The Fourth International Conference on Design Creativity (4th ICDC)
Atlanta, GA, November 2nd-4th, 2016

EMPIRICAL RESULTS FROM MEASURING DESIGN CREATIVITY: USE OF AN AUGMENTED CODING SCHEME IN PROTOCOL ANALYSIS

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Abstract: This paper presents preliminary results from using an augmented ontological coding scheme to generate quantitative descriptions of the cognitive behaviour of design creativity. The Function-Behaviour-Structure coding scheme is augmented with two new meta-issues coded as "new" and "surprising". This augmented coding scheme is applied to an existing protocol of an in-situ team of professional designers to produce empirical data to test two hypotheses about designer behaviour in terms of novelty and surprise in creative designing. It is hypothesized that the cumulation of new issues will occur in a logarithmic pattern whilst the cumulation of surprising issues will occur in a power curve or S-shaped pattern. The results from this case study indicate some support for the hypothesis about novelty and do not support the hypothesis about surprise.

Keywords: *protocol analysis, new and surprising, ontological model*

1. Introduction

Creativity can be studied from many different perspectives: cognitive, computational, biological, educational, social, historical and cultural (Boden, 1996; Boden, 2004; Runco, 2014; Taura & Nagai, 2010). In design research creativity is generally examined in term of the outcome and its related processes. We consider that the creative outcome of a design process is related to the designer's ability to generate design issues and hence to expand the space of possible designs (Gero, 1990). The design space is set by the variables that the designer is working with at any particular moment while designing. Hence, to expand the design space the designer needs to introduce new variables. Previous research has focused on the introduction of new goals by a designer while designing (Suwa, Gero & Purcell, 1999). That research used a semantically rich coding scheme to locate the introduction of new goals. It found that designers introduce new goals throughout the design session studied. In this paper we are interested in the introduction of any new design issue. Further, we are interested in which of those new design issues is also surprising, i.e., unexpected within the situation at the time. To study this we use an existing protocol from an in-situ brainstorming session of professional designers to empirically examine designers' behaviour of introducing new and surprising design issues during the design process.

1.1 Observing and assessing design creativity

There are different ways of observing and measuring design creativity– assessing the designers' traits and abilities (Meneely & Portillo, 2005), assessing the outcome of a design (Sarkar & Chakrabarti, 2011) and examining the process of designing (Howard, Culley& Dekoninck, 2008; Toh, Miller & Kremer, 2012), which is the focus of this paper. Some researchers argue that creativity should be measured directly in terms of novelty and usefulness of the outcomes (Sarkar & Chakrabarti, 2007; 2011), which primarily focuses on evaluating the results of the designed artefacts. However, we are interested in unfolding the process of creativity during designing. In this case the usefulness of an idea cannot yet be quantified as the design is not complete.

In studying creativity in the design process, Goldschmidt & Tatsa (2005) suggested the number of interlinking design ideas is a good indication of creative outcome. Suwa, Gero, & Purcell (1999) found that the unexpected discovery of the perceived visuo-spatial features correlate with the situated invention of design issues.

1.2 Novelty, Utility, and Surprise

In the study of measuring idea effectiveness, Shah, Smith, & Vargas-Hernandez (2003) considered novelty as unusual or unexpected ideas when compared to other ideas. Also, they consider engineering designs must have desired utility and the designers need to meet these desired goals. Grace, Maher, Fisher, & Brady (2015) proposed three distinct and essential characteristics of creative designs: novelty, value and surprise. Novelty "is the degree to which a design differs from those that have come before it". Value is similar to the notion of utility that is related to the usefulness of a design in the context. Surprise "is the degree to which a design is unexpected to an observer… surprise is both domain sensitive and subjective to the evaluator". They assessed surprise by comparing the expectations of previous designs with the new design.

We consider creativity has the essential elements of newness and surprise. The utility of an idea can only be evaluated after the artefact has been designed and its usefulness assessed. As we are concerned more on the process of creativity, utility of an idea is not considered further in this paper. Boden (2004) made the distinction between 'psychological' creativity (P-creative) and 'historical' creativity (H-creative). P-creativity concerns ideas that are novel with respect to the individual mind no matter how many others had that same idea before. H-creativity means the idea that is raised for the first time in recorded history. This paper focuses on *situated* P-creative ideas which can be seen as S-creative as an extension to the terms in Boden's labelling scheme (Gero, 2002). S-creativity is that element of creativity with respect to the current situation in that design session—ideas that first appear in the design session and ideas that are not expected in the current design context.

1.3 FBS coding scheme

The Function-Behaviour-Structure (FBS) ontology models design as transformation processes among fundamental FBS design issues (Gero, 1990; Gero & Kannengisser, 2014). Structure (S) issues describes the components and their relationships that makeup a design. Behaviour (B) issues describe the performance of structure and Function (F) issues deal with the teleology of a design.

Based on this ontology Kan & Gero (2009a; 2009b) proposed a coding scheme that segments and codes design protocol according to the non-overlapping—separate—FBS cognitive activation of design issues. There are six categories of codes (Kan & Gero, 2009a): Requirements (R), Function (F), Expected Behaviour (Be), Behaviour derived from Structure (Bs), Structure (S) and Documentation (D). Behaviour

(B) is separated into two sub-codes Be and Bs that represent Expected Behaviour (Be) which is the behaviour expected to be produced by the structure and Behaviour derived from Structure (Bs) is the behaviour produced by the structure. Any ideas or issues not aligned with the FBS framework are not coded, for example: jokes and issues related to the management of time. In this coding scheme there is a strict one-to-one mapping between segments and codes, i.e., one segment per code and one code per segment. If an utterance is directly read from the brief, it will be coded as R; drawings and writings will be coded as D.

1.4 Working definitions of *new* and *surprising* codes and augmented coding scheme

Two codes—*new* and *surprising*—are introduced to augment the original FBS coding scheme. They do not modify the FBS coding scheme, they add a hierarchical layer below the scheme. The effect of this is that any of the FBS coded segments can additionally be coded as *new* or *surprising*. Not all segments need to have this additional coding. Their definitions are given below.

1.4.1 New issues

An issue is coded as *new* when that design issue is introduced for the first time in that particular context of the design session. For example the issue of "cost" can appear *new* more than once in different contexts, like the overall expected selling price of the designed product and the cost of a specific proposed mechanism for a certain part of the design. The *new* coding can be used with any of the F, Be, Bs or S coded segments. One would expect there will be more *new* issues in the beginning of a design session. Examples will be described and exemplified in Section 3.1, where Table 1 shows examples of a function issue and one expected behaviour issue at the start of the design session. Since we are interested in the relation between design creativity and design issues, we do not code as *new* any R and D coded segments.

1.4.2 Surprising issues

An issue is coded as *surprising* when the design issue is *new* and is unexpected in its context. In our definition,*surprising* issues need to be *new* issues because if it is not new, there can be no unexpectedness. *Surprise* is assessed by coders if the *new* issue together with the variables being introduced are not within the expectation of the current context of designing. In addition to assessing the design issue directly the coder observes the reactions of other team members when they do not expect that issue. It is usually signalled by a pause or laugh after a *surprising* issue is introduced. As with the *new* issues, *surprising* issues can be any of F, Be, Bs or S segments. Section 3.1 contains an example and Table 2 shows two segments where the *surprising* issues being introduced were not aligned with the state of affair being considered.

The goal of this paper is to examine design creativity using the *new* and *surprising* codings as a means of locating and measuring creative activity during designing. The remainder of this paper presents two hypothesized behaviours of designers related to *new* and *surprising* segments. It then briefly describes an existing design session that has already been videoed, transcribed, segmented and coded using the FBS coding scheme. Empirical results from recoding the design session with *new* and *surprising* codes are presented.

2. Hypothesized behaviour of a typical session

Since we conjecture creativity depends on newness and surprise, we have the following two hypotheses.

2.2.1 Cumulative new issues can be described as a logarithm function

We hypothesize that there should be more new design issues at the beginning of any design session and that designers will work on those issues instead of introducing new issues as the design session proceeds, so the cumulative new issues will reached a plateau. We base this hypothesis on a number of different models of design models (Asimov, 1962; Kannengiesser & Gero, 2012; Pah & Beitz, 2013). The trend of cumulative new design issues is likely to be similar to a logarithmic function, Figure 1.

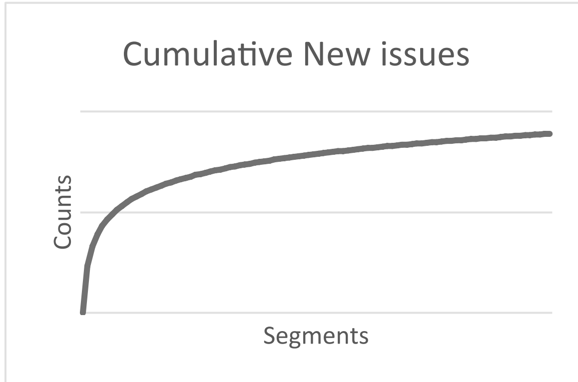

Figure 1. More new ideas/issues in the beginning and fewer as the session proceeds

2.2.2 Cumulative surprising issues can be described as a sigmoid function

Surprising issues need a common ground on which to base unexpectedness, therefore we hypothesize that there should be fewer surprising issues in the beginning of a design session as the context has not been set. Once the context has been set by new design issues, we would expect that an increasing number of new design issues might be unexpected. As the design session approaches its conclusion there would be fewer new design issues and hence fewer surprising design issues. The trend of cumulative surprising design issues is likely to be similar to a sigmoid function, Figure 2.

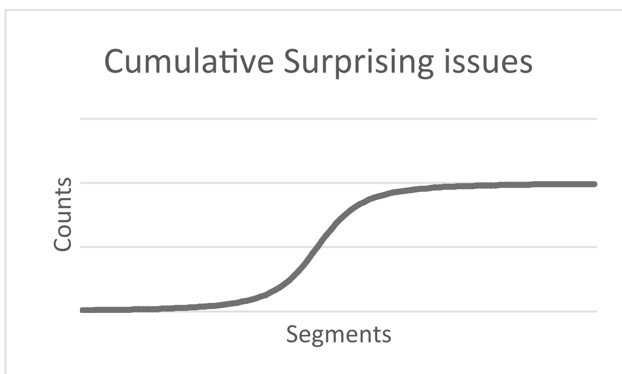

Figure 2. Less surprising issues in the beginning and at the end

3. Empirical results

3.1. The design session

The data was obtained from the 7th Design Thinking Research Symposium (McDonnell & Lloyd, 2009). The design session involved a heterogeneous team of designers from industry observed in-situ, being asked to provide ideas for solving technical issues of a working demonstrator of a thermal printing pen. The team consisted of a business consultant, who acted as the moderator, three mechanical engineers, an electronics business consultant, an ergonomist, and an industrial design student intern. The whole session was about one hour and thirty-five minutes. The two main problems requiring solutions were: keeping the print head in contact with the media protecting the print head from abusive use and preventing overheating. Several ideas were mentioned, such as a sledge, snowboard, wind surfboard, shaver, snowmobile, train, and slicer. Other concepts such as wheels, spirit level, and laser leveller were also discussed. Additionally, product behaviour, user behaviour and feedback to users were also discussed. Different ways of protecting the print head were discussed such as: a sheath, a viscous damper, spring loaded cap, dead man's handle and a dock or cradle. In our coding scheme when these ideas, concepts or issues are raised for the first time they will be coded as new issues. For example in the context of making sure the pen is levelled, laser levellers were suggested. It was coded as being a *new* structure issue but not unexpected, so it was not coded as a surprising issue. However, later on, within the same context, someone suggested "like dam busters", which was an analogy of the headlights shooting out in a scene from the British film of the same name. The analogy based on the use of focussed light within a scene in a film was unexpected as it was from a very different context, therefore that issue was coded not only as a new structure issue but also as a surprising issue. Tables 1 and 2 show some examples of new and surprising segments taken from this session.

Segment No.	FBS Code	Protocol	Remarks
1	F	What's quite important is it's about the thermal inclis pen	The first time the intention / function of the design was first bought up
3	Be	so it's the interaction between the special paper and the thermal pen	The expectation of interactive behaviour first suggested

Table 1. Examples of *new* issues

Segment No.	FBS Code	Protocol	Context and justification
51	S	is it only paper you're thinking about or could it be other things like mugs or fabric or pottery?	In the context of discussing the ideas of how to make the print head to follow a contour, suddenly the issue of different media was introduced
99	Bs	… it's not cheap	While a sub-group was discussing the position of resistor for heat generation, the cost issue was unexpectedly brought up by one member

Table 2. Examples of *surprising* issues

3.2. Coding

For the coding and segmenting of the protocol, two remotely-located independent coders segmented and coded the sessions and arbitrated through internet telephony resulting in 1,280 segments. The coders' agreements with the arbitrated set averaged 88%. The two augmented codes were multiply coded by a single coder using an arbitration method (Gero & Mc Neill, 1998). The first coding and second coding were carried out three weeks apart. However, in this preliminary study only the first decile of the protocol was arbitrated and was carried out a week after the second run of coding. Table 3 show the percentage agreement of the *new* and *surprising* code.

	1st and 2nd	1st and Arbitrated	2nd and Arbitrated
New	83%	87%	96%
Surprising	94%	95%	98%

Table 3. Coding consistency of the two augmented codes

3.3 Results

3.3.1. Cumulative New and Surprising issues

The results for cumulative new design issues are shown in Figure 3, where the horizontal axis is the segment number progressing with time, marked in deciles, and the vertical axis is the cumulative segments that are new design issues. The linear regression shows that the cumulative trend line for the new design issues is almost linear with R^2 value of 0.99. The logarithm curve fit yields a R^2 value of 0.79.

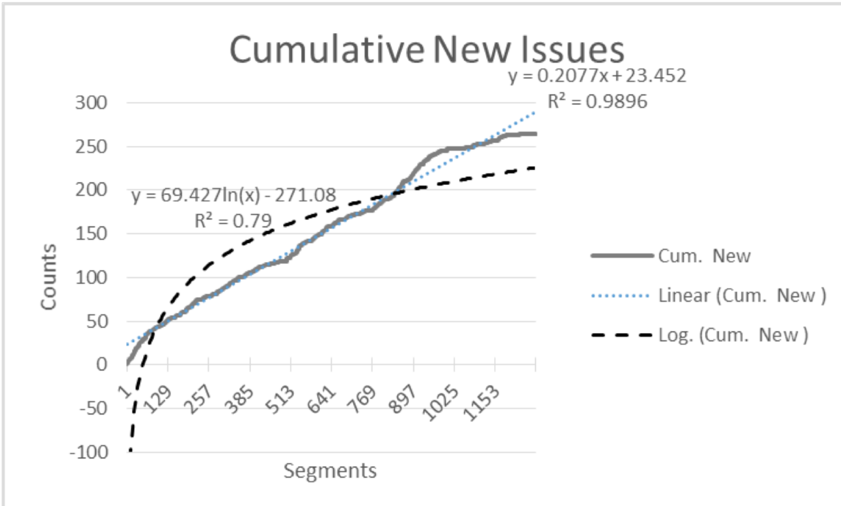

Figure 3. Cumulative *new* design issues

The results for cumulative surprising design issues are shown in Figure 4, where the horizontal axis is the segment number progressing with time, in deciles, and the vertical axis is the cumulative segments that are surprising design issues. The cumulative surprising issues appear to reach a plateau at the end; there is only one surprising issue in the last two deciles of the protocol.

3.3.2 Cumulative FBS New and Surprising issues

Figure 5 shows: 1) the slope of cumulative new function issues is much low than the B and S new issues; 2) the cumulative new behaviour and structure issues have very similar trends; 3) the cumulative new behaviour issues reach a plateau around the eighth decile; 4) the cumulative new structure issues reach a plateau around the tenth decile; 5) all types (F B and S) of new issues appear in the beginning and slow down towards the end; and 6) from F to B and then to S, the degree of linearity increases respectively.

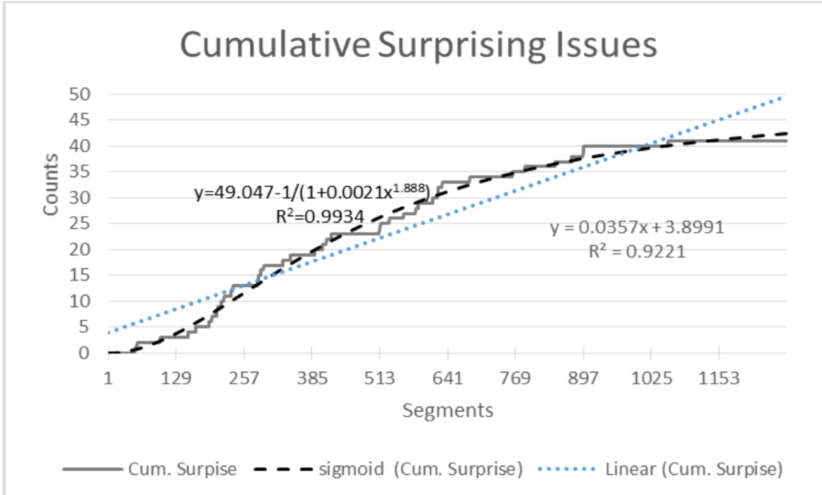

Figure 4. Cumulative *surprising* design issues

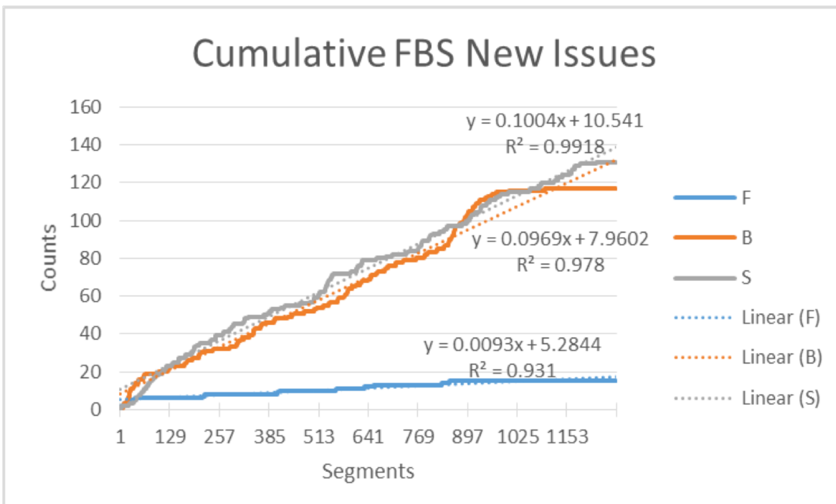

Figure 5. Cumulative *new* design issues separated into new function, new behaviour and new structure design issues

Figure 6 shows that structure issues dominate the number of surprising issues. They occur at double the rate of the surprising behaviour (B) issues that in turn occur at double the rate of the surprising function (F) issues. There are no surprising function issues (F) in the last five deciles, there are no surprising behaviour issue (B) after the eighth decile and the last surprising structure issue (S) is around the ninth decile. Figure 6 also indicates that all types of F, B and S cumulative surprising issues are fitted by a sigmoid function with R^2 values greater than 0.99.

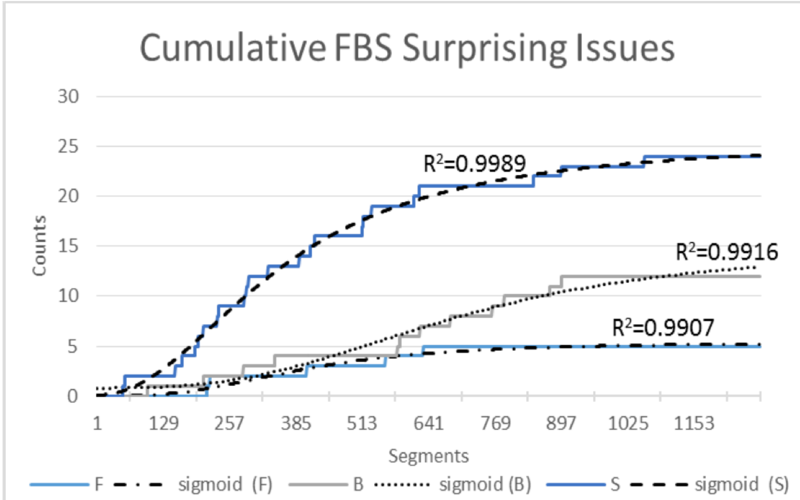

Figure 6. Cumulative *surprising* design issues separated into new function, new behaviour and new structure design issues and sigmoid lines of best fit showing R^2 values greater than 0.99 for F, B and S

4. Discussion and Conclusions

Based on theoretical design models, we hypothesize that there are more new design issues at the beginning of a design session and the trend of cumulative new design issues is likely to be similar to a logarithmic function. However, the empirical result, Figure 3 and 5, show that the trend is closer to linear, by comparing the R^2 value of curve fitting. A closer examination reveals that all types of new design issues reach a plateau.

To reach a certain level of cumulative new design issues, the hypothesised logarithm trend will have a much higher rate of generating new issues at the beginning of a session than the measured linear trend. The results do not fully support the first hypothesis that the trend of cumulative new design issues follows a logarithmic or similar function. If we consider the notion that creativity is positively correlated with the number of new ideas, our hypothesis suggests that creativity drops toward the end of any design session. However, the result shows creativity does not change in that manner.

The results, Figure 4 and 6, support the second hypothesis that the trend of cumulative surprising design issues is similar to a sigmoid function. The graphs in Figure 4 shows the time required to establish the common ground is rather linear throughout the first decile. Figure 6 also suggests that surprising function and structure issues appear mostly in the first half of the session while surprising behaviour is more or less equally divided between the two halves.

Overall, the opportunity for creativity, indicated by the rate of generating new and surprising issues, drops toward the end in this design session.

Novelty and surprise are essential elements for creativity, in this paper we have outlined a method to measure this empirically. Protocol analysis involves coding utterances and gestures that have been videoed previously. Instead of using the raw utterances from the video as the base to code we initially code the protocol using the FBS design issues coding scheme. This converts the raw video into a sequence of codes drawn from the FBS coding scheme. This sequence provides a structural and chronological scaffolding of design issues which forms the substrate design issues to be coded as new, surprising or neither. The codes "new" and "surprising" do not alter the FBS coding scheme, they are codes that hierarchically sit under the existing coding scheme. The benefit of carrying out coding in this manner is that the new and surprising segments are structured chronologically and can be analysed using standard statistical techniques for sequences. The statistical models developed from this coding of empirical data can be used to test the creativity of different designers and of designing under different conditions that can be compared and tested for significance.

It is now possible to recode already coded protocols with these two codes and develop models of creative design behaviour without having to collect new data.

Acknowledgement

This research is supported in part by grants from the US National Science Foundation grant nos. CMMI–1161715 and EEC-1463873. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We thank Dr Mary Lou Maher of the University of North Carolina at Charlotte for the idea of coding new and surprising after segmentation and coding of the FBS design issues.

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