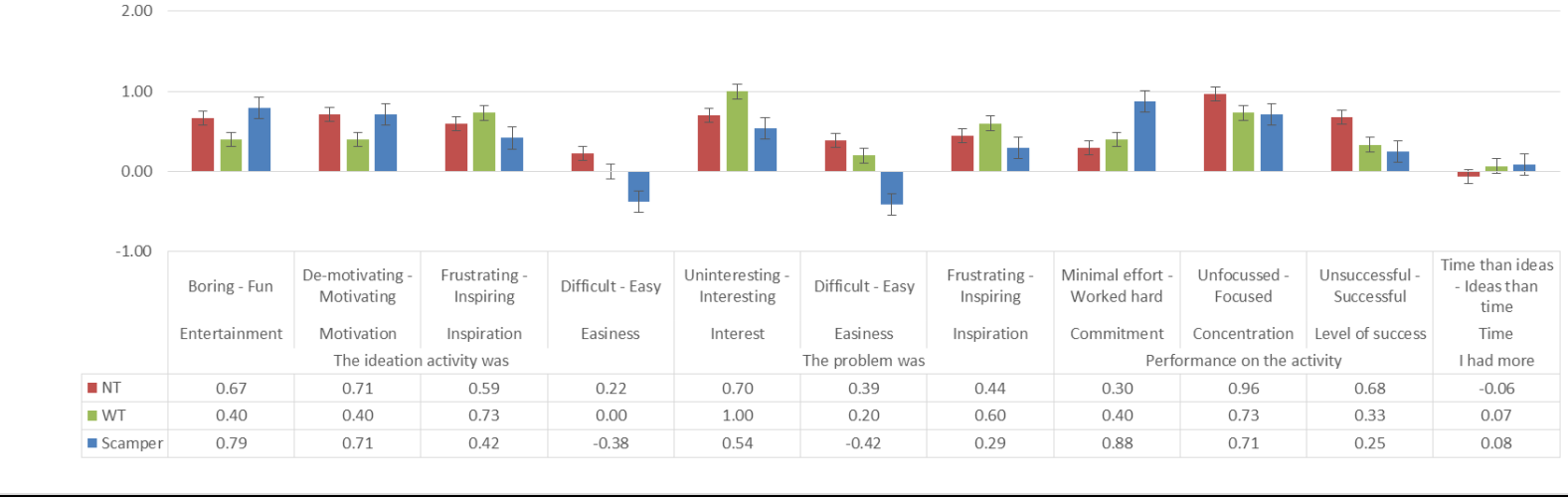
Appendix A. Questionnaire results

Phase I



	Boring - Fun	De-motivating - Motivating	Frustrating - Inspiring	Difficult - Easy	Uninteresting - Interesting	Difficult - Easy	Frustrating - Inspiring	Minimal effort - Worked hard	Unfocussed - Focused	Unsuccessful - Successful	Time than ideas - Ideas than time
	Entertainment	Motivation	Inspiration	Easiness	Interest	Easiness	Inspiration	Commitment	Concentration	Level of success	Time
	The ideation activity was				The problem was			Performance on the activity			I had more
NT in Phase II	0.68	0.32	0.71	0.39	0.74	0.03	0.42	0.52	0.97	0.41	-0.03
WT in Ph II	0.60	1.07	0.87	0.93	1.20	0.40	0.73	0.80	1.40	1.20	-0.67
Scamper in Ph II	1.08	1.04	0.83	0.38	0.50	-0.13	0.54	0.63	1.13	0.79	-0.17

Phase II



	Boring - Fun	De-motivating - Motivating	Frustrating - Inspiring	Difficult - Easy	Uninteresting - Interesting	Difficult - Easy	Frustrating - Inspiring	Minimal effort - Worked hard	Unfocussed - Focused	Unsuccessful - Successful	Time than ideas - Ideas than time
	Entertainment	Motivation	Inspiration	Easiness	Interest	Easiness	Inspiration	Commitment	Concentration	Level of success	Time
	The ideation activity was				The problem was			Performance on the activity			I had more
NT	0.67	0.71	0.59	0.22	0.70	0.39	0.44	0.30	0.96	0.68	-0.06
WT	0.40	0.40	0.73	0.00	1.00	0.20	0.60	0.40	0.73	0.33	0.07
Scamper	0.79	0.71	0.42	-0.38	0.54	-0.42	0.29	0.88	0.71	0.25	0.08

Appendix B. Regression results

Phase I Regression results

Regression Coefficients	Constant			The ideation activity was												The problem was									Performance on the activity									I had more		
				Entertainment			Motivation			Inspiration			Easiness			Interest			Easiness			Inspiration			Commitment			Concentration			Level of success			Time		
				Boring - Fun			De-motivating - Motivating			Frustrating - Inspiring			Difficult - Easy			Uninteresting - Interesting			Difficult - Easy			Frustrating - Inspiring			Minimal effort - Worked hard			Unfocussed - Focused			Unsuccessful - Successful			Time than ideas - Ideas than time		
	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA
Quantity Raw	7.9	5.7	9.7	2.27	1.18	0.12	-2.00	6.54	0.01	-1.59	-9.93	-0.23	0.40	1.00	2.08	-0.98	-1.11	1.30	1.37	9.18	6.19	1.87	-8.49	-4.62	2.53	-0.82	4.15	-0.76	6.20	3.00	0.24	4.43	-0.30	-0.64	0.79	1.33
Quantity Filtered	6.9	5.0	7.4	1.89	0.20	-0.42	-1.66	4.22	0.05	-0.93	-7.46	-1.45	0.45	1.33	0.74	-1.10	-0.51	1.00	0.94	6.94	2.59	1.95	-5.58	-1.12	2.16	-2.04	0.69	-0.60	4.90	3.45	-0.37	4.07	-0.64	-0.69	1.10	0.70
Fixation	0.1	0.4	0.3	0.02	0.06	-0.01	-0.01	0.04	0.02	-0.05	0.07	0.04	-0.01	-0.06	0.07	0.03	-0.04	-0.02	0.03	-0.05	0.15	-0.03	-0.04	-0.12	0.00	0.08	0.15	-0.01	-0.04	-0.11	0.06	-0.16	0.04	0.01	0.01	0.05
Repeated	0.9	0.8	2.2	0.38	0.97	0.54	-0.34	2.32	-0.04	-0.66	-2.46	1.22	-0.05	-0.33	1.34	0.12	-0.60	0.30	0.43	2.25	3.60	-0.09	-2.91	-3.51	0.37	1.23	3.46	-0.16	1.30	-0.46	0.61	0.36	0.34	0.05	-0.31	0.63

Phase II Regression results

Regression Coefficients	Constant			The ideation activity was												The problem was									Performance on the activity									I had more		
				Entertainment			Motivation			Inspiration			Easiness			Interest			Easiness			Inspiration			Commitment			Concentration			Level of success			Time		
				Boring - Fun			De-motivating - Motivating			Frustrating - Inspiring			Difficult - Easy			Uninteresting - Interesting			Difficult - Easy			Frustrating - Inspiring			Minimal effort - Worked hard			Unfocussed - Focused			Unsuccessful - Successful			Time than ideas - Ideas than time		
	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA	NT	WT	SCA
Novelty	0.0	0.7	1.1	0.24	2.50	-0.82	-0.20	-3.59	0.17	0.07	-0.06	0.16	0.03	-0.51	-0.06	0.00	-1.69	-0.09	0.01	1.96	0.36	0.00	-0.37	-0.01	-0.08	-0.02	-0.04	0.05	1.34	-0.04	-0.10	1.90	0.57	-0.03	-0.03	-0.07
Quantity Raw	8.8	8.4	14.2	1.02	1.52	-1.00	-1.60	-5.29	1.41	0.30	-3.31	-1.54	-0.46	-2.81	2.67	-0.31	-1.59	-0.46	0.88	2.73	0.93	1.13	-1.32	-2.83	1.92	2.59	1.44	-0.39	1.36	-0.01	-0.62	7.07	3.49	1.15	2.30	0.39
Quantity Filtered	4.6	5.6	7.5	-0.23	1.49	-0.42	0.07	-2.24	0.50	0.20	-3.25	-1.39	-0.56	-1.67	-0.59	0.56	-0.11	-0.06	0.25	2.40	0.20	0.18	-2.14	-1.03	0.58	0.45	0.18	0.19	1.11	-0.37	-1.33	4.86	2.66	0.87	0.41	1.34
Fixation	0.5	0.5	0.5	0.08	0.14	0.04	-0.08	-0.30	-0.01	0.01	0.06	0.02	0.05	-0.15	0.10	-0.04	-0.21	-0.02	0.01	0.01	0.01	0.02	0.07	0.00	0.05	0.04	0.01	-0.07	-0.03	0.03	0.09	0.13	-0.08	-0.06	0.22	-0.05
Repeated	4.2	2.8	6.7	1.25	0.03	-0.58	-1.68	-3.05	0.91	0.09	-0.06	-0.15	0.10	-1.13	3.26	-0.87	-1.48	-0.40	0.63	0.33	0.73	0.94	0.82	-1.80	1.35	2.14	1.26	-0.58	0.25	0.36	0.71	2.22	0.83	0.27	1.89	-0.95

Significance Levels (α) 0.05 0.10

Influencing Factors	Entertainment	Motivation	Inspiration	Easiness	Interest	Easiness	Inspiration	Commitment	Concentration	Level of success	Time

Influencing factor: if for a given metric it affects more than one method, or, if for a given method it affects more than one metric

Appendix C. Correlation Matrixes (Matrixes display Pearson Correlation and p-value underneath.)

No Tool Correlation Matrix

	Entertainment	Motivation	Inspiration	Easiness	Interest	Easiness	Inspiration	Commitment	Concentration	Level of success	Time	Quantity Raw	Quantity Filtered	Fixation
Motivation	0.657													
	0													
Inspiration	0.494	0.637												
	0	0												
Easiness	0.072	0.289	0.339											
	0.558	0.016	0.004											
Interest	0.404	0.508	0.336	0.302										
	0.001	0	0.005	0.012										
Easiness	0.096	0.118	0.191	0.339	0.213									
	0.431	0.334	0.116	0.004	0.079									
Inspiration	0.425	0.511	0.655	0.191	0.414	0.277								
	0	0	0	0.115	0	0.021								
Commitment	0.23	0.22	0.183	-0.118	0.287	-0.165	0.178							
	0.058	0.069	0.133	0.335	0.017	0.177	0.145							
Concentration	0.491	0.614	0.61	0.336	0.46	0.059	0.46	0.305						
	0	0	0	0.005	0	0.627	0	0.011						
Level of	0.584	0.538	0.706	0.302	0.302	0.195	0.484	0.247	0.541					
Success	0	0	0	0.012	0.012	0.108	0	0.041	0					
Time	0.52	0.501	0.4	0.112	0.286	-0.047	0.254	0.211	0.37	0.374				
	0	0	0.001	0.359	0.017	0.703	0.035	0.081	0.002	0.002				
Quantity	0.115	0.221	0.111	0.22	0.27	0.078	0.033	0.188	0.297	0.102	0.152			
Raw	0.345	0.068	0.366	0.069	0.025	0.524	0.791	0.121	0.013	0.405	0.213			
Quantity	0.037	0.233	0.026	0.252	0.278	0.008	0.028	0.05	0.306	0.04	0.069	0.826		
Filtered	0.76	0.054	0.835	0.037	0.021	0.947	0.822	0.684	0.011	0.747	0.573	0		
Fixation	-0.006	-0.124	0.037	-0.019	-0.026	0.125	-0.069	0.126	-0.132	0.03	0.074	0.038	-0.46	
	0.961	0.309	0.763	0.874	0.83	0.305	0.575	0.302	0.281	0.807	0.545	0.754	0	
Repeated	0.153	0.075	0.16	0.048	0.101	0.126	0.02	0.265	0.111	0.126	0.175	0.649	0.107	0.689
	0.21	0.541	0.188	0.695	0.41	0.301	0.869	0.028	0.364	0.302	0.151	0	0.382	0
Novelty	0.26	-0.047	0.06	0.048	0.165	0.029	0.111	-0.098	0.116	-0.045	0.014	0.278	0.16	0.119
	0.157	0.801	0.749	0.797	0.375	0.879	0.554	0.602	0.536	0.809	0.941	0.131	0.391	0.525

DbA Correlation Matrix

	Entertainment	Motivation	Inspiration	Easiness	Interest	Easiness	Inspiration	Commitment	Concentration	Level of success	Time	Quantity Raw	Quantity Filtered	Fixation	Repeated
Motivation	0.717 0														
Inspiration	0.708 0	0.64 0													
Easiness	0.109 0.515	0.204 0.218	0.32 0.05												
Interest	0.23 0.164	0.23 0.165	0.304 0.064	0.343 0.035											
Easiness	0.001 0.993	0.038 0.822	0.096 0.566	0.706 0	0.342 0.035										
Inspiration	0.321 0.05	0.435 0.006	0.406 0.011	0.511 0.001	0.721 0	0.48 0.002									
Commitment	0.264 0.11	0.141 0.398	0.087 0.605	-0.353 0.03	-0.157 0.346	-0.339 0.037	-0.104 0.535								
Concentration	0.666 0	0.578 0	0.631 0	0.114 0.496	0.229 0.166	-0.038 0.821	0.224 0.176	0.206 0.216							
Level of success	0.626 0	0.691 0	0.77 0	0.427 0.007	0.406 0.011	0.092 0.584	0.582 0	0.132 0.429	0.662 0						
Time	0.453 0.004	0.316 0.053	0.369 0.023	0.411 0.01	0.296 0.071	0.231 0.163	0.114 0.496	-0.217 0.191	0.375 0.02	0.295 0.072					
Quantity Raw	0.312 0.056	0.316 0.054	0.11 0.51	0.214 0.197	-0.067 0.689	0.016 0.925	0.035 0.835	0.225 0.175	0.234 0.158	0.32 0.05	0.275 0.095				
Quantity Fil	0.242 0.144	0.315 0.054	0.061 0.717	0.083 0.62	0.018 0.916	-0.081 0.63	0.014 0.932	0.196 0.238	0.257 0.119	0.389 0.016	0.289 0.079	0.775 0			
Fixation	0.238 0.15	-0.013 0.94	-0.048 0.776	-0.009 0.957	-0.168 0.314	-0.037 0.826	-0.082 0.624	-0.058 0.73	-0.069 0.68	-0.21 0.207	0.258 0.117	0.254 0.124	-0.213 0.198		
Repeated	0.276 0.093	0.227 0.17	0.116 0.489	0.25 0.129	-0.111 0.507	0.083 0.622	0.04 0.811	0.182 0.273	0.15 0.367	0.179 0.282	0.187 0.262	0.884 0	0.391 0.015	0.528 0.001	
Novelty	0.122 0.467	0.298 0.069	0.199 0.231	0.44 0.006	0.187 0.26	0.347 0.033	0.44 0.006	-0.083 0.622	-0.037 0.826	0.342 0.035	0.1 0.551	0.229 0.167	0.299 0.069	-0.049 0.772	0.113 0.499

REFERENCES

[1] R. Sternberg and T. Lubart, "The concept of creativity: Prospects and paradigms," in *Handbook of creativity*, R. Sternberg, Ed., Cambridge, Cambridge University Press, 1999, p. 3–15.

[2] P. Sarkar and A. Chakrabarti, "Development of a Method for Assessing Design Creativity," in *International Conference on Engineering Design (ICED07)*, Paris, France, 2007.

[3] J. Förster, R. Friedman and N. Liberman, "Temporal construal effects on abstract and concrete thinking: Consequences for insight and creative cognition," *Journal of Personality and Social Psychology,* vol. 7, no. 2, p. 177–189, 2004.

[4] P. Bila-Deroussy, C. Bouchard and S. Diakite Kaba, "A systemic model of creativity to address complexity in design: the state of the art and perspectives," in *Third International Conference on Design Creativity (3rd ICDC)*, Bangalore, India, 2015.

[5] H. Farzaneh, K. M. and U. Lindemann, "Creative processes in groups. Relating communication, cognitive processes ans solution ideas," in *2nd International Conference on Design Creativity (ICDC’12)*, Glasgow, United Kingdom., 2012.

[6] T. Amabile, How to kill creativity, Harvard Business School Publishing, 1998, pp. 77-87.

[7] T. Amabile, "A model of creativity and innovation in organizations," in *Research in organizational behavior*, vol. 10, B. Staw and L. Cummings, Eds., Greenwich, CT: JAI, 1988, p. 123–167.

[8] S. Smith and S. Blankenship, "Incubation and the persistence of fixation in problem solving," *American Journal of Psychology,* vol. 104, pp. 61-87, 1991.

[9] S. Smith, "Getting Into and Out of Mental Ruts: A theory of Fixation, Incubation, and Insight," in *The Nature of Insight*, Cambridge, MIT Press, 1994, pp. 229-251.

[10] S. Smith and J. Linsey, "A three-pronged approach for overcoming design fixation," *The Journal of Creative Behavior,* vol. 45, pp. 83-91, 2011.

[11] T. Lubart, C. Mouchiroud, S. Tordjman and F. Zenasni, Psychologie de la créativité, Paris: Armand Colin, 2003.

[12] R. Sternberg, "The nature of creativity," *Creativity Research Journal,* vol. 18, no. 1, p. 87–98, 2006.

[13] S. &. W. B. Graham, "Theories and principles of motivation," in *Handbook of educational psychology*, 4 ed., D. Berliner and R. Calfee, Eds., New Jersey, Lawrence Erlbaum Associates, 1996, pp. 63-84.

[14] M. Kröper, D. Fay, T. Lindberg and C. Meinel, "Interrelations between Motivation, Creativity and Emotions in Design Thinking Processes – An Empirical Study Based on Regulatory Focus Theory," in *Design creativity*, London, Springer, 2010, pp. 97-104.

[15] A. Chakrabarti, "Motivation as a major direction for design creativity research," in *Design creativity*, London, Springer, 2011, pp. 49-56.

[16] E. Crowe and E. Higgins, "Regulatory focus and strategic inclinations: Promotion and prevention in decision-making," *Organizational behavior and human decision processes,* vol. 69, no. 2, p. 117–132, 1997.

[17] B. Lopez-Mesa and R. Vidal, "Novelty metrics in engineering design experiments," in *9th International Design Conference (DESIGN 2006)*, Dubrovnik, Croatia, 2006.

[18] P. Choo, Z. Lou, B. Camburn, B. Koo, K. Wood and F. Grey, "Ideation Methods: A First Study on Measured Outcomes with Personality Type," in *ASME 2014 International Design Engineering Conferences & Computers and Information in Engineering Conference, IDETC/CIE* , Buffalo, NY, 2014.

[19] M. Pandey, V. Luthra, P. Yammiyavar and A. P.Y., "Role of Immersive Virtual Reality in Fostering Creativity Among Architecture Students," in *Third International Conference on Design Creativity (3rd ICDC)*, Bangalore, India, 2015.

[20] L. Ball and T. &. M. N. Ormerod, "Spontaneous analogising in engineering design: a comparative analysis of experts and novices," *Design Studies,* vol. 25, no. 5, pp. 495-508, 2004.

[21] j. Linsey, K. Wood and A. Markman, "Increasing Innovation: Presentation and Evaluation of the WordTree Design-by-Analogy Method," in *ASME Design Theory and Methodology Conference, DETC2008*, New York, 2008.

[22] N. Bonnardel, "Towards understanding and supporting creativity in design: analogies in a constrained cognitive environment," *Knowledge-Based Systems,* vol. 13, no. 7, pp. 505-513, 2000.

[23] A. Markman, K. Wood, J. Linsey, J. Murphy and J. Laux, "Supporting innovation by promoting analogical reasoning," in *Tools for Innovation*, New York, Oxford University Press, 2009, pp. 85-103.

[24] A. Osborn, Applied imagination: principles and procedures of creative thinking, New York: Charles Scribner’s, 1953.

[25] B. Eberle, Scamper: Games for imagination development, Waco, TX: Prufrock Press, 1996.

[26] J. Linsey, J. Murphy, K. Wood, A. Markman and T. Kurtoglu, "Representing analogies: increasing the probability of innovation," in *Proceedings of IDETC/CIE 2006 ASME 2006 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Philadelphia, PA, 2006.

[27] J. Linsey, A. Markman and K. Wood, "Design by Analogy: A Study of the WordTree Method for Problem Re-representation," *ASME Journal of Mechanical Design (JMD),* vol. 134, no. 4, p. 041009, 2012.

[28] D. Moreno, M. Yang, L. Blessing and K. Wood, "Analogies to Succeed: Application to a Service Design Problem," in *NordDesign 2014*, Espoo, Finland, 2014.

[29] D. P. Moreno, A. A. Hernandez, M. C. Yang, K. N. Otto, K. Hölttä-Otto, J. S. Linsey, K. L. Wood and A. Linden, "Fundamental studies in Design-by-Analogy: A focus on domain-knowledge experts and applications to transactional design problems," *Design Studies,* vol. 35, no. 3, pp. 232-272, 2014.

Figure Captions List

Figure 1. Experiment design

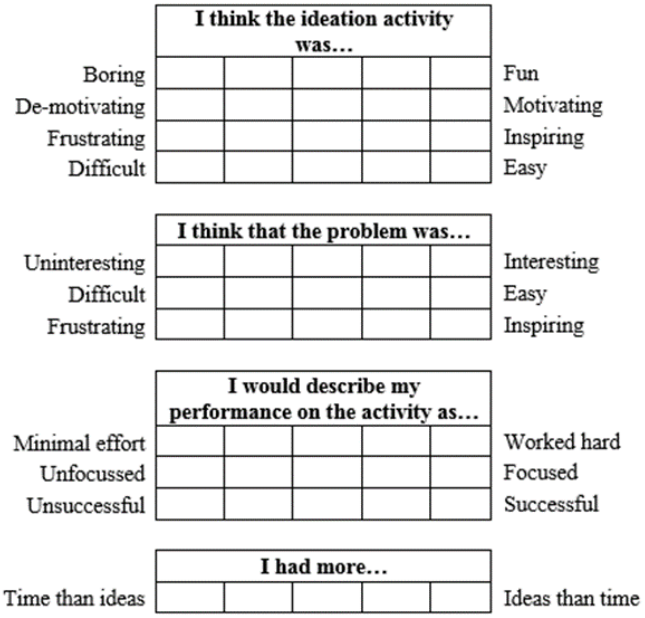


Figure 2. Questionnaire template

	I think the ideation activity was…					
Boring	*-2*	*-1*	*0*	*1*	*2*	Fun

Figure 3. Coding example

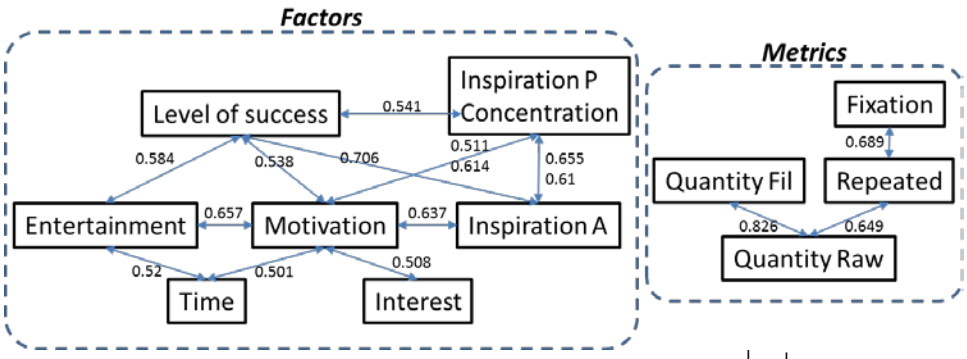


Figure 4. No Tool ideation condition relationship model ($|\rho|$>0.5; and α=0.05)

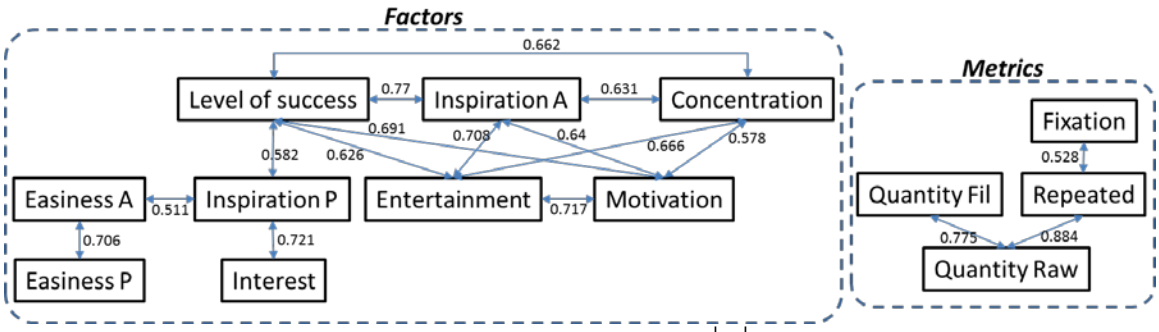


Figure 5. DbA ideation conditions relationship model ($|\rho|>0.5$; and $\alpha=0.05$)

Table Caption List

Table 1. Factors found to influence creativity

Factor	Description
Intrinsic motivation	Excited by the work, Enthusiastic, Challenge by the problem
Incubation	Taking a time apart from the problem (design task) or performing a non-related task
Intellectual abilities	Talents in the problem solver's field; Tactics for creative thinking
Knowledge	Broad knowledge; Experience
Cognitive style	Open to different ideas; High level of intelligence; Being naïve; Not biased by preconceptions; Not bound by old ways of doing things
Environment (context)	Time; Recognition; Pressure (sense of urgency); Competitive and jealous of someone else's success
Intensity	Commitment; Energy
Persistence to perform an assigned activity	Sense of working on something important

Table 2. Selected factors

Type or factor	Factor Name	Negative-Positive Attributes
Individual	Entertainment	Boring – Fun
	Motivation	De-motivating – Motivating
	Inspiration	Frustrating – Inspiring
	Easiness	Difficult – Easy
	Interest	Uninteresting - Interesting
	Easiness	Difficult - Easy
	Inspiration	Frustrating - Inspiring
Performance	Commitment	Minimal effort - Worked hard
	Concentration	Unfocussed - Focused
	Level of success	Unsuccessful - Successful
Contextual	Time	Time than ideas - Ideas than time

Table 3. Indifferent and negative average results extracted from Appendix A

		Easiness (of activity)	Easiness (of problem)	Time
Phase I	NT in Ph II	0.39	0.03	-0.03
	WT in Ph II	0.93	0.40	-0.67
	SCA in Ph II	0.38	-0.13	-0.17
Phase II	NT	0.22	0.39	-0.06
	WT	0.00	0.20	0.07
	SCA	-0.38	-0.42	0.08

Table 4. Results for factor self-perceived changes

			p-value		
			Mann-Whitney Test	Kruskal-Wallis Test (Ph1)	Kruskal-Wallis Test (Ph2)
The ideation activity was	Entertainment	NT	0.666	0.103	0.423
		WT	0.667		
		SCA	0.170		
	Motivation	NT	0.109	0.005	0.580
		WT	0.102		
		SCA	0.181		
	Inspiration	NT	0.776	0.816	0.546
		WT	0.759		
		SCA	0.204		
	Easiness	NT	0.736	0.203	0.041
		WT	0.013		
		SCA	0.007		
The problem was	Interest	NT	0.797	0.128	0.305
		WT	0.550		
		SCA	0.898		
	Easiness	NT	0.211	0.156	0.022
		WT	0.557		
		SCA	0.219		
	Inspiration	NT	0.504	0.489	0.566
		WT	0.911		
		SCA	0.418		
Performance on the activity	Commitment	NT	0.797	0.627	0.150
		WT	0.212		
		SCA	0.453		
	Concentration	NT	0.587	0.261	0.355
		WT	0.091		
		SCA	0.166		
	Level of success	NT	0.375	0.024	0.430
		WT	0.025		
		SCA	0.105		
I had more	Time	NT	0.983	0.249	0.978
		WT	0.120		
		SCA	0.521		

Significance level (α)	0.05	0.10