Assessing design creativity

Prabir Sarkar and *Amaresh Chakrabarti*, Indian Institute of Science, Centre for Product Design and Manufacturing, Innovation Design Study and Sustainability Laboratory, Bangalore 560012, India

Creativity is crucial for designing products and enabling innovation. Assessing creativity can help identify innovative designers and products, and support improvement of both. The literature variously defines creativity as a function of degree of novelty, usefulness, or both. Most methods for assessing creativity, however, focus only on assessing novelty of products. This research proposes a new method for assessing the creativity of products as a function of their novelty and usefulness. We develop individual methods for assessing novelty and usefulness of products, and then combine these into a method for assessing creativity of products. The proposed methods have been evaluated by benchmarking them, and other methods available from literature, against the collective, intuitive assessment of product creativity of experienced designers.

Keywords: creativity, engineering design, measure creativity

Engineering designers, managers, entrepreneurs, researchers and other stakeholders involved in product development need to be creative. Creativity affects a wide spectrum of business portfolios and is crucial for designing products (Chakrabarti, 2001, 2004; Chakrabarti & Bligh, 1994, 1996a, 1996b; Chakrabarti, Morgenstern, & Knaab, 2004; Eisentraunt & Badke Schaub, 1995; Gero, 1993; Liu, Chakrabarti, & Bligh, 2000; Westwood & Sekine, 1988). It initiates innovations, aids in problem solving (Amabile, 1996; Eder, 1995; Hubka & Eder, 1996), and enables a company to capture a large market share (Ottosson, 1995). However, increase in competition pressurizes engineering designers to develop new products faster (Molina, Al-Ashaab, Timothy, Young, & Bell, 1995). This often results in a simultaneous introduction of many similar products, e.g. cell phones, printers, car or computers, by various competitors in the market, and it is often found difficult to appreciate the creativity of these new products. A method for assessing the degree of creativity is necessary to help select the most creative product. Besides, since creativity is a prerequisite for innovation, creativity assessment should help also to assess the degree of innovation taking place in design firms and identify better inventors and designers (Sundstorm & Zika-viktorsson, 2003). Therefore, a method that can help identify the *degree of creativity* of products is required; we need to be able to assess not only whether a product is creative, but also how much creative it is. To develop

Corresponding author:
Amaresh Chakrabarti.
ac123@cpdm.iisc.ernet.in

www.elsevier.com/locate/destud
0142-694X $ - see front matter *Design Studies* ■■ (2011) ■■–■■
doi:10.1016/j.destud.2011.01.002

such a method, an understanding what is meant by creativity, and what its current measures are, and how adequate these are, is first necessary.

1 Defining and measuring creativity

There exist many definitions of creativity. For instance, Amabile (1983) defines creativity as 'the process by which something judged (to be creative) is produced'; Torrance (Torrance, 2010) expresses it as 'fluency, flexibility, originality, and sometimes elaboration.' In a recent comprehensive survey of the definitions of creativity, Sarkar and Chakrabarti (2008) analyzed over 160 definitions. From these, with two different methods – majority analysis and relationship analysis – they proposed a 'common' definition of creativity, as follows: 'Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable.' Value, in the context of technical or engineered products (hence forth referred to as 'products'), take on the meaning of utility, or usefulness. Similar views of creativity have also been expressed by other researchers; for instance, Sternberg and Lubart (1999) define creativity as that which 'produce(s) work that is both *novel* (i.e., original, unexpected) and *appropriate* (i.e., useful, adaptive concerning task constraints), Weisberg (1993) defines creativity as '*novel and valuable* products, capacity to produce such works and the activity of generating such products'. However, this is the first time (Sarkar & Chakrabarti, 2008) that existing definitions have been linked to, and brought together in a comprehensive manner under a single overarching definition. According to this 'common' definition, to assess the creativity of designers or creativeness of newly designed products, one must be able to assess the '*novelty*' and '*usefulness*' of these products, where usefulness represents the value of products.

Adopting Sarkar and Chakrabarti's (2008) definition, we argue that, since the core components of creativity are 'novelty' and 'usefulness', a direct measure of creativity should be in terms of measures of both product novelty and product usefulness.

The objectives of this paper are to:

1. Understand the concepts of novelty and usefulness, and identify the need for developing new methods for their assessment.
2. Develop methods for assessing novelty and usefulness of products and combine these into a method for assessing creativity of products.
3. Evaluate the proposed methods by benchmarking these and other existing methods against the collective, intuitive assessment by experienced designers.

2 Understanding novelty

'Novel' products are those that are 'new' to the entire human race. 'Novelty' encompasses both new, i.e., something that has been recently created, and orig-

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

inal, i.e., the first one made and not a copy (Cambridge, 2010). Sternberg and Lubart (1999) define novelty as 'not resembling something formerly known'. According to Boden (1999), novelty may be defined with reference, either to the previous ideas of the individual concerned, or to the whole of human history. The former definition is related to P-creativity (P for Psychological) and the later to H-creativity (H for Historical). H-creativity presupposes P-creativity, for if someone has a historically novel idea, it must be new to both the person and others (Boden, 1999). Generation of novel products requires H-creativity.

One way of assessing novelty of a product, is to compare the characteristics of that product with those of other products, available at the time of its introduction, that are meant to fulfil the same need. The differences among these characteristics should indicate how novel the product is with respect to the products compared. If no other product had satisfied the same need before (i.e., if this product fulfils a need for the first time in history), this new product should be considered as having some novelty. Thus, to assess novelty of a product, one should know both the *time line* of similar inventions (i.e., the sequence of the invention of products belonging to the same category in terms of their functionality to identify which product has satisfied the need first) and the *characteristics* of similar products (to assess how this is satisfied).

2.1 Existing methods for assessing product novelty

Patent offices of many countries employ experts to determine primarily the 'novelty', 'usefulness', and 'obviousness' of the invention stated in a patent application (Patents, 2010). However, they are mainly interested in identifying whether the invention is novel and useful or not, and not the degree of novelty of these inventions. However, determination of the degree of novelty is essential to identify incremental differences among products as discussed earlier.

A number of researchers proposed methods for measuring novelty (Chakrabarti & Khadilkar, 2003; Saunders, 2002; Shah & Vargas-Hernandez, 2003). However, except for the method proposed by Chakrabarti and Khadilkar (2003), these methods mainly focus on the identification of novelty of products and not on their degree of novelty. These methods are briefly discussed below.

Saunder's (2002) work focuses on assessing the novelty of patterns, restricting mainly to aesthetic novelty of patterns. This method is based on asking three questions related to similarity or recentness of patterns: (1) How often similar patterns have been experienced; (2) How similar these patterns have been; and (3) How recently these patterns have been experienced. Novelty is assessed using procedures that estimate one or more of these properties for a given stimulus pattern, and a representation of previous stimuli.

Shah and Vargas-Hernandez (2003) focus on ideation effectiveness. They proposed two methods for measuring novelty: the first using the function of

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

products and the second using the physical principles of products. The first method is based on grading the functions that a product or an idea satisfies, and the second method is based on posterior classification and counting of distinct solution ideas with respect to prior knowledge.

Redelinghuys (2000) defined invention gain as a differential contribution, which is the difference between system-achieved and previous state-of-the-art projected values. However, no method has been suggested for measuring this term.

Chakrabarti and Khadilkar (2003) propose a method for assessing novelty of a product with respective to another product, using the following criteria: (1) vertical criteria weightages: at the need, task, subsystem structure (principle), technology, sub technology and implementation levels; (2) horizontal criteria: at the main, supplementary and additional levels. Their overall method for assessing product novelty is as follows. First, the product is compared with the reference product, and differences are identified at each vertical level. Next, the novelty value of each difference is weighted by its importance using the horizontal criteria, and aggregated.

Lopez-Mesa and Vidal (2006) proposed a method to identify the novelty of solutions generated by a design team 'by identifying the similarities of every alternate solution of a team with every alternate solution of other teams at the level of action Function (F), conceptual Structure (S) and Detail structure (D)'. Once the similarities are found, given a solution Xy (where, 'X" represents a global solution and 'y' signifies a distinct alternative of that global solution), the total number of teams having this solution or similar ones at level 'F' is calculated with the following expression: $N_{F,Xy} = n_{F,xy} + 1$, where $N_{F,Xy}$ is the number of teams with a similar solution to Xy at level 'F', ranging from 1 to 3. For levels S and D, similar calculations are carried out. A current limitation in the validation of this method is that the method is evaluated using only a single design experiment. This method is similar to that proposed by Shah and Vargas-Hernandez (2003); both the methods assess novelty of a solution by identifying the similarity between attributes of solutions. In the method proposed by Lopez-Mesa and Vidal, the sequence of invention is not taken into account, and thus a solution with more uncommon action function could always get higher value for novelty. In addition, issues of possible influences of factors due to problem, team and individual – which could affect the outcome – are not addressed.

In summary, existing methods for assessing novelty are inadequate in the following:

- Some of them take unusualness as a measure of novelty (i.e., less frequently produced products are more novel), which need not be true, and at best could provide an indirect measure of novelty.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

- None of the methods take into account the timeline of invention in determining novelty.
- Most of the methods establish only whether a product is novel or not, rather than how novel it is – the degree of novelty.
- While some methods acknowledge the importance of assessing products at multiple levels of abstraction, the abstraction levels considered are rather arbitrary, and not logically connected via any model that provides a theoretical basis for their inclusion.

3 *Development of a new method for assessing product novelty*

Based on the limitations of the current methods, a new method for assessing novelty is proposed in this paper. Its development is influenced by two observations:

The first observation comes from an analysis of Altshuller's work, the inventor of TRIZ methodology (Terninko, Zusman, & Zlotin, 2000). He categorized design solutions into five levels: (i) routine design problems (no major invention), (ii) minor improvements, (iii) fundamental improvements, (iv) a new generation that uses a new principle to perform the primary functions of the system and (v) a rare scientific discovery or pioneering invention (Mazur, 1996). Since products can be different from each other in terms of the level of innovation, and since innovation requires novelty, one could argue that this difference is, at least partly, due to the difference in their relative degree of novelty. Since all solutions that are patented are novel (else they cannot be patented, according to the patent laws), it should be the degree of their novelty that places them at different levels. Most of the current novelty assessment approaches (see previous section) are inadequate in assessing this distinction in their level or degree of novelty, since they support identification of only whether a product is novel or not.

The second observation is that, often newly introduced products such as pens and scientific calculators contain only some new features compared to those of their predecessors; these new products are normally considered novel. In contrast, there are other products that provide a new function for the first time in history, such as a new medicine to cure cancer or AIDS; these products are also considered novel. However, while in both the cases, the new products are novel, the degree of novelty of the products in the latter case should be much higher than that in the former. This is because in the former cases, the main product already existed and is only incrementally modified into a new product, while in the latter cases, the products did not exist at all. Novelty detection alone will not be able to differentiate between them – the degree of novelty should also be established. The method proposed in this paper is intended to assess novelty of a product as well as its degree of novelty.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

3.1 Development of a methodology to assess the novelty of a newly generated product

One way to determine the novelty of a recently developed product with respect to products earlier to it is to compare the features or characteristics of the new product with the previous products. Models and methods that can be used to decompose a product into its characteristic components or features should be potentially suitable for aiding this assessment. A widely used model in this regard is the Function–Behaviour-Structure (FBS) model. Many researchers (Chandrasekaran, 1994; Deng, 2002; Goel, 1997; Qian & Gero, 1996; Umeda, Ishii, Yoshioka, & Tomiyama, 1996) have developed definitions, models and methods to determine the FBS of products. Extensive work conducted on FBS models illustrates its value for classifying product-characteristics. Based on literature, function, behaviour and structure are defined as follows (Chakrabarti, Sarkar, & LeelavathammaNataraju, 2005).

- *Function:* Descriptions of what a system does: it is intentional and at a higher level of abstraction than behaviour.
- *Behaviour:* Descriptions of how a system does its function. This is generally at a lower level of abstraction than function.
- *Structure:* Structure is described by the elements and interfaces with which the system and its immediate interacting environment are constructed.

Since novel products are those that are both new (recently generated) and original (appearing for the first time in history), we argue that if the *functions* of a new product are different from those of other available products, the new product must be novel, and should have the highest degree of novelty. We ascribe the qualitative degree of novelty associated with this as '*very highly novel*' – the need it fulfils was not fulfilled by any other product at the time of its introduction. Some examples of very highly novel products are (when introduced for the first time):

- Television to broadcast video and audio data over long distances without a physical (wired) connection between the sender and the receiver;
- Camera (pin hole) for capturing images;
- X-ray machine;
- Drugs such as penicillin.

Next, if the *structure* of a new product matches with that of any other available product, the new product is '*not novel*' (the product would be a recently manufactured product rather than a newly developed one); otherwise, it is novel, see the initial steps in the proposed method for detection of novelty in Figure 2.

The above method should help identify very highly novel products. In addition, it should help ascertain whether or not a product has some degree of

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

novelty. However, it would not be able to help assess the relative degree novelty of these products; a more comprehensive model for describing the product functionality is necessary. In a study (Chakrabarti et al., 2005), functionality of a product has been described using a model of causality that uses a set of elementary constructs. We use this model to assess the relative degree of novelty of products. The constructs of the model are (Srinivasan & Chakrabarti, 2009):

1. *Phenomenon:* interaction between system and its environment.
2. *State change:* change in property of the system (and environment) that is involved in interaction.
3. *Effect:* principle that governs interaction.
4. *Action:* abstract description or high-level interpretation of interaction.
5. *Input:* physical quantity (material, energy or information) that comes from outside the system boundary, and is essential for interaction.
6. *oRgans:* properties and conditions of system and environment required for interaction.
7. *Parts:* physical elements and interfaces that constitute system and environment.

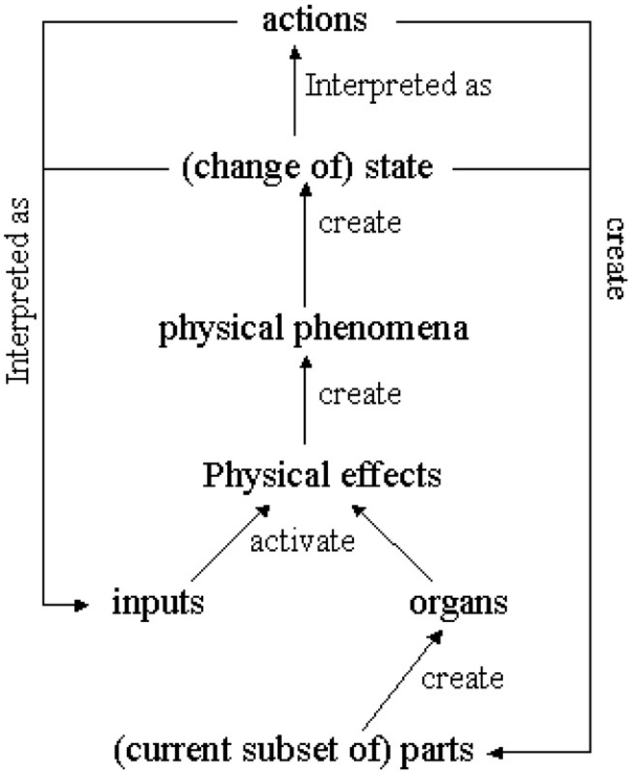

Figure 1 SAPPhIRE Model of Causality (Chakrabarti et al., 2005)

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

This model of causality built upon the above constructs and links is called SAPPhIRE model; the acronym SAPPhIRE stands for *S*tate-*A*ction-*P*art-*Ph*enomenon-*I*nput-o*R*gan-*E*ffect, see Figure 1.

The relationships between these constructs are as follows: parts are necessary for creating organs. Organs and inputs are necessary for activating physical effects. Activation of physical effects is necessary for creating physical phenomena and changes of state, and changes of state are interpreted as actions or inputs, and create or activate parts. Essentially, there are three relationships among these constructs: activation, creation and interpretation. It is found that if a product is different from other existing products in terms of 'state change', 'physical phenomenon' or 'physical effect' (higher constructs), they are also different in terms of 'organs' and 'parts' (lower constructs). Some empirical justification for this is found in (Srinivasan & Chakrabarti, 2010).

If we map SAPPhIRE model to FBS model, we see that the construct 'action' in SAPPhIRE could be taken as 'function' in FBS; 'parts' in SAPPhIRE could be interpreted as 'structure' in FBS; the other constructs of SAPPhIRE work together to generate the 'behaviour' in FBS. In the context of detection of relative degree of novelty in products, we had attributed products with a difference at the level of function (action) as 'very highly novel'. Now we develop novelty attributes for the other, lower novelty products that are different from existing products at least at the physical component level (i.e., at the 'part' or 'structure' level).

For products that are not 'very highly novel', 'state change' and 'input' constitute the highest level at which they can be different from existing products (see Figure 2). Therefore, if two products, one new and the other existing, fulfil the same function (action), and the new product differs from the existing product in terms of all the other six constructs (except 'action'), the new product is taken as having *'high novelty'*.

Next, we argue, that products that are different from existing products at the 'physical effects' or 'physical phenomena' level, are more novel than those that are different only at the 'organ' or 'part' level. We qualitatively attribute these products with *'medium novelty'*. Similarly, if a new product is different from existing products only in terms of organs or parts, the product is qualitatively taken as of '*low novelty*'. For instance, if two products are based on the same physical effect to carry out the same action but the recent one is only a structural (i.e., part-level) variant of an existing product, it is a product having 'low novelty' (for an example see Section 3.4).

With these steps, we propose a method for novelty assessment (see Figure 2) that employs FBS model first, to identify whether a product is very highly

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

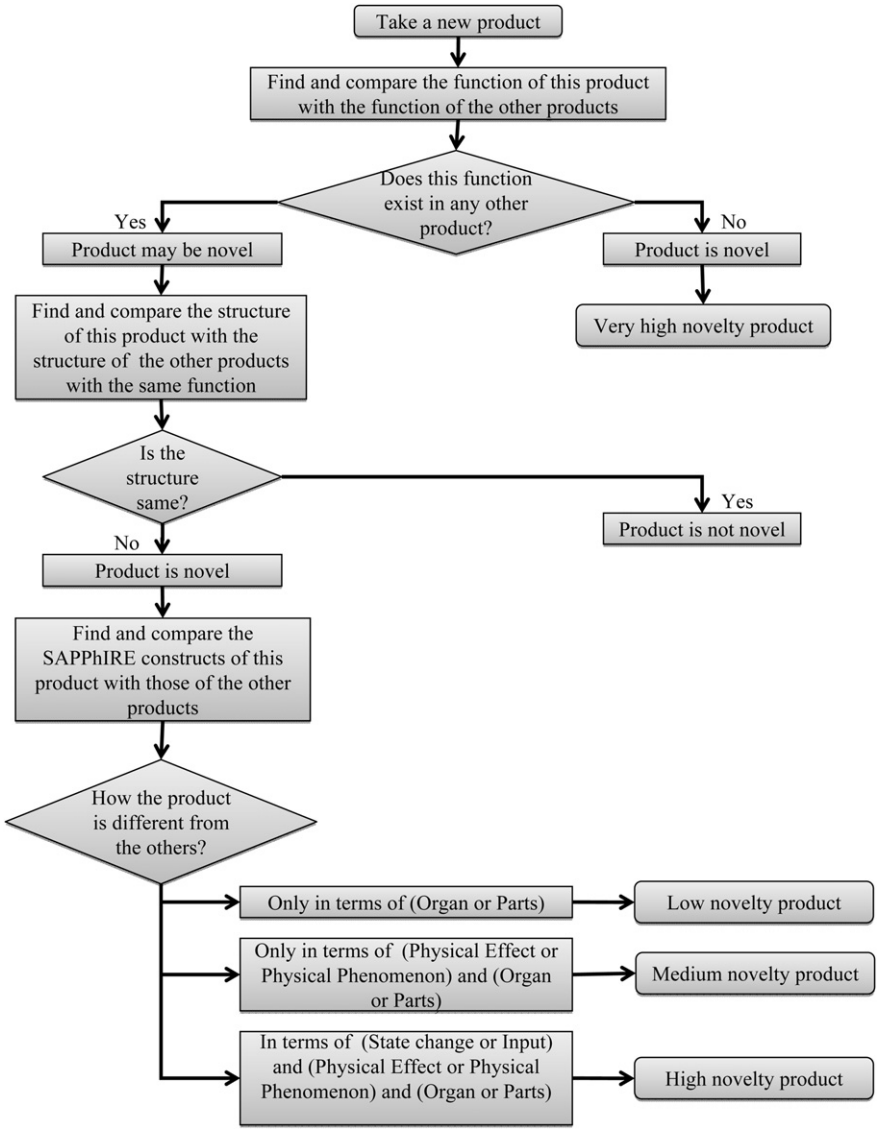

Figure 2 Steps of the proposed method for assessing novelty

novel or not, and SAPPhIRE model next, to assess relative degree of novelty with respect to previous products.

3.2 Discussion

For a new product with several functions, each function should be compared separately with those of the previously existing products. Note that the relative importance of these functions is not to be considered in this comparison, since importance reflects usefulness and will be taken into account by the usefulness parameters, see Section 4.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

The proposed method can be used not only for products, but also for solutions and ideas, as long as the ideas or solutions are sufficiently detailed for FBS or SAPPhIRE constructs for these ideas and solutions to be possible to be identified.

When novelty of many products are to be assessed, and if after using this method it is found that all these products fall within the same degree of novelty (e.g., low or high), the products that have a larger number of differences at higher levels of the SAPPhIRE hierarchy is proposed to be considered more novel.

3.3 Examples

3.3.1 Very high novelty products

The first safety lamp used in underground mines, the first sewing machine, the first stapler, the first dynamite developed, all of them fall within this category. These products have 'very high novelty' because no other product existed at the time of their introduction that performed the same function as these products did.

If we consider the existing cooking appliances in terms of the sequence of their invention, wood burning ovens were the first to have been used, since 1490 (Inventors, 2010). Next came coal burning ovens (1833), followed by kerosene burning oven, (after 1833). Next, gas ovens (1834) are invented, followed by electric oven (1882) and microwave ovens (1946), see (Inventors, 2010). From novelty point of view, wood burning ovens should be considered 'very high novelty' products, since before that there was no cooking system that enabled controlled burning of fuel to cook food.

3.3.2 High novelty products

Continuing with the example of cooking appliances, we see that at the time when electric ovens were invented, wood, coal, kerosene and gas burning ovens were already available. Thus, electric oven is not a 'very high novelty' product for the function of controlled burning of fuels to cook food. However, an electric oven uses a different input (electricity), and differs from all its predecessors in the physical phenomena, physical effect, organs and parts used to achieve the action. Hence, an electric oven has been a 'high novelty' product at the time of its invention.

3.3.3 Medium novelty products

When microwave cooker was invented, electric ovens as well as the other ovens (i.e., wood, coal, kerosene, and gas) were already available. Microwave ovens are more similar to electric ovens than the other ovens, as both these products run on electricity (same input). These products are compared in Table 1, using their FBS and SAPPhIRE models.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 1 Comparison of electric oven and microwave oven

FBS	*SAPPhIRE*
For electric oven: Function: To produce heat to cook food. Behaviour: A coil heats up when electricity passes through it, thus producing heat to cook food in a container placed over it. Structure: A container housing a coil placed inside a non-conducting material. The two ends of the nichrome wire are connected to the electric plug.	Action: Generate heat State change: The wire turns from cold to red hot PP: Due to resistance in the wire the coil generates heat PE: Ohms law, heat transfer laws Organ: Ohmic resistance, specific heat capacity. Parts: Coil, holder Input: Electric power
For microwave oven: Function: To produce heat to cook food. Behaviour: Microwave generated in one part of the oven goes inside the food particles and these particles vibrate internally, producing heat. Structure: Magnetron − the microwave generator, a closed container, controls and safety systems.	Action: Generates heat State change: Rise in temperature PP: vibration of the molecules. PE: Heat generation principles when micro wave is used Organ: Oscillation of polarized food molecules, eddy current Parts: Microwave generator, enclosure Input: Electric power.

Now, novelty of a 'micro wave cooker' is assessed by asking the following questions.

(i) 'Does the function exist in any other product?'− The answer is 'yes'. Thus, this product is not a 'very high novelty' product, see Figure 2.
(ii) 'Is the structure same as that of any other products?' The answer is 'no' − the structure of the microwave oven is different from that of electric or other ovens and stoves. Thus, the product has some novelty, see Figure 2.
(iii) Next, the SAPPhIRE models of a microwave oven and an electric oven are compared. The microwave oven is found to be different from the electric oven in terms of its physical effects, physical phenomena, organ, and parts. Therefore, microwave oven is a 'medium novelty' product.

Note that if the sequence of invention is ignored, comparisons of an electric oven with microwave oven, gas oven, and kerosene fuel stove would show that the electric oven is a medium novelty product. The confusion is caused by the fact that microwave oven came after electric oven, and should therefore not have been considered in assessing novelty of the electric oven; it, in fact is of high novelty, as explained earlier.

4 *Understanding usefulness*

The Oxford Dictionary (2010) defines usefulness as 'effective; helping you to do or achieve something.' Sternberg and Lubart (1999) define 'usefulness' in terms of 'appropriateness.' Similarly, Mumford and Gardner (1994) define

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

'utility' in terms of 'usefulness, appropriateness and social value.' From these we understand that 'useful' things are those that are 'socially valuable', and usefulness could be used to represent social value.

4.1 Existing methods for assessing product usefulness

From review of literature in the area of design, we were unable to find any existing, direct measure for usefulness. In order to assess patentability of an invention, patent office employs experienced engineering designers to determine novelty and usefulness of the invention. Even though several researchers define usefulness (e.g., Mumford & Gardner, 1994; Sternberg & Lubart, 1999), no method for measuring usefulness has been suggested. We argue that methods for evaluation of designs and products (e.g., those cited in Rozenberg & Eekels, 1995) are the closest available to what could be used for assessment of usefulness of products. Shah and Vargas-Hernandez (2003) propose to measure the 'quality' of a product using a variant of the 'weighted objective method'. Therefore, we take the 'weighted objective method' as a representative evaluation method as the closest available in literature for this purpose.

5 Development of a method for assessing usefulness of products

While a product may be perceived as useful, this impression can be validated only when this conclusion is supported by results from its actual use; it is the actual use of the product that conclusively validates its usefulness. For example, let us analyze a scenario in which an affluent family, that already possesses many cars, purchases another car 'A' but never uses it. In contrast, a middle-class family buys a similar car 'A' and uses it frequently. Even though car 'A' is a potentially useful product, the usefulness of the same car to the affluent family is very little, while it is very useful to the middle-class family. Extending this idea from families to communities, we develop a broad notion of the use of a product with which to assess the degree of usefulness of a product. Thus, we argue that the usefulness of a product should be measured by its actual use (which would reflect an instance of the notion of 'social value').

The proposed method for measuring the usefulness of a product is, therefore, based on the argument that usefulness should be measured in terms of its *actual* use. The concept of use, in this context, has several connotations, as follows. First, we argue that products such as a pacemaker or a lifesaving drug are more useful than products such as a pen or a video game. Thus, products need to be categorized into different levels according to their importance, i.e., their effect per usage in society. Next, we argue that if a product is used by many people in contrast to a few, it should be considered to have been more useful to the society. Lastly, with the above two factors remaining the same, if a product is used for a longer period than another

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

product or have a longer persistence of effect per usage, it should be considered more useful than the other product. The parameters used in the method are explained below.

5.1 Importance of use or level of importance

As to how important the use of a product is depends on the impact of that product on the lives of its users. Some products are indispensable, while others are not; thus, products that are more important to the society should have a higher value for usefulness. We have identified five levels of usefulness of a product (see Table 2).

We could relate the level of importance classification as discussed above with Maslow's hierarchy of needs (Maslow, 2010). Since, most of the products that we use aim to fulfil our biological and safety needs (the first two levels in Maslow's hierarchy); the level of importance as shown in Table 2 essentially classify products that satisfy these two kinds of needs into five different levels of importance.

5.2 Rate of popularity of usage

As argued before, if more people use a product, it should be considered more useful than those that are used by less number of people. Thus, all other parameters remaining same, the products that are used by a larger number of people are considered more useful to the society. We propose that the 'popularity' of usage of product should be an important factor for assessing usefulness. This is expressed as 'rate of popularity of usage' within a specified time period.

5.3 Rate of use or rate of duration of benefit

Products that are used for a longer period should be considered more useful to the society, assuming that the 'level of importance' and 'rate of popularity' are constant across these products. Thus, duration of use of a product affects

Table 2 Level of importance of different products

Code	*Points in a scale of 5*	*Level of importance*	*Type of importance*	*Examples*
A	5 (>4.0–5.0)	Extreme importance	Life saving drugs, life support systems	Oxygen cylinder, pace makers
B	4 (>3.0–4.0)	Very high importance	Compulsory daily activities	Taking food, using restroom
C	3 (>2.0–3.0)	High importance	Shelter, social interaction	Pen, belt, clothes, housing, spectacles, shoes
D	2 (>1.0–2.0)	Medium importance	Machines for daily needs	Cleaning machine, vacuum cleaner, water pump, water heaters
E	1 (0.0–1.0)	Low importance	Entertainment systems, recreation systems	Computer games, bowling, go-carting

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

usage of products. We propose 'rate of use' of a product as 'the duration of use of a product in a given time period'. In a given period, this can be calculated by multiplying the 'frequency of usage of a product' with the 'duration of usage of that product per usage'. Frequency of usage of a product is the number of times the product is used in a given period (e.g., hour, day, or month) and duration of usage is measured in terms of the unit time (e.g., hour, day, or month).

Where rate of use is not known or not applicable (e.g., when the beneficial effect of taking a medicine stays for the whole life rather than for a year or a day), the 'rate of duration of benefit' could be used. 'Rate of duration of benefit' is expressed as 'the total time within a given time period that the user is benefitted by using that product'.

5.4 Assessment of usefulness of a product

We argue that all three parameters (viz. importance of use, rate of popularity of usage, and rate of use or duration of benefit) are equally important in assessing the overall usefulness of a product. Thus, considering these parameters, we propose the following equation, as shown below, for assessing the usefulness of a product.

$$\begin{aligned}\text{Usefulness (U)} = {} & \text{Level of importance (L)} \times \text{Rate of popularity of use (R)} \\ & \times \text{Frequency of usage (F)} \\ & \times \text{Duration of use or Duration of benefit per usage (D)} \end{aligned} \quad (1)$$

Note that the unit of time for all the above terms should be the same, i.e., day, month, or year. For those products whose usage changes over a specific period, say over a month, a larger unit such as 'year' should be considered. For instance, the usage of a fan fluctuates over several seasons, and therefore, a year may be the preferred unit. In contrast, usage of a toothbrush does not change over days, and therefore, a month or day can be chosen as the preferred unit.

Usefulness of 'ideas' and 'solutions' could also be determined using this method, given that these ideas and solutions are matured enough to predict, assess or extrapolate data required for these three parameters (viz. importance of use, rate of popularity of usage, and rate of use or duration of benefit). Below we discuss possible conditions under which special care needs to be exercised when determining the values of these parameters.

5.5 Discussion – importance of use or level of importance

In order to distinguish among very similar products with the same level of importance, assigning intermediate points to the 'level of importance' (see Table 2) could be beneficial. For instance, there is a higher health-hazard involved in consuming unpurified water compared to that in cleaning a room. Thus, one

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

can assume that the importance of a water purifier in our lives is more than that of a vacuum cleaner. So, if water purifiers and vacuum cleaners are compared (both with a 'medium level of importance'), water purifiers could be assigned a higher level of importance (say 1.6) than vacuum cleaners (say 1.2). Similarly, when comparing the usefulness of sports equipment with movie CDs (both with a 'low level of importance'), sports equipment could be assigned a higher level of importance, since sports provide both entrainment and fitness while a movie provides only entrainment. However, this could also be based on user preferences, ascertained using various methods such as user survey.

5.6 Discussion – rate of popularity of usage

For assessing usefulness of a product across different communities, we propose that the ratio of the number of people using the product in a community to the total population of that community be used. For example, product 'A' could be more useful to community 1 than to community 2, depending upon the population of these communities.

For products that are intended for public use, the entire population of the community should be considered. A few such products are thermal power stations, public parks, and tree plantations.

5.7 Discussion – rate of use/rate of duration of benefit

There are certain products that are commonly reused or resold, such as cars and two wheelers, while others are used for alternative purposes after they completed their design life, e.g., after a motor has lived its useful life and became defunct, it may be used in classrooms to explain internal structure of motors. In these cases, the usefulness of these products should be calculated as a sum of all usages of the product = (usefulness due to usage 1) + (usefulness due to usage 2) + (usefulness due to usage 3) and so on.

6 Example

Let us consider an example case of assessing the usefulness of a pair of leather shoes 'A' and a pair of leather slippers 'B'; let us also assume that 210 and 332 people, respectively, use these products per day in a community of 1000 people. Also, let the average usage of a pair of leather shoes be 5 h per day and that of a pair of leather slippers be 9 h per day.

Both products fall under Category C of 'highly important products' with a 3 ($>2.0-3.0$)/5 value (Table 2). From experience, one might assume that shoes have a higher importance than that of slippers, because shoes protect the legs better (also, wearing shoes is mandatory for some sport). Therefore, the level of importance of shoes may be increased to say 2.5/5, while that of slippers is kept at 2.1/5 (note that this judgment is subjective). Using these numbers, usefulness will be estimated as follows using the proposed method:

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

For leather shoes:

Importance of use (L): 2.5/5.

Rate of popularity for use (R): 210/1000 (ratio of number of people who use the product/total number of people who could potentially use it)

Rate of use (F × D): 5/24 (ratio of number of hours of use/total number of hours in a day)

Usefulness (U) using Equation (1) = (2.5/5) × (210/1000) × (5/24) = **0.0218**

For leather slippers:

Importance of use (L): 2.1/5

Rate of popularity or use (R): 332/1000

Rate of use (F × D): 9/24

Usefulness (U) using Equation (1) = (2.1/5) × (332/1000) × (9/24) = **0.0523**

Alternatively, we could assess the ratio of usefulness of these products: usefulness of leather shoes: usefulness of leather slippers = 1: 2.4. Thus, for the given conditions, the leather slippers are more useful than leather shows to the specified community.

7 *Assessing relative product creativity*

With the argument that 'novelty' and 'usefulness' of products should be taken as the *only* two direct influences on creativity (as established in the common definition), it should now be possible to express creativity as a function of these two parameters.

We propose that the relationship be reflected as a product of the two parameters, in order to embody the notion that absence of either will lead to a lack of creativity in an outcome:

$$\text{Creativity (C)} = \text{Novelty (N)} \times \text{Usefulness (U)} \tag{2}$$

The following steps are carried out for assessing the relative degree of creativity of a given set of products:

Step 1: Assess the novelty of each product on a qualitative scale: 'Very high novelty', 'High novelty', 'Medium novelty', and 'Low novelty'.
Step 2: Convert the qualitative novelty value of each product into a quantitative value, as follows: Very high novelty = 4 points, High novelty = 3 points, Medium novelty = 2 points, and Low novelty = 1 point.
Step 3: Assign relative grading to each product. For example, if there are five products that are compared with each other, then allocate 1/5, 2/5, 3/5, 4/5, 5/5 points to those ranked 1−5, respectively. If products fall in the

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

same degree of novelty category (e.g., low, high), the products that have a larger number of differences at higher levels of the SAPPhIRE hierarchy, is should be considered more novel. Assign intermediate points for these products.

Step 4: Assess the usefulness of each product using the method described in Section 5.

Step 5: Convert the usefulness value into relative grading using the following scale: if there are five products that are ranked 1−5, give them 1/5, 2/5, 3/5, 4/5, and 5/5 points, respectively.

Step 6: Calculate the creativity of a product by multiplying its degree of novelty and usefulness using Equation (2).

8 Evaluation

Evaluation of the proposed methods for assessing novelty, usefulness, and creativity of products is carried out using a comparative study in which the results of using the proposed method and other existing methods are compared with the collective, intuitive assessment of novelty, usefulness, and creativity of three sets of products by a common group of experienced designers. The reasons for comparing the results of the proposed methods and existing methods with the intuitive evaluation of novelty, usefulness, and creativity of designers are explained in the following sub-section.

8.1 Need for benchmarking creativity measures against the intuitive notion of experienced designers

Identification of novelty of a product, in an absolute sense, is difficult, as one cannot become knowledgeable enough about all current and previous products in all countries. Knowledge of all products with their characteristics would be an ideal resource base against which novelty of a newly generated product could be accurately assessed. In absence of such a knowledge base, assessment of novelty and creativity of products solely depends upon the knowledge of the experienced designers of a domain in which the newly generated product belongs. Currently, experienced designers are regularly used to judge creativity of conceptual solutions in design firms, and in patent offices, experienced designers from similar domains are used to judge novelty and usefulness of products. We argue, like Amabile (1996) who suggested the use of experts to identify what 'creative' is, that ultimately for any measure of novelty, usefulness or creativity to be valid, the results should match the notion of these constructs as collectively held by experienced designers.

8.2 Selection of methods to be compared and evaluated

8.2.1 For novelty assessment

As discussed in Section 2, there are several existing methods for assessing novelty. Among these, the method proposed by Saunders (2002) is applicable only for detecting aesthetically novel (architectural) products; hence we have not included this method in the comparative study. Thus, three methods are used in

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

this comparative study: Shah and Vargas-Hernandez's method (2003), Chakrabarti and Khadilkar's method (2003), and the method proposed in this paper. These three methods are compared against the collective, intuitive assessment by a group of experienced designers.

8.2.2 For usefulness assessment

As discussed in Section 4, weighted objective ranking method and the proposed method for usefulness detection are compared with the collective, intuitive assessment group by a of experienced designers.

8.2.3 For creativity assessment

Since no other method seems to exist that measures creativity of outcomes, only the method proposed is evaluated against the collective, intuitive assessment of creativity by a group of experienced designers.

8.3 Steps followed during evaluation of the proposed methods

The evaluation of the methods was a tedious process, it took several days, and analysis of the results took many months. The broad steps followed are:

Step 1: Selection of a set of products for evaluation.
Step 2: Carrying out pilot evaluation. This is done by four experienced designers, two in each team.
Step 3: Identification of inputs required by the methods for assessing novelty, usefulness, and creativity.
Step 4: Collection of the required inputs from the responses of a group of experienced designers through an Internet-enabled form. Sixteen designers with an average of four years of design experience in industry were used.
Step 5: Determination of novelty, usefulness, and creativity using each method under evaluation. This is carried out by four experienced designers, two in each team (none of whom took part Step 1 or 4).
Step 6: Comparison of the results.

Note that we had three sets of experienced designers: one for the pilot study, one for the internet survey and one for final evaluation using the data collected from the survey.

8.4 Step 1: selection of a set of product for the evaluation

Three sets of products were selected for analysis. All products in each set have similar functions. Relatively simple products were selected, so that the designers were aware of the working mechanisms of each product. These were listed according to the sequence of their invention – with the chronologically first invention being listed first. The products selected were:

Product Set 1 – common writing instruments: The products considered are 'a pencil,' 'an ink pen,' 'a ball point pen,' and 'a marker pen.'

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Product Set 2 – popular communicating devices: The products considered are 'a postal letter,' 'a telephone,' 'a pager,' 'a mobile,' and 'a video mobile.'

Product Set 3 – domestic cooling devices: The products considered are 'a hand held fan,' 'an electric fan,' and 'an air conditioner.'

8.5 Step 2: carrying out pilot evaluation

Four designers, two in each team, evaluated the methods through a pilot evaluation process. First all the methods were explained by the researchers to the designers. Next, they are asked to use their own intuitive methods, the selected methods, and the proposed methods, to assess the novelty, usefulness, and creativity of each product in a set. The two teams were debarred from interacting with each other until the end of the study. After evaluation, the attributes used by these groups while evaluating different methods are noted down. These attributes are provided as initial suggestions to the experienced designers who were to take part in the Internet based survey used in the main design experiment as detailed in Step 4 (Section 8.7).

8.6 Step 3: identification of inputs for assessing novelty, usefulness, and creativity using the selected methods

For novelty assessment:

1. *Intuitive evaluation by experienced designers (hence forth called 'experienced method'):* This includes any method that the experienced designers have used in the past to determine the novelty of the products. Experienced method also includes intuitive evaluation used by designers without using any formal evaluation method. The inputs required are: relative ranking of the selected products by each experienced designer. These are collected using an Internet-enabled form used by the experienced designers (see Appendix 1).

2. *Shah and Vargas-Hernandez's (2003) method (hence forth called 'Shah's method'):* This requires the following inputs: novelty attributes, relative weights of each set of products considered, and the novelty values given to each of these products. The novelty attributes with their weights are collected using the Internet-enabled form.

3. *Chakrabarti and Khadilkar's (2003) method:* This requires the weights of the various levels, e.g., technology, sub technology, etc. These values are mutually agreed upon by the experienced designers who took part in the final evaluation.

4. *The proposed method for assessing novelty:* It requires the sequence of inventions to be available. This was already available from earlier literature on the product sets used.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

For usefulness assessment:

1.*Collective, intuitive notion of the experienced designers (henceforth called 'experienced method'):* This includes any method that experienced designers normally use to determine the values for usefulness of products. The inputs required are the relative rankings of the selected products. These values are collected from the results of the Internet-enabled survey.

2. *'Weighted objectives method':* The inputs required are evaluation attributes for each product set. These values are collected from the results of the Internet-enabled survey.

3. *The proposed method for assessing usefulness:* The inputs required are data used to estimate the 'rate of popularity of use' and 'rate of use'. These values are taken as that mutually agreed upon by the designers who worked in the final evaluation.

For creativity assessment:

1. *The proposed method for assessing creativity:* The inputs required are the values of novelty and usefulness from the proposed novelty and usefulness assessment methods.

8.7 Step 4: collection of required inputs from the responses of a group of experienced designers through an Internet-enabled form

An Internet-enabled survey form (see Appendix. 1: Survey) developed by the authors is used for collection of inputs from practicing experienced designers. In the survey, the following questions are asked:

(1) Rank each product of each product set relative to others in that product set, in terms of novelty, usefulness, and creativity. This provides the values of the relative novelty, usefulness, and creativity of the products as intuitively perceived by the designers.
(2) *Find the attributes with their corresponding weights for general evaluation of each set of products (3 sets)*. This helped is identifying the evaluation criteria to be used in the 'weighted objectives method' and Shah's method.
(3) *Provide some personal information like name, number of years of experience as a designer, etc*. This was used to determine the level of experience of the designers who took part in the survey.

The attributes proposed by the designers who participated in the pilot study were provided as initial suggestions for the first two questions (Appendix 1 shows the complete list of questions asked in the survey). Sixteen designers with an average of four years of design experience in industry responded. These designers have a formal master's degree in design (either in industrial

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

design, product design or in engineering design) and have industrial experience in designing products for at least two years. The average of the values suggested by these designers for each input, for each method, is computed and used in the final evaluation.

The immediate findings are: (i) the average values of the intuitive notion of novelty, usefulness, and creativity of these products by 16 experienced designers (see Table 3) (iii) novelty attributes with their corresponding weights (Column 1, Table 4), and (iii) the evaluation criteria with their corresponding weights (Table 4) as perceived intuitively by the experienced designers, for use in the 'Weighted Objectives method'.

8.8 Step 5: determination of novelty, usefulness, and creativity using the selected methods

Four experienced designers, two in each team, used the average of the inputs from the 16 experienced designers through the Internet based form, in order to complete the novelty evaluation of the product sets using each of the methods considered. Each of these teams was provided with printed information on the methods to be used.

First, inputs that are possible to be collected for use in evaluating the products were collected from an Internet-enabled form. Next, these inputs are used by the above two teams of experienced designers within a laboratory setting to complete the evaluation of the products using each of the methods. This was done in order to have many responses from a large number of highly experienced designers through the internet-enabled form (who have too little time to spare to be involved in the entire evaluation process) so to increase statistical validity, and yet ensure that the evaluation is completed in a rigorous manner using experienced designers which required explaining each method to

Table 3 Product ranking (average) by experienced designers using their intuitive notion

Product sets	*Product name*	*Novelty*	*Usefulness*	*Creativity*
Product set 1	A pencil	4	2	3
	An ink pen	1	3	2
	A ball point pen	2	1	1
	A marker	3	4	4
Product set 2	A postal Letter	3	4	5
	A telephone	1	2	1
	A pager	2	5	3
	A mobile	4	1	2
	A video mobile	5	3	4
Product set 3	A hand held fan	3	2	3
	A electric fan	2	1	2
	An air conditioner	1	3	1

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 4 Attributes

Product sets	*Weights*
For product set 1	
1. Number of surfaces it can write on	0.1
2. Smoothness	0.3
3. Maintenance required	0.3
4. Ease of writing	0.2
5. Ease of erasing	0.1
Total	*1.0*
For product set 2	
1.Time taken	0.3
2. No. of features	0.3
3. Ease of use	0.2
4. Cost	0.1
5. Medium used	0.1
Total	*1.0*
For product set 3	
1. Comfort	0.4
2. Type of power used	0.2
3. Maintenance required	0.2
4. Amount of effort required	0.1
5. Portability	0.1
Total	*1.0*

the designers via direct interaction in the laboratory. It took more than 3 h for these two teams of experienced designers to understand all the methods before evaluating them using the inputs provided by the larger group of experienced designers provided via the Internet-enabled form.

Novelty assessment methods:

First, the two teams evaluated the three sets of products using Shah's method, Chakrabarti and Khadilkar's method and finally the proposed method. The results are shown in Table 5.

Usefulness assessment methods:

Using the evaluation attributes shown in Table 4, each team of designers evaluated the products using the 'Weighted Objectives method' (Weighted, 2010). Each team took each attribute and evaluated each product in each set against that. They then multiplied these points with the weights of these attributes. The products were then ranked, as shown in Table 6. Next, the designers assessed the usefulness of the products using the proposed method (Table 6).

Note: 4,5 means that the rank for the product can be taken either as 4 or 5.

Creativity assessment methods:

The value of novelty and usefulness as estimated before are multiplied as shown using Equation (2) to obtain the value of creativity of the products. This value is

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 5 Ranking of usefulness of products using different methods

		Shah's method		*Chakrabarti and Khadilkar's method*		*Proposed method*	
Product sets	*Product name*	*Team 1*	*Team 2*	*Team 1*	*Team 2*	*Team 1*	*Team 2*
Product set 1	A pencil	2	2	4	3	4	4
	An ink pen	4	4	3	4	1	1
	A ball point pen	3	3	1	1	3	3
	A marker	1	1	1	1	2	2
Product set 2	A postal Letter	1	1	4	2	3	3
	A telephone	5	5	4	1	1	1
	A pager	2	2	3	2	2	2
	A mobile	2	2	2	2	4	4
	A video mobile	2	2	1	5	5	5
Product set 3	A hand held fan	1	1	3	3	3	3
	A electric fan	3	3	2	2	2	2
	An air conditioner	2	1	1	1	1	1

Note: Rank 1(highest) followed by other ranks.

then compared with the collective, assessment of creativity of the experienced designers (as average of the individual assessments), see Table 7.

8.9 Step 6: comparison of the results

Novelty:

Since the evaluations of the same product sets using different methods are in the form of ranks, to determine the correlation among these, we use Spearmen's rank correlation (Spearman, 2010). Table 8 shows correlations among evaluations using different methods.

Table 6 Ranking of usefulness of products using the methods considered

		Weighted objectives method		*Proposed method*	
		Team 1	*Team 2*	*Team 1*	*Team 2*
Product set 1	A pencil	3	3	3	3
	An ink pen	1	2	2	2
	A ball point pen	2	1	1	1
	A marker	4	4	4	4
Product set 2	A postal letter	5	4	5	4,5
	A telephone	3	1	2	2
	A pager	4	5	4	4,5
	A mobile phone	2	2	1	1
	A video mobile phone	1	3	3	3
Product set 3	A hand held fan	1	1	2	3
	A electric fan	3	2	1	1
	An air conditioner	2	3	3	2

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 7 Assessing creativity of products

		Novelty rank		*Usefulness rank*		*Creativity value = Novelty rank × usefulness rank*	*Creativity rank (highest = 1)*	
		Team 1	*Team 2*	*Team 1*	*Team 2*	*Team 1; Team 2*	*Team 1*	*Team 2*
Set 1	Pencil	4	4	3	3	12; 12	4	4
	Ink pen	1	1	2	2	2; 2	1	1
	Ball point pen	3	3	1	1	3; 3	2	2
	Marker	2	2	4	4	8; 8	3	3
Set 2	Postal Letter	3	3	5	4	15; 12	4,5	4
	Telephone	1	1	2	2	2; 2	1	1
	Pager	2	2	4	4	8; 8	3	3
	Mobile phone	4	4	1	1	4; 4	2	2
	Video mobile phone	5	5	3	3	15; 15	4,5	5
Set 3	Hand held fan	3	3	3	3	9; 9	3	3
	Electric fan	2	1	1	1	2; 1	1,2	1,2
	Air conditioner	1	1	2	2	2; 2	1,2	1,2

As shown in Table 8, the results using the proposed method correlate highly with that of the designers' collective, intuitive method. This indicates that the proposed method for assessing novelty reflect better the experienced designers' intuitive notion of novelty.

Shah's method is based on the assumption that less frequently generated means of achieving a function are more novel. Shah's method was originally intended to be used in evaluating novelty as people solved a design problem, and not for novelty of final products. However, since not many novelty-assessment methods are currently available, and since several researchers use infrequent ideas as a measure of novelty, we included this for comparison. Chakrabarti and Khadilkar's method is based on the assumption that systems that have more components and also differ from their predecessors more in terms of their principle or technology rather than embodiment, are more novel. The proposed method is based on the assumption that if a system is different from its predecessors more in terms of function or behaviour rather than structure, it will be considered more novel, and the degree of novelty is based both on the amount (number of functions) and intensity (very high, high, medium, low, etc.) of these differences.

Table 8 Correlation

Correlations	*Product set 1*	*Product set 2*	*Product set 3*	*Average*
Experienced- Shah's method	−0.8	−0.667	−0.5	**−0.656**
Experienced-Chakrabarti and Khadilkar's method	0.316	−0.820	1	**0.165**
Experienced- Proposed method	0.8	1	1	**0.933**

Note: Levels of significance of the correlations: $p < 0.1$ for values >0.62, $p < 0.05$ for values (0.63−0.70), $p < 0.02$ for values (0.71−0.79) and $p < 0.01$ for values >0.83 (Corr, 2010).

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 9 Correlation among usefulness ranks using different methods

Methods compared	*Product set 1*		*Product set 2*		*Product set 3*		*Average*	
	Team 1	*Team 2*	*Team 1*	*Team 2*	*Team 1*	*Team 2*	*Team 1*	*Team 2*
Experienced-weighted objective method	0.4	0.8	0.6	0.9	−0.5	0.5	**0.167**	**0.733**
Experienced-proposed	0.8	0.8	0.9	0.975	1	0.5	**0.9**	**0.758**
Weighted objective method-proposed	0.8	1	0.7	0.975	−0.5	−0.5	**0.333**	**0.491**

Note: 'experienced' represents 'designers' intuitive method'; 'proposed' represents the 'proposed method'. Levels of significance: $p < 0.1$ for values >0.62, $p < 0.05$ for values (0.63−0.70), $p < 0.02$ for values (0.71−0.79), and $p < 0.01$ for values >0.83 (Corr, 2010).

Usefulness:

Table 9 shows the correlation between ranks as determined using the various methods for assessing usefulness.

It is interesting to note that, in contrast to the weighted objective method, ranking of products using the 'proposed method' has a much higher correlation with ranking using the 'designers' intuitive method'. It indicates that the proposed method better reflects the designers' intuitive notion of usefulness.

Creativity:

Table 10 shows correlations between the ranks obtained using the selected methods (designers' intuitive method and the proposed method) for assessing creativity.

Other results:

Next, the relationship between novelty, usefulness, and creativity using the designer's intuitive method and the proposed methods are correlated (Table 11).

From Table 11, we see that the average correlations of evaluating using the proposed method match are much higher with those using the designers' intuitive method than those with the other methods. This is a possible indication that the proposed method for assessing novelty, usefulness, and creativity more adequately reflects the experienced designers' intuitive notion of these.

Table 11 also shows that even though creativity can be seen as a product of novelty and usefulness (see Equation (1)), which is empirically validated by

Table 10 Correlation among creativity ranks using different methods

Experienced-proposed	*Correlation (Team 1)*	*Correlation s(Team 2)*
Product set 1	0.6	0.6
Product set 2	1	0.9
Product set 3	1	1
Average	**0.867**	**0.833**

Note: Levels of significance: $p < 0.1$ for values >0.62, $p < 0.05$ for values (0.63−0.70), $p < 0.02$ for values (0.71−0.79), and $p < 0.01$ for values >0.83 (Corr, 2010).

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 11 Relationships among novelty, usefulness, and creativity ranks using the designers' intuitive method and the proposed method

	Experienced method	*Proposed method (Team 1)*	*Proposed method (Team 2)*
Product set 1			
Novelty-creativity	0.6	0.8	0.8
Usefulness-creativity	0.8	0.6	0.6
Novelty-usefulness	0	0	0
Product set 2			
Novelty-creativity	0.5	0.615	0.7
Usefulness-creativity	0.6	0.718	0.564
Novelty-usefulness	−0.2	−0.1	−0.153
Product set 3			
Novelty-creativity	1	0.866	1
Usefulness-creativity	−0.5	0	0.5
Novelty-usefulness	−0.5	−0.5	0.5
Average correlation			
Novelty-creativity	0.7	0.760	0.833
Usefulness-creativity	0.3	0.439	0.554
Novelty-usefulness	−0.233	−0.2	0.115

Note: Levels of significance: $p < 0.1$ for values >0.62, $p < 0.05$ for values (0.63−0.70), $p < 0.02$ for values (0.71−0.79), and $p < 0.01$ for values >0.83 (Corr, 2010).

the fact that both have a positive correlation with creativity, novelty seems to have a higher influence on creativity than usefulness does. Also, novelty and usefulness have very low correlation between themselves, which shows that they are independent of each other.

Finally, we calculate the correlation between the correlations obtained using the designers experienced method and the proposed method (see Table 12).

A high correlation between the designers' intuitive method and the proposed method indicates that the proposed method represents the intuitive notion of the designers adequately.

9 *Discussion of the results*

Based on the finding that the ranks of novelty, usefulness, and creativity of multiple sets of products using a group of experienced designers' collective, intuitive method match highly with that using the proposed method, we argue that the proposed method reflects well the designers' intuitive notion of creativity. The results also demonstrate that:

(1) The proposed methods for assessing novelty, usefulness, and creativity are able to match the intuition of experienced designers better than currently available methods.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Table 12 Correlation among different methods

	Experienced method	*Correlation*	*Proposed method*	*Correlation*
Team 1	Novelty-creativity	0.7	Novelty-creativity	0.760
	Usefulness-creativity	0.3	Usefulness-creativity	0.439
	Novelty-usefulness	−0.233	Novelty-usefulness	−0.2
Team 2	Novelty-creativity	0.7	Novelty-creativity	0.833
	Usefulness-creativity	0.3	Usefulness-creativity	0.555
	Novelty-usefulness	−0.233	Novelty-usefulness	0.115
Average	Novelty-creativity	0.7	Novelty-creativity	0.797
	Usefulness-creativity	0.3	Usefulness-creativity	0.497
	Novelty-usefulness	−0.233	Novelty-usefulness	−0.042
			Experienced-proposed (average of average)	0.997
			Experienced-proposed (correlation)	0.958

Note: Levels of significance: $p < 0.1$ for values >0.62, $p < 0.05$ for values (0.63−0.70), $p < 0.02$ for values (0.71−0.79), and $p < 0.01$ for values >0.83 (Corr, 2010). 'Average of average' is the average of the average correlation of the ranks of the individual teams, where as 'correlation' represents the correlation of the ranks without considering the teams.

(3) The evaluation method commonly used by designers − the Weighted Objectives Method − seems to be positively correlated to the measure of usefulness.
(4) A higher correlation between novelty and creativity for both the intuitive method and the proposed methods (as compared to that between usefulness and creativity) shows that novelty has a greater impact on creativity than usefulness.

It can be concluded from the evaluation that the outcome of the proposed methods matched well with the general perception of designers − or designers' intuitive method − for evaluating a product's novelty, usefulness, and creativity. Further, the feedback of the designers who evaluated the methods, indicate that the proposed method is easy to use.

10 Application of this method in design

To assess the usability of this method in product design, another design study was conducted in which two experienced designers (each with at least two years of experience in developing engineering products in industry) and two novice designers (having less than one year of experience in designing engineering products in industry) were asked to develop design solutions for a given problem. Each designer has a formal design degree at the post-graduate level. The problem given was to '*design a machine for a manufacturing company that can drill a hole inside a component and can change its direction (in 3D) and diameter while drilling is still in progress. In that manufacturing company 20 employees out of 200 employees are assumed to use this machine*.' The designers were asked to use blank sheets of paper to capture their ideas. All designers worked individually

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

in a laboratory setting and without any given time constraint. Designers were not provided or asked to follow any particular design method. The final outcome from each design process was a design selected by the designer, which was subsequently judged by an independent set of experienced designers.

The final solutions chosen by the four designers are explained below. All designers sketched their final solutions (see Figure 3).

Designer 1 (D1): The solution essentially consists of a small spherical robot and has a cutter head that can move in any direction. The robot is like a tank that can move using a crawler and it has two sets of legs that hold the robot in position while the drilling is carried out. The robot is remotely controlled using cables.
Designer 2 (D2): The component would be immersed in a special fluid and two individual lasers would be focused at one point to burn material from the component. The sources of these lasers are movable.
Designer 3 (D3): The solution consists of a small movable system (like a robot) which has a laser cutter attached to it. Gears are provided to enable change of angle of the laser cutter. The system can be moved inside a drilled hole.
Designer 4 (D4): The cutting system consists of a set of expandable cutting blades arranged in a circular fashion. The diameter of the cutter can be

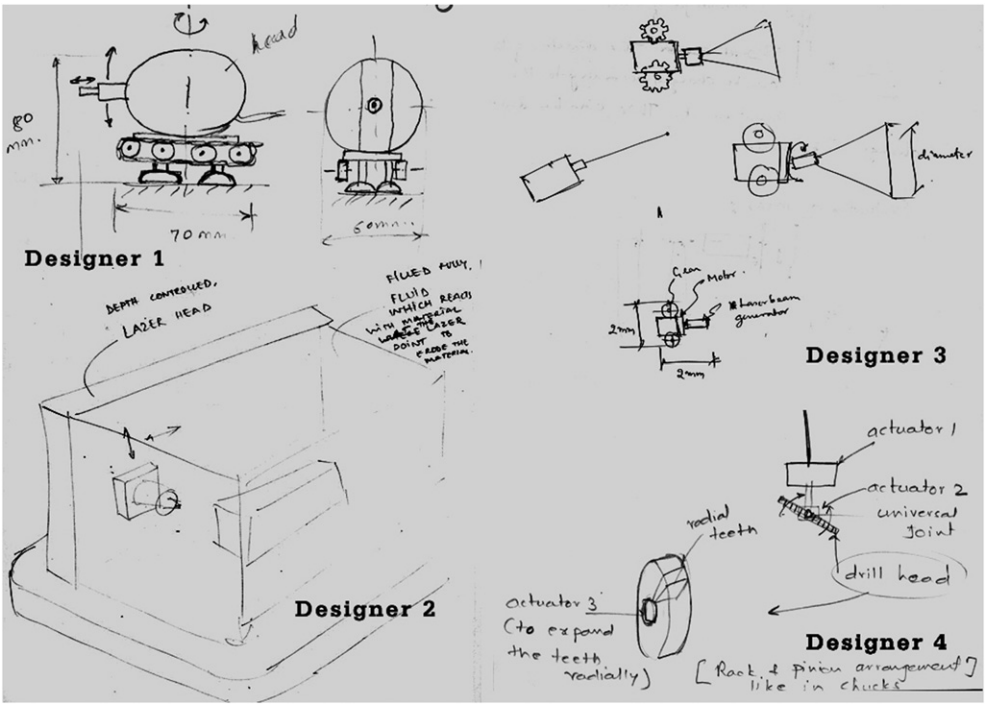

Figure 3 Final solutions from the four designers

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

increased by changing the angle of these blades. The system is controlled by three actuators. The drill head is joined with the main system using a universal joint to transfer motion in any direction.

Finding novelty: The function 'drilling' already existed in other products such as drilling machine, so none of the solutions is of 'very high novelty'. Next, the structures of all these solutions are different from existing drilling machines. Thus, all the solutions are at least of 'low novelty'. Next, Designers 2 and 3 have used laser for cutting, thus the solutions are different from that of a conventional drilling machine in terms of physical phenomena and physical effects. Again, the inputs (electrical) and the change of states (removing material even though using different processes) are the same for all the solutions and the conventional drilling machine, thus none of them are highly novel products; note that solutions such as systems which add material to generate profile, say rapid prototyping, using new physical phenomena would have made a solution highly novel. This makes the outcome of D1 and D4 as having 'low novelty' and that of D2 and D3 as having 'medium novelty'. However, D4 uses an extendable cutting system and uses different parts and organs, whereas D1 uses a conventional drill head; therefore, compared to D1, the outcome from D4 is more novel. Similarly, the outcome from D2 has a higher novelty than that of D3.

Evaluating usefulness: Using Table 2, a drilling machine falls into the category of medium importance (>1.0−2). Therefore, all solutions could be considered as having the same importance (say 1.2). Solutions 2 and 3 would take more time to use, since a laser takes more time to remove material compared to conventional cutting machines; thus the output of this machine is less than that of the other two. As a result, the rate of popularity of use of these machines should be less, and the evaluators assigned values accordingly (shown in Table 13). Creativity of the outcomes can now be assessed by taking into account the novelty and usefulness ranks of these products. As novelty ranks are D1: 4; D2: 1; D3: 2: D4: 3), and usefulness ranks are (D1: 4; D2: 2: D3: 2; D4: 4), their creativity ranks (using Equation (2) are (D1: 2; D2: 1; D3: 2: D4: 4).

11 Conclusions

According to the 'common definition of creativity' proposed by Sarkar and Chakrabarti (2008), creativity should be measured directly in terms of novelty

Table 13 Application of usefulness measures

Designers	*Importance of use*	*Rate of popularity of use (h/day)*	*Rate of use (no. of people) per 100*	*Product*	*Rank (1 high, 5 low)*
Designer 1	1.2	5	10	60	4
Designer 2	1.2	3	10	36	2
Designer 3	1.2	3	10	36	2
Designer 4	1.2	5	10	60	4

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

and usefulness of the outcomes. Assessing creativity therefore requires assessment of novelty and usefulness. New methods for assess novelty, usefulness, and creativity are proposed in this paper.

It is noted that product-characteristics can be employed to ascertain the relative degree of novelty of products. The FBS model has been used for determining novelty of products; SAPPhIRE model is used to assess the relative degree of novelty of these products. A method for assessing the usefulness of products is proposed that uses the importance of usage, popularity of usage, and rate of use as criteria for assessing overall usefulness. A method for assessing the degree of creativity of products that uses the values of degree of novelty and usefulness is then proposed.

The proposed methods and other existing methods are evaluated by comparing their performance in assessing novelty, usefulness, and creativity with that of existing novelty and usefulness measuring methods. The collective, intuitive notion of novelty, held by experienced designers is used as the benchmark for comparison. The results indicate that the proposed methods reflect the experienced designers' collective, intuitive notion of product novelty, usefulness, and creativity better than the existing methods compared.

Acknowledgements

We acknowledge the help of the twenty-eight designers who have helped us to evaluate the proposed methods.

Appendix 1. Survey (Internet based survey form)

Survey name: Creativity survey (survey faculty provided by FreeOnline Surveys.com was used to conduct this survey.)

This survey is to know designers' notions of novelty, usefulness and creativity of various sets of products. Please read the following three definitions from literature.

Definitions

Creativity: Creativity occurs through a process by which an agent uses its ability to generate ideas, products or solutions that are novel and useful. Measures of creativity: 'Novelty' and 'Usefulness' are the two direct measures of creativity.

Novelty: 'New' is something that has been recently created. 'Novel' products are those that are new to the entire human race. 'Novelty' encompasses both new and original. Novelty is 'not resembling something formerly known'. Novelty may also be defined with reference, either to the previous ideas of the individual concerned, or to the whole of human history. The former definition

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

concerns P-creativity (P for Psychological), the latter H-creativity (H for Historical).

Usefulness: The basic understanding of usefulness can be developed from some dictionary definitions: 'Able to be used for a practical purpose or in several ways', or, 'having a beneficial use' or 'being of practical use'. So, novel outcomes with one or more applications are a reflection of the creativity of the agent who created the outcomes.

Finding criteria/attributes for evaluating products and for assessing relative novelty of the given three sets of products. Please use the above mentioned definitions for attributes finding. Now please find attributes and give relative rating.

Assume that a problem is given (like design a gun, design a writing equipment etc.) and assume that the given sets of products are the possible outcome from a set of designers. You can also assume that following sets of products are organized according to the chronological order in which they had been invented. Taking all the products together on what basis will you evaluate them in general and on what basis you will compare their novelty?

Evaluating attributes

What criteria will you use to evaluate them in general? – make a list of attributes and give relative weightage, between 0 and 1. Assume that for a given problem these sets of products (set 1, set 2, and set 3) are the solutions. Find the attributes that you would use to judge the given set of products.

Novelty attributes

What criteria will you use to judge their relative novelty? – make a list of attributes and give relative weightage between 0 and 1.

Example: A gun, a pistol, a machine gun. Evaluating attributes: No. of bullets per unit time (0.7), Price (0.3) Novelty attributes: No. of bullets/time (0.4), Distance it can travel (0.4), Weight (0.2)

Put any number of attributes, with min. as 1. Please put the weightage corresponding to the attributes you regard as important. Note: Some attributes may be common for evaluating and identifying novelty. Please put weightage between 0 and 1. The sum of all the evaluating criteria/attributes should be equal to 1. The sum of all the novelty criteria/attributes is 1.

1) Product set 1: A pencil, ink pen, ball point pen, marker

Evaluating attributes (attributes for general evaluation and selection): Note: Select among these or mention in 'other' and then put weightage in the box, e.g., 0.7, 0.4 etc. Leave blank for attributes not selected.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

You can select from the following: 1. No. of surfaces it can write on (weightage) 2. Smoothness of writing (weightage) 3. Maintenance required (weightage) 4. Ease of writing (weightage) 5. Ease of erasing (weightage) 6. Writing medium used (weightage) 7. Any other (weightage).

Example: No. of surfaces it can write on (0.3), Ease of writing (0.5), reliability (0.2)

Your response:

2) Product set 1: A pencil, ink pen, ball point pen, marker

Novelty attributes (attributes for judging the novelty of the given sets of products): Note: select among these or mention in 'other' and then put weightage in the box, e.g., 0.7, 0.4 etc. Leave blank for not selected attributes.

You can select from the following: 1. No. of surfaces it can write (weightage) 2. Smoothness (weightage) 3. Maintenance required (weightage) 4. Ease of writing (weightage) 5. Ease of erasing (weightage) 6. Writing medium used (weightage) 7. Any other (weightage).

Your response:

3) Product set 2: A postal Letter, a telephone, a pager, an ordinary mobile, a video mobile

Evaluating attributes: You can select from the following: 1. Time taken (weightage) 2. No. of features (weightage) 3. Ease of use (weightage) 4. Cost(weightage) 5. Medium used (weightage) 6. Portability (weightage) 7. Any other (weightage)

Your response:

4) Product set 2: A postal Letter, a telephone, a pager, an ordinary mobile, a video mobile

Novelty attributes: You can select from the following: 1. Time taken (weightage) 2. No. of features (weightage) 3. Ease of use (weightage) 4.Cost(weightage) 5. Medium used (weightage) 6. Portability (weightage) 7. Any other (weightage).

Your response:

5) Product set 3: A hand held fan, electric fan, air conditioner

Evaluating attributes: You can select from the following: 1. Comfort (weightage) 2. Type of power used (weightage) 3. Maintenance required (weightage) 4.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Amount of effort required (weightage) 5. Portability (weightage) 6. Cost (weightage) 7. Any other (weightage).

Your response:

6) Product set 3: A hand held fan, electric fan, air conditioner

Novelty attributes: You can select from the following: 1. Comfort (weightage) 2. Type of power used (weightage) 3. Maintenance required (weightage) 4. Amount of effort required (weightage) 5. Portability (weightage) 6. Cost (weightage) 7. Any other (weightage).

Your response:

Rank these 3 sets of products in terms of novelty, usefulness and creativity. You can use any technique that you know or else use your intuition.

7) Rank product set 1 in terms of their RELATIVE NOVELTY.
1. A pencil 2. An ink pen 3. A ball point pen 4. A marker

8) Rank product set 1 in terms of their RELATIVE USEFULNESS.
1. A pencil 2. An ink pen 3. A ball point pen 4. A marker

9) Rank product set 1 in terms of their RELATIVE CREATIVITY.
1. A pencil 2. An ink pen 3. A ball point pen 4. A marker

10) Rank product set 2 in terms of their RELATIVE NOVELTY.
1. A postal Letter 2. a telephone 3. a pager 4. a mobile 5. a video mobile

11) Rank product set 2 in terms of their RELATIVE USEFULNESS.
1. A postal Letter 2. a telephone 3. a pager 4. a mobile 5. a video mobile

12) Rank product set 2 in terms of their RELATIVE CREATIVITY.
1. A postal Letter 2. a telephone 3. a pager 4. a mobile 5. a video mobile

13) Rank product set 3 in terms of their RELATIVE NOVELTY.
1. A hand held fan 2. A electric fan 3. An air conditioner

14) Rank product set 3 in terms of their RELATIVE USEFULNESS.
1. A hand held fan 2. A electric fan 3. An air conditioner

15) Rank product set 3 in terms of their RELATIVE CREATIVITY.
1. A hand held fan 2. A electric fan 3. An air conditioner

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Personal information

16) Your name, No. of years of designing experience (Product/industrial/ engineering etc.), Email address, Company you have been working for (optional).

References

Amabile, T. M. (1983). *The social psychology of creativity*. New York: Springer-Verlag.

Amabile, T. M. (1996). *Creativity in context*. Boulder, Colorado: Westview Press.

Boden, M. A. (1999). Computer models of creativity in Robert. In J. Sternberg (Ed.), *Handbook of creativity*. Cambridge University Press.

Cambridge. (2010). Cambridge dictionary. URL: http://dictionary.cambridge.org/.

Chakrabarti, A., & Bligh, T. P. (1994). Functional synthesis of solution-concepts in mechanical conceptual design. Part I: knowledge Representation. *Research in Engineering Design, 6*(No. 3), 127–141.

Chakrabarti, A., & Bligh, T. P. (1996a). Functional synthesis of solution-concepts in mechanical conceptual design. Part II: kind synthesis. *Research in Engineering Design, 8*(1), 52–62.

Chakrabarti, A., & Bligh, T. P. (1996b). Functional synthesis of solution-concepts in mechanical conceptual design. Part III: spatial configuration. *Research in Engineering Design, 8*(No. 2), 116–124.

Chakrabarti, A. (2001). Improving efficiency of procedures for compositional synthesis using bi-directional search. *AI EDAM, 15*(1), 67–80.

Chakrabarti, A. (2004). A new approach to structure sharing. *ASME JCISE, 1*(1), 1–78, 2004.

Chakrabarti, A., Morgenstern, S., & Knaab, H. (2004). Identification and application of requirements and their impact on the design process: a protocol study. *Research in Engineering Design, 15*, 22–39.

Chakrabarti, A., Khadilkar, P. (2003) A measure for assessing product novelty, *Proceedings of the International conference on Engineering Design, 2003, Stockholm*, 2003.

Chakrabarti, A., Sarkar, P., & Leelavathamma, Nataraju, B. (2005). A functional representation for aiding biomimetic and artificial inspiration of new ideas. *Artificial Intelligence in Engineering Design, Analysis and Manufacturing, 19*, 113–132.

Chandrasekaran, B. (1994). *Functional representation and causal processes, advances in computers, Vol. 38*. Academic Press. 73–143.

Corr. (2010). Critical values of the correlation coefficient. URL: http://www.microbiologybytes.com/maths/rtable.html.

Deng, Y. (2002). Function and behavior representation in conceptual mechanical design. *Artificial Intelligence in Engineering Design, Analysis and Manufacturing, 16*, 343–362, 1994.

Eder, W. E. (1995) Introduction, In. *The proceedings of the International Workshop: Engineering design and creativity, Pilsen, Czech Republic*.

Eisentraunt, R., & Badke Schaub, P. (1995). Creativity: a personality trait or an Illusion?. In *International workshop: Engineering design and creativity* Pilsen, Czech Republic: State Scientific Library.

Gero, J. S. (1993). Towards a model of exploration in design. In J. S. Gero, & F. Sudweeks (Eds.), *Preprints formal design methods for CAD, key centre of design computing* (pp. 271–292). Sydney, IFIP: University of Sydney.

Goel, K. A. (1997). Design, analogy and creativity. *IEEE Expert, 12*, 62–70.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Hubka, V., & Eder, W. E. (1996). *Design science: Introduction to the need, scope and organization of engineering design knowledge*. London: Springer Verlag.

Inventors. (2010). URL. http://inventors.about.com/od/ofamousinventions/a/oven.htm.

Liu, Y. C., Chakrabarti, A., & Bligh, T. P. (2000). Further developments of FuncSION. In J. S. Gero (Ed.), *Artificial intelligence in design'00* (pp. 499–519). Kluwer Academic Publishers.

Lopez-Mesa, B. and Vidal, R. (2006) Novelty metrics in engineering design experiments, In. *Proceedings of the International Design Conference – Design 2006, Dubronik – Croatia, May 15–18*.

Maslow. (2010). URL. http://www.abraham-maslow.com/m_motivation/Hierarchy_of_Needs.asp.

Mazur, G. (1996). Triz. http://www.mazur.net/triz/ URL.

Molina, A., Al-Ashaab, H. A., Timothy, E. I. A., Young, I. M. R., & Bell, R. (1995)*A review of computer aided simultaneous engineering systems, research in engineering design, Vol 7*. Springer-Verlag. 38–63.

Mumford, R. P., & Gardner, R. (1994). In Robert J. Sternberg (Ed.), *Handbook of creativity*. Cambridge: Cambridge University Press.

Ottosson, S. (1995) Boosting creativity in technical development, In. *The proceedings of the International Workshop: Engineering design and creativity, 16–18 November, 1995, Pilsen, Czech Republic*.

Oxford. (2010). Oxford dictionary. http://www.askoxford.com URL.

Patents. (2010). URL. http://www.freepatentsonline.com/help/item/When-and-how-is-a-patent-granted.html.

Qian, L., & Gero, J. (1996). Function-behavior-structure paths and their role in analogy based design, artificial intelligence for engineering design. *Analysis and Manufacturing, 10*(No. 4).

Redelinghuys, C. (2000). Proposed criteria for the detection of invention in engineering design. *Journal of Engineering Design, 11*(No. 3), 265–282.

Roozenburg, N. F. M., & Eekels, J. (1995). *Product design: Fundamentals and methods*. Willey.

Sarkar, P., & Chakrabarti, A. (2008). Studying engineering design creativity – developing a common definition and associated measures. In J. Gero (Ed.), *Studying design creativity*. Springer Verlag.

Saunders, R. (2002) *Curious design agents and artificial creativity a synthetic approach to the study of creative behavior*, Ph.D. thesis, Department of Architectural and Design Science, Faculty of Architecture, University of Sydney.

Shah, J., & Vargas-Hernandez, N. (2003). Metrics for measuring ideation effectiveness. *Design Studies, 24*, 111–143.

Spearman. (2010). URL: http://geographyfieldwork.com/SpearmansRank.htm.

Srinivasan, V., & Chakrabarti, A. (2009). SAPPhIRE – An approach to analysis and synthesis, 17th International Conference on Engineering Design (ICED09), Stanford, USA, 23–27 August, 2009.

Srinivasan, V., & Chakrabarti, A. (2010). Investigating novelty-outcome relationships in engineering design. *AI EDAM, 24*, 161–178.

Sternberg, R. J., & Lubart, T. I. (1999). The concept of creativity: prospects and paradigms. In Robert J. Sternberg (Ed.), *Handbook of creativity*. Cambridge: Cambridge University Press.

Sundstorm, P. and Zika-viktorsson, A. (2003) Innovation through explorative thinking in product development, In. *Proceedings of International Conference on Engineering Design, ICED, '03, Stockholm, August 19–21*.

Terninko, J., Zusman, A., & Zlotin, B. (2000). *Systematic innovation, an introduction to TRIZ (theory of inventive problem solving)*. St. Lucie Press.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002

Torrance. (2010). URL: http://www.uwsp.edu/education/lwilson/creativ/define.htm.

Umeda, Y., Ishii, M., Yoshioka, M., & Tomiyama, T. (1996). Supporting conceptual design based on the function behavior state modeler. *Artificial Intelligence in Engineering Design, Analysis and Manufacturing, 10*(No. 4).

Weighted. (2010). URL: http://www.wikid.eu/index.php/Weighted_objectives_method.

Weisberg, R. W. (1993). *From creativity − Beyond the myth of genius*. W H Freeman and Co.

Westwood, Albert R. C., & Sekine, Y. (1988). Fostering creativity and innovation in an industrial R&D laboratory. *Research-Technology Management, 31* (No 4), 16−20.

Please cite this article in press as: Sarkar, P., & Chakrabarti, A., Assessing design creativity, Design Studies (2011), doi:10.1016/j.destud.2011.01.002