Creativity of ‘Process’ and ‘Product’: The Impact of Tools?

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This paper examines the relationship between creativity domains and computing tools. It reports on the findings of a design computing experiment with 2 groups of subjects while they were engaged with a problem solving design task using two types of CAD tools, non-parametric and parametric-algorithmic. The paper aims to address two questions. Does a more creative process by implication 'correlate' with and yield a more creative product? And does the 'type' of CAD tool deployed by the user impact on the creativity of their product? The findings revealed that creativity of the process correlated significantly with each measure of 'product' creativity, namely: novelty, technical goodness and aesthetic appeal. Factor loading on components confirmed two constructs, one for product creativity and another for process. Additionally a difference in CAD tools produced no statistical 'variance' in creativity of 'product' or process. A regression equation to predict product ratings from creativity process ratings is also presented.

Keywords: Creativity, Process, Product, Parametric, Non-parametric, Statistics

CREATIVITY

Creativity of Process

The difficulty in defining the concept of creativity has been highlighted by many researchers. For instance, Simonton (2012) intimated: 'although creativity has recently attracted considerable theoretical and empirical research, researchers have yet to reach a consensus on how best to define the phenomenon.' However, according to Runco and Jaeger (2012), the standard definition of creativity contains two parts. Creativity requires both originality (unusual, novel, or unique) which is vital for creativity but is not sufficient and effectiveness (usefulness, fit, or appropriateness). They also questioned the number of criteria that should be used in defining creativity. The standard view point is to two criteria, but according to both maybe there are more or fewer criteria. Simonton (2012), on the other hand, suggested three criteria: novelty, utility, and surprise. Additionally, he argued that creativity measurements based on these three criteria are 'quantitative and multiplicative rather than qualitative or additive.' On its own and sometimes allied with originality, creativity has always featured in architectural design definitions. The design process has often been described as an epitome of many subtle elements including creativity, intuition and imagination. Creativity is the ability to produce work that is novel, original, unexpected and appropriate, i.e. useful.

The literature on creativity is wide, deep and varied with emphasis on four domains: process, product, person and context (environment). Much of the research on creativity of the process has been carried out by a small number of researchers during the
1960s and whose seminal work had established the foundation and the measures for the creative process.

Hennessey and Amabile (2010) conducted an extensive and rigorous electronic (EBSCO) review searching for empirical journal articles, chapters and books on creativity published between 1998 and 2008. They remarked that 'since the 1990s we have seen a virtual explosion of topics, perspectives and methodologies in the creativity literature. Yet there seem to be few, if any, big question being pursued by a critical mass of creativity researchers.' (Hennessey and Amabile 2010) They identified 7 levels at which creativity forces can operate, Fig. 1

Silvia (2008) introduced an advanced methodology to examine the relationship between creativity and intelligence and statistically found that ideation fluency (volume of ideas) and originality variables significantly predicted intelligence. Creativity’s link to personality has been researched. MacKinnon's study (1965), for instance, linked the creativity of three groups of architects to 'variance' in preferences on conformity to internal or external standards of excellence. Using the Barron-Welsh Art scale, Barron and Welsh administered a 400-item test to a sample of artists and non-artists. Artists were found to prefer figures that are ‘complex, asymmetrical, freehand rather than ruled and moving in their general effect’. Artists described them as organic (Barron 1953)

A number of tests have been devised for measuring creativity. One of the most common ones is RAT (remote association test), word association, where the subject is usually given three words and required to find a fourth word which could provide an associative link between the three unrelated ones. However, Datta (1964) questioned the suitability of this method for all professions suggesting 'the production of remote verbal associations is not as important a component of behavioural creativity for professional engineers (and perhaps architects and sci-

![Figure 1](image-url)
Torrance's seminal work identified four main parameters for creativity: fluency (generating a volume of ideas); flexibility (to do with the variety of ideas); originality (uncommonness of ideas); elaboration (advancing an idea). These parameters formed the basis for the Torrance Tests of Creative Thinking (TTCT). (Torrance 1966) Two additional modes of thinking, convergent and divergent, were widely reported in the literature to have influenced creativity in problem solving. (Runco & Albert 1985) Convergent thinking follows a single prescribed path to arrive at a single solution to the problem. Divergent thinking on the other hand is speculative as it explores ideas and combinations to arrive at 'possible' solutions to the problem. However one could argue that the widely used creativity tests (TTCT) are basically divergent thinking tests (Kim, 2006).

Baer (2008) maintained that creativity is not a general ability or set of traits that can be applied across domains; it is domain specific. He argued that the across domain issue is the reason as to why 'divergent thinking tests have not done a better job' and not the deficiency of various scoring systems that have been used when assessing divergent thinking ability. Furthermore, he questioned the potential value of divergent thinking tests as predictors of creativity. However, Lee (2008) supported the reliability and validity of divergent thinking tests but argued that uniqueness scores increase as a subject generated more responses, resulting in confounding of uniqueness and fluency.

Creativity of Product

Hennessy, Amabile and Mueller (2011) summarised a conceptual definition for the creativity of product suggesting that 'A product is considered creative to the extent that it is both a novel and appropriate, useful, correct, or valuable response to an open-ended task.' They also introduced two concepts: first, there is a need for judges who are expert in the domain knowledge of the product to rate the product independently and agree that it is creative and second the ratings have to be reliable, i.e. consistent with each other. These ideas stemmed from an earlier work, Amabile (1982) where she argued that well liked creativity tests and the 'subjective assessment techniques' deployed in some creativity researches are inappropriate for the social psychological studies of creativity. She went on to suggest that social conformity in judgement cannot be avoided in identifying creativity, and offered a slant that considers a consensual definition: 'A product or response is creative to the extent that appropriate observers independently agree it is creative'. Observers were defined as: 'those familiar with the domain in which the product was created'. This attitude was sustained by Csikszentmihalyi (1999), and resulted into the method of consensual assessment. Amabile has developed and refined this approach, and the Consensual Assessment Technique (CAT) is now well known. The method frequently deploys a panel of judges, usually experts in the domain to which the product belongs, to rate the creativity of a product on three measures: creativity cluster, technical cluster and aesthetic judgement. However, Runco (2004) questioned the underlying logic behind this approach, which is based on the assumption that 'studies of products (e.g., publications, paintings, poems, designs) are highly objective and therefore amenable to the scientific method'. He argued that the assessment of product creativity is seldom used with non-prominent persons. He suggests that CAT as an approach is mainly developed for and is handy for the everyday study of creativity.

Parametric Approach

Chien and Yeh (ecaade 2012, vol. 1) examined the association between 'unexpected outcomes' through parametric design tools (Grasshopper) and the creativity of the design process. Using protocol analysis as their research methodology they compared and analysed the design behaviour of 3 students each using 3 different design media (paper and pencil, non-parametric software and parametric software). For the measurement of creativity Chien and Yeh
adopted Khandwalla’s (1993) measures on divergent thinking as a predictor for process creativity. The finding from this study suggests that the space of possible design solutions ‘was expanded with the existence of unexpected outcomes’ and this was more pronounced with novice designers than experienced ones. However, the small sample size of 3 students makes it difficult to extend the validity beyond the context of this investigation.

Using a larger sample of 10 students divided into 5 groups of 2 each, Iordanova et al. (2009) compared the design behaviour affected by the use of parametric tools and descriptive direct modelling tools. A team of 4 students (2 groups of 2 each) used parametric tools, another team of 4 students (2 groups of 2) used descriptive direct modelling tools and a team of 2 used both. The findings from this study confirmed that ‘the ideas generated were many more in number when the modelling was performed by parametric methods.’ Regarding the evolution of ideas the study found that development of ideas was taking longer with the descriptive direct modelling tools and ‘ideas were taking form and evolving quicker when parametric methods were used.’ (Iordanova et al. 2009)

In a pilot study Yu, G. and Oswald (2013) compared the design behaviour in two software modelling environments: parametric and geometric. Five students were asked to carry out two design tasks one in each modelling environment with each task lasting 40 minutes. The analysis of behaviour was carried out using protocol analysis and the study confirmed that protocol analysis is a viable research methodology to analyse the parametric design behaviour. Additionally the study also confirmed that in parametric environment the subjects designed using two mechanisms: design knowledge and algorithmic rules and relations between parameters.

RESEARCH METHODOLOGY

Measurement of process. The seminal work of both Guilford (1950) and Torrance (1966) suggest four measures for the creativity of 'process': ideation fluency (number of ideas); ideation flexibility (variety between ideas); originality (uncommonness of ideas); elaboration (advancement of an idea). However, this research used ideation fluency as the main indicator of creativity as there is an ample amount of literature which highlights the significance of ‘fluency’ to both originality and flexibility and in turn creativity in problem solving. (Wallach and Cogan 1965) Furthermore, after an empirical investigation, Moran et al. (1984) conclude that ‘quantity of ideational output was related to its originality’. The researchers explain the link between the two concepts and suggest that ‘there is a relationship between the quantity of response and its quality such that the generation of many potential solutions leads to the production of a few highly original solutions that are statistically unusual.’ Mednick (1962) had also examined the associative basis of creative process. He argued that ‘the greater the number of associations that an individual has to the requisite elements of a problem, the greater the probability of his reaching a creative solution.’ However, Hocevar suggested that the TTCT and Guilford’s divergent thinking tests measure only fluency and Dixon was concerned that originality scores of the TTCT were significantly influenced by fluency scores. (Kim 2006) A further support for the link between ‘volume’ of ideas and originality came from Milgram and Arad (1981) who examined the issue in a case study among 50 college students. Their findings supported the ‘validity of conceptualisation of original problem solving based on ideational fluency and specify the critical role of unusual responses of low quality.’ In another experiment, Milgram (1983) used a larger sample of 142 middle and lower class children (7-13 years old) to examine the validity of ‘using measures of ideational fluency’ as predictors of ‘original problem solving’. The findings confirmed the existence of high relationship between quantity and quality of ideas as they indicated that ‘the ability to generate many unusual high quality responses to problems...is a valid predictor of the ability to produce original solutions.’ (Milgram 1983)

In this experiment the subjects were all postgraduate students in architecture who were ran-
domly chosen from a pool of students who were all very proficient in using both tools. They were asked to design a surface from 3 curves that can be used as a shelter from rain. The first group of 10 subjects used Rhinoceros, a non-parametric software package and the second group of 12 subjects used Grasshopper, a visual algorithmic editor software programme, for the design task. Protocol analysis, which is a cognitive research method that extracts verbal reports from research participants, was the main vehicle deployed to obtain information about design during the experiment. Students were asked to 'think aloud' during design sessions which were videotaped. The verbalised concurrent protocols were transcribed and transcripts were segmented according to subjects' design intentions. The design process steps were classified into: problem reframing; search for metaphors; express difficulty (i.e. blockage); ideation; testing. In this study the protocols were segmented according to subjects' design intentions. A segment is equivalent to a design move which has been defined by Goldschmid (1991) as an 'act of reasoning which presents a coherent proposition pertaining to an entity that is being designed.' The counted number of successful segments in each subjects' protocols was taken as a measure for ideation fluency.

**Measurement of product (design output).** The study adopted the 'consensual assessment technique' developed by Amabile (1982) to measure the creativity of completed design schemes. The technique has three dimensions for the artistic creativity judgement. The first dimension, the creativity cluster, includes: novel idea, variation in shapes, detail, complexity and novel use of materials. The technical cluster, contains: technical goodness, organisations, neatness, symmetry and expression of meaning. The third dimension, the aesthetic judgement, consists of: liking and aesthetic appeal. Three dimensions were expanded to create 3 parallel dimensions for the creativity of 'process'.(Hennessey 1994) The finished projects (products) and the design steps (process) leading to these products were saved on the computer. Three practicing architects were asked to independently 'judge' the design process and outputs (schemes) on a 10 point scale on each of the three dimensions twice, once for process and once for product. They were asked to judge the subjects' work relative to each other rather than follow an external reference for excellence. Each Subject showed their finished design on the computer to the judges. The judges then went back to the computer and rated each product for 'creativity' on a 10-point scale. The judges were shown the products for the second time and made ratings for product 'technical goodness'. Finally the judges were shown the products for the third time and rated them for product 'likableness'. Regarding the 'process' the judges were shown 22 design processes, one per subject. The judges returned to the computers and rated each 'process' for 'creativity' on a 10-point scale. They were shown the process for the second time and made scores for process 'technical goodness'. Finally the judges were shown the process for the third time and they gave ratings for process 'likableness'. The idea of showing the judges one dimension of creativity at a time and repeating the procedure for the second and third dimensions was reported in the literature.(Hennessey 1994) The researcher then calculated the mean score across the three dimensions. Cronbach's Alpha, a statistical technique, was used to estimate the internal consistency (reliability) associated with the scores from the three judges. The statistical analysis between variables of creativity 'process' and those of 'product' were calculated using IBM-SPSS (Statistical Package for Social Sciences).

**FINDINGS**

Table 1 shows that the number of segments in subjects' protocol, which was used as a measure for ideation fluency, correlated significantly (P<0.05) with each of the three judges score on the product (subjects' design outputs). This implies that subjects with a higher score on ideation fluency were consistently judged by the three judges to have also achieved a higher score on the artistic creativity
### Table 1
The relationship between ideation fluency (segments) and each of the three judges’ score on the output

<table>
<thead>
<tr>
<th></th>
<th>Segments: Ideation Fluency</th>
<th>Creativity of Product Rating-Judge 1</th>
<th>Creativity of Product Rating-Judge 2</th>
<th>Creativity of Product Rating-Judge 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segments: Ideation</td>
<td>Pearson Correlation</td>
<td>.759**</td>
<td>.773**</td>
<td>.640**</td>
</tr>
<tr>
<td>Fluency</td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.001</td>
</tr>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Creativity of Product Rating-Judge1</td>
<td>Pearson Correlation</td>
<td>.759**</td>
<td>1</td>
<td>.686**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Creativity of Product Rating-Judge2</td>
<td>Pearson Correlation</td>
<td>.773**</td>
<td>.855**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.001</td>
</tr>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Creativity of Product Rating-Judge3</td>
<td>Pearson Correlation</td>
<td>.640**</td>
<td>.686**</td>
<td>.635**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.001</td>
<td>.000</td>
<td>.001</td>
</tr>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

### Table 2
Cronbach’s Alpha: inter-reliability score between the three judges

<table>
<thead>
<tr>
<th>Cronbach’s Alpha</th>
<th>Cronbach’s Alpha Based on Standardized Items</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>.885</td>
<td>.888</td>
<td>3</td>
</tr>
</tbody>
</table>

### Table 3
The ANOVA test on the type of CAD tool (parametric/non-parametric) and ideation fluency

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2.305</td>
<td>1</td>
<td>2.305</td>
<td>.079</td>
<td>.782</td>
</tr>
<tr>
<td>Within Groups</td>
<td>586.650</td>
<td>20</td>
<td>29.332</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>588.955</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Correlation Coefficients between the three parameters of 'product' and 'process' creativity judgement. It is possible that the generation of many potential solutions leads to the production of few very original solutions that are uncommon and statistically unusual.

Regarding the consistency between judges’ score, which has an impact on the validity and reliability of the given scores, Table 2 shows that the value of Cronbach's Alpha was 0.883 which is well above 0.7, the statistically recommended value of good inter-reliability between subjective scores.

However, the parametric process was found to be slightly more productive than the non-parametric as the ratio of design time to ideation segment was marginally higher in the parametric process (median=1.16), Figure 2.

This difference may be related to tools, but it can also be attributed to individual differences between the design ability of subjects. On the impact of tool on ideation fluency, the Analysis of Variance test (ANOVA), Table 3, did not show any difference that is statistically significant between the use of parametric/non-parametric tools on ideation fluency and in turn creativity (P>0.05).

**. Correlation is significant at the 0.01 level (2-tailed).
The three parameters of 'process' creativity [novelty of ideas, technical goodness and likableness (aesthetic appeal)] were correlated with their counterparts in 'product' creativity, Table 4. Creativity of process (novelty) correlated significantly with the three parameters of 'product' creativity [product (novelty)=0.769, product technical goodness=0.877, product likableness=0.654]. The other two parameters of process correlated with each other but not with any of product parameters.

These relationships were explored further using factor analysis in SPSS to determine whether these multiple observed variables (of creativity) have similar patterns of responses because they are all associated with a dormant (i.e. not directly measured) variable. The eigenvalue is a degree of how much of the variance of the observed variables a factor elucidates.

Any factor with an eigenvalue >1 explains more variance than a single observed variable. Figure 3 confirms that there are 2 factors that can explain the 6 creativity variables. Factor 1 explains as much variance as 3.6 of 4 variables whereas factor 2 explains as much variance as 1.5 of 2 variables.

Looking at Table 5, under component 1 there are 4 values that are very close to each other, i.e. little variance which implies that the 4 variables which correspond to these values represents the same construct. Under component 2 there are figures with little variance (0.99 and 0.97) which suggests that the 2 variables corresponding with these figures represents the same construct. We can call factor/component 1 (the dormant variable) the 'product+1' variable and component 2 the 'process-1' variable. However, this paper needed to establish whether the 2 components did in fact belong to 2 distinct 'cognitive' clusters regarding creativity. Hence the research deployed cluster analysis which is a discovery tool that uncovers patterns, relationships, and structures in data.

Figure 4 reveals that there are 2 main clusters in the data; the smaller cluster contains variable 3 and 4 whereas the second larger cluster contains 4 variables organised in 2 groups each in a sub-cluster. This validates the earlier results from factor analysis. The question that needs further investigation is that why did 'process' creativity align itself with the 3 measures for 'product' creativity? Does this imply that creativity of the process and creativity of the product represent the same thing?
CONCLUSIONS

The correlation of 'process' creativity with the three measures of 'product' creativity and results from factor analysis produced multiple similar patterns of responses because they were all associated with a latent (i.e. not directly measured) variable which the study called 'product+1'. One possibility could be that the process in design is sometimes overlooked in favor of the output, i.e. design outcome. It could also be that the CAD tools used particularly grasshopper added complexity to the design process which blurred the boundary between what is design and what is an algorithmic procedure. Additionally, the research found that both tools more or less produced similar ratings on product and process creativity which suggests that both sets of tools yielded no variance in the levels of outcome regarding creativity. Judges' ratings on product and process were used to compute a 'regression' equation. Figure 5 shows a regression equation, \( Y = 0.83X + 1.83 \), that can be used to predict the ratings of 'product' creativity from 'process' creativity. It is interesting that the equation will give rating score for the 'product' which is always lower than rating score for the 'process'. This implies that architectural judgement is about 'potential' of ideas in the design process rather than 'actuality' of ideas when they become product. Products are concrete, hence they can be tested empirically against a set of criteria whereas processes are somehow more abstract and thus cannot be judged and rated in the same objective manner.
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