DEVELOPMENT OF A METHOD FOR ASSESSING DESIGN CREATIVITY

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ABSTRACT

Creativity is regarded as a core ingredient of innovation as it enhances the possibility of generating superior products. The core components of creativity are 'novelty' and 'usefulness' and a direct measure of creativity should be in terms of measuring these components. This paper proposes a method for assessing creativity of technical products. Empirical studies have been conducted to validate this method.

First this paper reviews existing methods for measuring 'novelty' of technical products, proposes a new method for measuring novelty, and evaluates the proposed method and the existing measures by benchmarking them against the intuitive notion of creativity of experienced designers. Next, it reviews existing literature on 'usefulness', proposes a method for assessing usefulness of technical products, and evaluates this by comparing its outcome with the outcome of the existing methods taking the evaluation by experienced designers as reference. Later, 'creativity' measures for these products are calculated using the values of the novelty and usefulness of the products and benchmarked against the outcomes of intuitive evaluation of creativity of these products by experienced designers.

Keywords: Novelty, usefulness, creativity, creativity measures

1   INTRODUCTION

Creativity is the core ingredient of engineering design and innovation, and it enhances the possibility of generating superior products. The importance of creativity in product development and on market success has been stressed by many researchers [1, 2]. Products are designed to satisfy needs of the society. These products are variously creative. Assessing creativity is important for the following reasons:

(1) To identify good products from the chafe.
(2) To assess and compare the amount of innovation.
(3) To identify better inventors or designers.

So, a method that can assess creativeness of products is required.

1.1   Requirement for a common definition of creativity

In earlier work [3], we developed a common definition of creativity by analyzing a comprehensive list of definitions of creativity proposed by researchers. The common definition that we have proposed is taken as the basis of work of this paper. The definition proposed is: *'Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and useful.'*

Similar views of creativity have been expressed by other researchers such as Sternberg and Lubart [4] who defined creativity as that which 'produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints)', or Weisberg [5] who defined creativity as 'novel and valuable products, capacity to produce such works and the activity of generating such products'. So, in order to be able to assess creativity of designers, or creativeness of newly designed products, one must be able to assess the 'novelty' and 'usefulness' of these products.

In this paper, we propose a new measure for both novelty and usefulness, and evaluate these measures by benchmarking them against the intuitive notion about these of experienced designers, as well as comparing them against other currently available measures of these elements. We argue, like Amabile [6] who suggested the use of experts to identify what is 'creative', that ultimately for any measure of novelty, usefulness or creativity to be meaningful and usable, the results should match the notion held by experienced designers (experts). Current scope on the work has been limited to technical products.

1.2 Research objectives
The objectives of this research are to:

(1) Develop a method for assessing novelty of products.
(2) Develop a method for assessing usefulness of products.
(3) Develop a method for assessing creativity of products.
(4) Evaluate and benchmark these proposed methods and other available methods against the intuitive notion of experienced designers.

2 NOVELTY
'New' is something that has been recently created [7]. 'Novel' products are those that are new to the entire human race. Novelty' encompasses both new and original [7]. Novelty is 'not resembling something formerly known' [4]. Novelty may also be defined with reference, either to the previous ideas of the individual concerned (P-creativity, P for Psychological), or to the whole of human history (H-creativity, H for Historical) [8].

For detection of novelty, the characteristics of a new product should be compared with that of old products which fulfil the same need; differences among these characteristics should indicate how novel the new product is. So, to assess novelty of a product, one should know both the time line of similar inventions (i.e., the sequence of invention of products belonging to the same category in terms of the domain and functionality) and the characteristics of similar products.

2.1 Existing methods for assessing product novelty
Patent offices of many countries employ experts to determine the 'novelty', 'usefulness' and other aspects of patent applications, but they are mainly interested in identifying whether the patent is novel and useful or not, and not in the degree of novelty of these products. A few approaches to measuring novelty are available in literature [9-12]. The proposed work is distinct from existing research in these:
(1) With the proposed method, novelty as well as its degree for a product is possible to assess.
(2) It is based upon a detailed FBS model [13], providing foundation for a detailed scale for assessing the degree of novelty of a product, solution or idea.

2.2 Development of a methodology to assess the novelty of a newly generated product
Comparison of products is carried out by comparison of their features or characteristics. Therefore, any methodology which can decompose a product into its characteristic components of features should be potentially suitable for comparing products. A widely used model in this regard is the Function-Behaviour-Structure (FBS) model. Many researchers [14-16] have extensively worked on FBS models, thus illustrating its value for classifying characteristics of products.

Since novel products are those that are new (recently generated) and original (appearing for the first time in human history), it could be argued that if the functions of a new product are different from those of other available products, then the new product must be novel, and it should have the highest degree of novelty. We ascribe the qualitative degree of novelty associated as 'very high novelty' - the need it fulfils was not fulfilled by any other product at the time of its introduction, such as the case for X-ray machines or Pin-hole camera. In contrast, if the structure of a new product matches completely with that of any existing product, the new product cannot be novel.

To assess the relative degree of novelty of products, a more detailed model for describing the FBS of products is necessary. In a recent study, the product characteristics in an FBS model have been

subdivided into seven elementary constructs, see Fig.1 for details [13]. We use this model to assess the relative degree of novelty of products. These seven constructs and links are taken together to form a model of causality acronymed as SAPPhIRE model, SAPPhIRE standing for *State-Action-Part-Phenomenon-Input-oRgan-E*ffect, see Fig. 1.
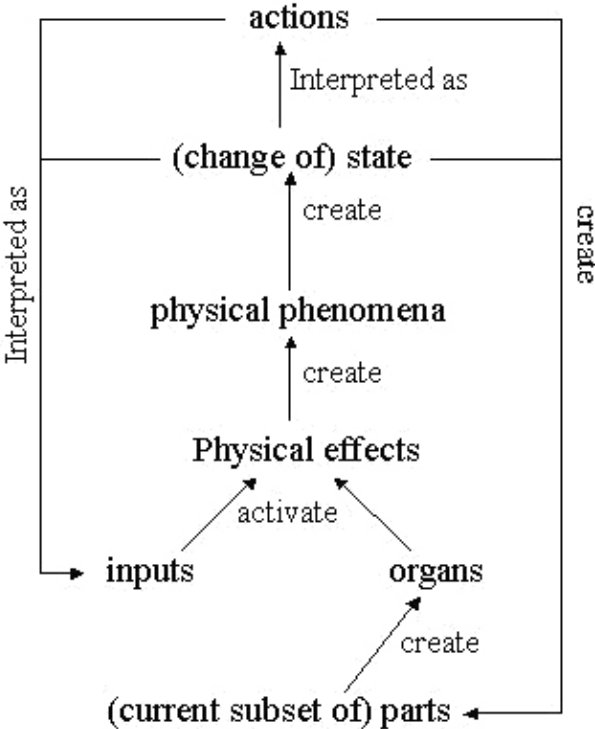

Fig. 1. SAPPhIRE Model

The relationships between these constructs are as follows: parts and interfaces (called parts here) are necessary for creating organs. Organs and inputs are necessary for activation of 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 these in turn create or activate parts. Essentially, there are three relationships: activation, creation and interpretation.

In the context of detection of relative degree of novelty in products that are not 'very highly novel', physical phenomena and physical effect constitute the highest level at which a product can be different from other products. We argue, therefore, that products that are different at the physical effect or phenomena level will be more novel than those that are different only at the organ or part level. Hence, for instance, if two products are based on the same physical effect and do the same action but the more recent one is only a structural improvement of the previous, this product should be taken as a product of 'low novelty'.

Using the above arguments, a method for novelty detection has been developed, see Fig. 2. In the first part of decision making using this method, FBS model has been used to identify whether or not a product is very highly novel. Next, SAPPhIRE model has been employed to assess the relative degree of novelty of other products.

If a product has many functions, then each of these functions should be compared with that of the corresponding similar functions of existing products. Besides products, novelty of solutions and ideas could also be assessed using this method, given that the ideas or solutions are sufficiently matured for their FBS or SAPPhIRE constructs 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 many products fall in the same degree of novelty category (low, high etc.), then the products that have a

larger number of difference at a higher level of the SAPPhIRE hierarchy is proposed to be considered more novel.
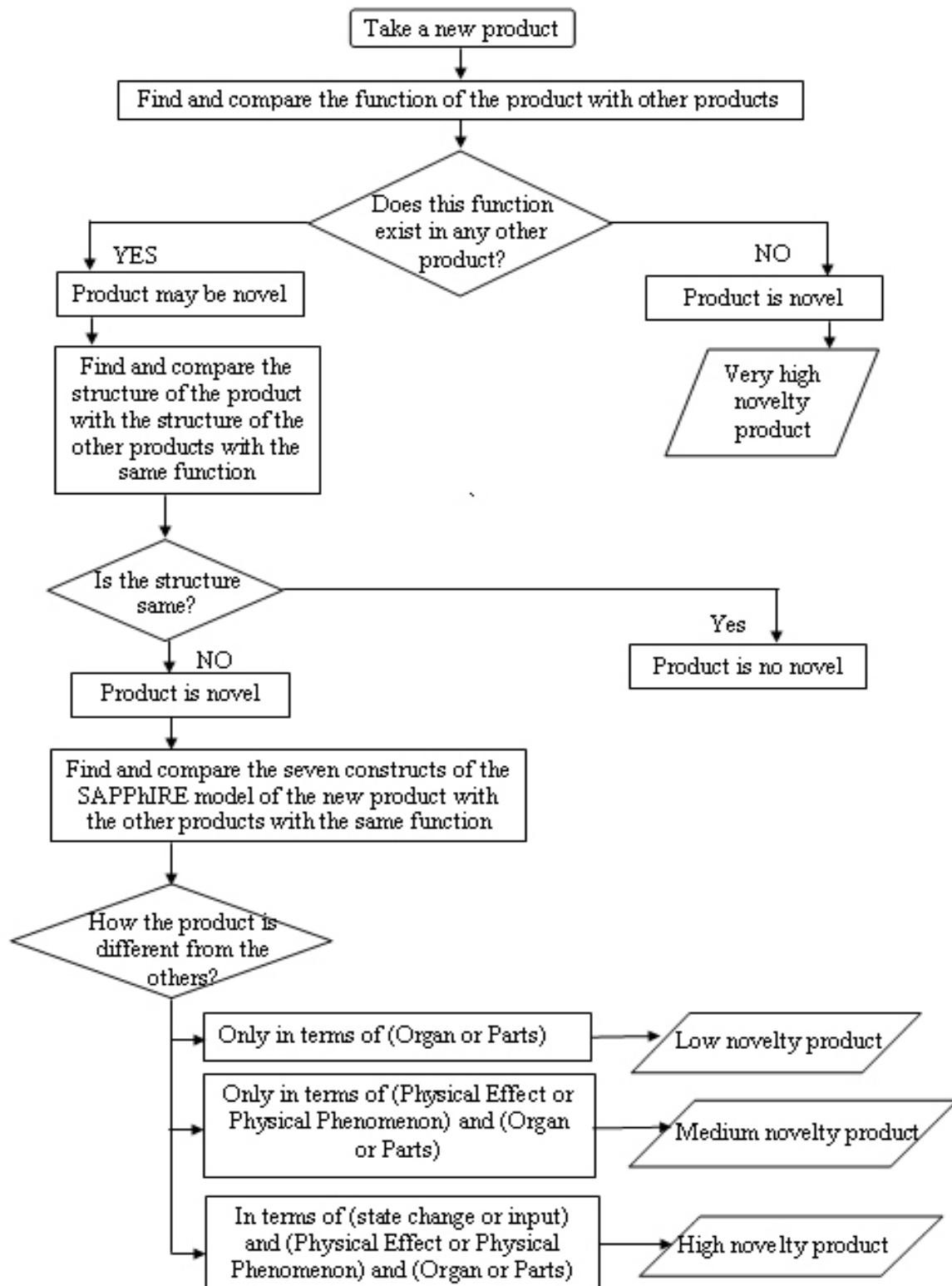
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                         ┌─────────────────────┐
                         │  Take a new product │
                         └─────────────────────┘
                                    │
          ┌─────────────────────────────────────────────────┐
          │ Find and compare the function of the product with other products │
          └─────────────────────────────────────────────────┘
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                              ╱─────────────╲
                             ╱ Does this function ╲
        YES                 ╱  exist in any other   ╲        NO
         │                  ╲     product?         ╱          │
 ┌──────────────────┐        ╲─────────────────╱      ┌──────────────────┐
 │ Product may be novel │                              │  Product is novel │
 └──────────────────┘                                 └──────────────────┘
         │                                                      │
 ┌──────────────────┐                                  ┌──────────────────┐
 │  Find and compare the │                              │    Very high      │
 │  structure of the product │                          │     novelty       │
 │  with the structure of the │                         │     product       │
 │  other products with the │                           └──────────────────┘
 │    same function      │
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  ╱ Is the structure ╲───────────────────────────────┐
  ╲    same?        ╱                                 │
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 │ Find and compare the seven constructs of the │
 │ SAPPhIRE model of the new product with │
 │ the other products with the same function │
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  ╲ different from the  ╱
   ╲   others?       ╱
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         ├──► ┌──────────────────────────┐      ┌──────────────────┐
         │    │ Only in terms of (Organ or Parts) │──► │ Low novelty product │
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         ├──► ┌──────────────────────────┐      ┌──────────────────┐
         │    │ Only in terms of (Physical Effect or │──► │ Medium novelty product │
         │    │ Physical Phenomenon) and (Organ │      └──────────────────┘
         │    │         or Parts)        │
         │    └──────────────────────────┘
         │
         └──► ┌──────────────────────────┐      ┌──────────────────┐
              │ In terms of (state change or input) │──► │ High novelty product │
              │ and (Physical Effect or Physical │      └──────────────────┘
              │ Phenomenon) and (Organ or Parts) │
              └──────────────────────────┘
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Fig. 2. Steps of the proposed method for assessing novelty

2.3 Examples

Very high novelty products: The first safety lamp used in underground mines, the first sewing machines, dynamites etc. fall into this category. When introduced, these products have very high novelty because no product existed which performed the same task or function at that time.

High novelty products: At the time when microwave cooker was invented, there were electric cookers, gas cookers and kerosene fuel stoves. The time line of invention is first kerosene stove, next appeared gas cookers, then electric cookers are invented and later micro oven came into existence. An electric cooker is more similar to the microwave cooker compared to the other two above, since both these products run also on electricity. These are compared in Table 1, using their FBS and the SAPPhIRE models.

Table 1. Comparison of electric cooker and microwave oven

For electric cooker:

FBS	SAPPhIRE
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:

FBS	SAPPhIRE
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.

Following the above method of novelty detection, we see that compared to an electric heater, a microwave oven is highly novel since it differs from existing products in terms of organ, parts, input, physical effects, physical phenomena and change of state. The other comparisons, of micro wave oven with gas cookers and kerosene fuel stoves are not shown, but since they are even more different from micro wave oven than electric cookers, such comparison would also have shown micro wave oven to be highly novel compared to them.

3   USEFULNESS

A product may be perceived as useful, and yet this impression could be validated only if this is supported by results from its actual use. We argue that it is the actual use of a product that validates its usefulness. Therefore, usefulness of a product should be measured by its actual use.

A designer with a high degree of flexibility in thinking may identify many uses of a product. Thus the product's potential usefulness is increased. But, this would not automatically make the product more useful. Usefulness of a product would be determined based on the 'actual use' of the product.

3.1   Usefulness and its measures from literature

Sternberg and Lubart [4] define usefulness in terms of appropriateness. Mumford and Gardner [17] define utility in terms of usefulness, appropriateness and social value. Thus, 'useful' things are socially valuable.

Creativity can be measured in terms of novelty and usefulness [3]. Even though there can be many novel ideas, solutions or products that are socially new, unless these outcomes are useful to the society, they are not creative. So, novel outcomes with applications are creative.

Patent offices employ experts to determine both novelty, and usefulness to ascertain validity patentability of applications. Our review of literature in the area of design did not yield any direct measure for usefulness. Even though a number of researchers defined usefulness [17, 4], no method for measuring usefulness was suggested. We argue that methods for evaluation of designs or products [1] are the closest available to what could be used for assessing usefulness of products. Shah and Vargas-Hernandez [9] proposed to measure 'quality' of products using a variant of the 'weighted objective method'. So, we take the 'Weighted Objective Ranking method' as a representative evaluation method for this purpose, and evaluate the method we proposed in this paper by comparing with this method, using the intuitive notion of usefulness of experienced designers as benchmark.

3.2 Development of a method for measuring usefulness of products

The proposed method for measuring usefulness of a product is based on the argument that usefulness should be measured in terms of its *use*. The basic terminology used in the method are explained below.

3.2.1 Importance of use or level of importance

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

Table 2. Level of importance of different products

Code	Points in a scale of 5	Relative range	Level of importance	Type of importance	Examples
A	5	4.1-5	Extremely important	life saving drugs, life supporting systems	oxygen cylinder, pace makers, inhalers
B	4	3.1-4	Very highly important	compulsory daily activities	taking food, using restroom
C	3	2.1-3	Highly important	shelter, social interaction	Pen, belt, clothes, housing, spectacles, shoes
D	2	1.1-2	Medium im-portant	machines for daily needs	cleaning machine, vac-uum cleaner, water purifier, water pump, water heaters
E	1	0-1	Low importance	Entertainment systems, recreation systems	computer games, bowl-ing, go carting

3.2.2 Rate of popularity of usage

All other parameters being the same, the products that are used by a larger number of people should be more useful to the society. So, as the number of people using a product increases, the usefulness of such products should also increase. We propose that rate of popularity should be assessed by the number of people using a product within a given period of time.

3.2.3 Rate of use

Products that are used for a longer duration of time, compared to those that are used less frequently, should be more useful to the society, assuming that the 'level of importance' and the 'rate of popularity' of both of these sets of products are same. Therefore, rate of use is used as the product of the frequency of usage and the duration of its use, in a given unit of time. In case the rate of use cannot be decided or is irrelevant, duration of *benefit obtained* and benefit of use per usage can be used.

Survey in a given community may be required to be carried out in order to identify the values for these parameters for subsequent assessment of usefulness of a product in that community. Alternatively, when designing a new product, a designer could use values of these parameters which may be extrapolated from other, similar products available, and predict the usefulness of the new product.

Taking the above three parameters into account we can construct the following equation for assessing usefulness of a product.

$$U = I\,(T\,L)\,N \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \ldots\ldots (1)$$

Where, I stands for Level of importance, T stands for Frequency of usage, L stands for Length of usage and N stands of Rate of popularity of use. Note: The unit time for all the above terms that is for N, T and L should be same i.e. day, month or year.

In order to use this equation, the following steps are proposed to be used:
(1) Take a product.
(2) Find how many people use it. This gives its rate of popularity of use (N).
(3) Find how many times they are using it. This will determine its frequency of usage (T).
(4) Find how long they use it. This would give its length of usage (L). Rate of usage is calculated as T x L. In the absence of (relevance of) value for T and L take 'benefit obtained' for using the product.
(5) Determine how important it is to use it for then. This would give its level of importance (I).
(6) Find the overall usefulness using the formula in equation *(1)*.

The unit of time in the terms used in the equation *(1)* should be selected carefully. For those products whose usage changes over a period of time, say over a month, it is better to take a large unit (like a year) to calculate the usefulness. For instance, the usage of a fan fluctuates over seasons (so, year may be the preferred unit), while usage of tooth brushes practically does not change over days (so day could be chosen as the preferred unit). So, in order to find the frequency of use, the rate of use and popularity of use, should have the same unit for the time. Usefulness of ideas and solutions can also be determined by using this method.

3.4   Examples

Let us take the example case of determine the usefulness of a leather shoe (A) and a leather slipper (B). Let us assume that 210 and 332 people respectively are using these products per day, in a community of 1000 people. Also, let the average usage of leather shoe is 5 hours per day and that of the leather slipper is 9 hours per day.

Both these products fall under the category of 'highly important products' in the 'C' category with 3/5 value (Table 2). Now from experience, one could assume that shoe has a higher usefulness than that of slippers, because shoes protect the legs better (also, for some kind of sports, wearing shoe is mandatory). So, let us increase the level of importance of shoe to 3.4/5 and keep that of the slippers at 3/5 (note that this judgment may be subjective).

For leather shoe: Importance of use: 3.4/5
Rate of popularity or use: 210/1000 (ratio of no. of people who use the product/ total number of people)
Rate of use: 5/24 (ratio of no. of hours of use/ total hours in a day)
Usefulness = (3.4/5)*(210/1000)*(5/24) = 0.02975.

For leather slipper: Importance of use: 3.0/5, Rate of popularity or use: 332/1000, Rate of use: 9/24, Usefulness = (3.0/5)*(332/1000)*(9/24) = 0.0747.

We can also find their relative usefulness, usefulness of leather shoe: usefulness of leather slipper = 1: 2.54. Thus for the given conditions the leather slipper is more useful to the specified community.

4   ASSESSING RELATIVE PRODUCT CREATIVITY

Since 'novelty' and 'usefulness' of products are the only direct influences of creativity (established in the common definition), creativity should be possible to be expressed as a function of these two parameters. We propose that the relationship be a product of the two parameters, in order to reflect our belief that novelty and usefulness reinforce the perceived creativity in an outcome, and absence of either would render creativity to be zero:

Creativity (C) = Novelty (N) X Usefulness (U)   … (2)

The following steps are followed while assessing the relative degree of creativity of a set of products:

Step 1: Determine novelty of all the Products that are required to be assessed for their relative degree of creativity.

Step 2: Convert the novelty value into a quality as shown: The degree of novelty can be converted into a quantitative value, for instance, 'Very high degree of novelty' can be taken as 4, Very high novelty = 4 point, High novelty = 3 point, Medium novelty = 2 point and Low novelty = 1 point.

Step 2: Give relative grading. For example, if there are three products that are compared then allocate 1/3, 2/3, 3/3 points.

Step 3: Find out the usefulness of each product as described in the previous section.

Step 4: Convert the usefulness value into relative grading Give relative grading: if there are three products that you are comparing then give them 1/4, 2/4, 3/4 points.

Step 5: Calculate creativity of a product = degree of novelty of that product X usefulness.

5   EVALUATION

The aim of this evaluation is to assess how closely the values of novelty, usefulness and creativity assesed using the proposed methods match with those assessed by the experienced designers using their own, intuitive methods. This evaluation also aims at assessing the relative efficacy of these proposed methods in comparison with other existing methods.

The following methods are used in the comparative study of novelty : (i) Shah and Varghas-Hernandez's [9] method (ii) Chakrabarti and Khadilkar's [10] method and (iii) the method proposed in this paper. These are compared with the intuitive evaluation by experienced designers.

The following methods are used in the comparative study of usefulness: (i) Evaluation of the products using 'weighted objective method' (ii) the proposed methods. These are compared with the intuitive evaluation by experienced designers.

The following methods are used in the comparative study of creativity: (i) The proposed method and the (ii) intuitive evaluation by experienced designers.

Three sets of products are selected for analysis. Each product in the same set of products does a similar function. Relatively simple products are selected, so that the designers are better aware of the internal working mechanisms of each product. The selected products are:
Product set 1: A pencil, an ink pen, a ball point pen, a marker
Product set 2: A postal Letter, a telephone, a pager, a mobile, a video mobile

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

Next, the various inputs as required for using all these methods are analyzed like Shah and Varghas-Hernandez's [9] method requires novelty attributes with relative weightage. Next, an Internet enabled survey form, developed by the authors is used (http://FreeOnlineSurveys.com) to get inputs from various experienced designers to understand their intuitive notion, by inviting them to rank specified products for their novelty, usefulness and creativity and give weightages to various attributes of these products (for these to be used in other existing methods evaluated).

We received 16 responses from designers, who have an average of 4 years of design experience in industry. The average value of each response is then calculated.

The results from the survey are: ranking of products in terms of their novelty, novelty attributes with their corresponding weightages, rankings of products in terms of their usefulness , evaluating criteria with their corresponding weightages to be used in the 'Weighted Objective method' as perceived intuitively by the expert designers and rankings of products in terms of their creativity.

Next, remaining steps in all the methods, for detection of novelty, usefulness and creativity, are completed by two teams of experienced designers, comprising of two designers in each team, working in a laboratory setting.

Spearmen's rank correlation has been used to correlate the data. Table 3 shows correlations among different methods for novelty detection.

Table 3. Correlation

Methods	Correlation
For product set 1	
Experienced- Shah and Varghas-Hernandez's method	-0.8
Experienced-Chakrabarti and Khadilkar's method	0.316228
Experienced- Proposed method	0.8
For product set 2	
Experienced- Shah and Varghas-Hernandez's method	-0.666886
Experienced-Chakrabarti and Khadilkar's method	-0.820783
Experienced- Proposed method	1
For product set 3	
Experienced- Shah and Varghas-Hernandez's method	-0.5
Experienced-Chakrabarti and Khadilkar's method	1
Experienced- Proposed method	1
Average correlation	
Experienced- Shah and Varghas-Hernandez's method	-0.65563
Experienced- Chakrabarti and Khadilkar's method	0.16514
Experienced- Proposed method	0.9333

From the above table we see that the proposed method correlate highly with that of the designers' intuitive method as compared to other methods. This indicates that the proposed method for assessing novelty reflect better the experienced designers' intuitive notion of novelty.

Table 4 shows inter-method correlation for the ranks obtained using various methods for assessing usefulness.

Table 4. Correlation of different groups for usefulness

Inter-method	Correlation (group 1)	Correlation (group 2)
Product set 1		

experienced-weighted objective method	0.4	0.8
experienced-proposed	0.8	0.8
weighted objective method-proposed	0.8	1
Product set 2		
experienced-weighted objective method	0.6	0.9
experienced-proposed	0.9	0.975
weighted objective method-proposed	0.7	0.975
Product set 3		
experienced-weighted objective method	-0.5	0.5
experienced-proposed	1	0.5
weighted objective method-proposed	-0.5	-0.5
Average		
experienced-weighted objective method	0.167	0.733
experienced-proposed	0.9	0.758
weighted objective method-proposed	0.333	0.491

Note: 'experienced' represents 'designers' intuitive method'.

The analysis shows high correlation between the ranking of the products using 'designers' intuitive method' and 'the proposed method', for all three product sets, for both the groups. This indicates that the proposed method reflects better the designers' intuitive notion of usefulness.

Table 5 shows correlations between the ranks as determined by each group using the selected methods (designers' intuitive method and the proposed method) for assessing creativity.

Table 5. Correlation of different groups or creativity

Product sets	Correlation (Group 1)	Correlation (Group 2)
experienced-proposed for product set 1	0.6	0.6
experienced-proposed for product set 2	1	0.9
experienced-proposed for product set 3	1	1
experienced-proposed (average)	0.867	0.833

We have also found out the average (for the three sets of products) of correlations between novelty, usefulness and creativity across all product sets for designers' intuitive method. The results are Novelty- Creativity = 0.7, Usefulness- Creativity = 0.3 and Novelty – Usefulness = -0.2.

Similarly, the average correlation of novelty, usefulness and creativity using the designer's intuitive method and the new methods are correlated. We found that average correlation values in the proposed method match closely with that of the designers' intuitive method. It shows that the proposed method for assessing novelty, usefulness and creativity adequately represents the experienced designers' intuitive notion of these terms.

It also shows that creativity can be seen as a product of novelty and usefulness (see equation (1), which is validated by the fact that both novelty and usefulness have a positive correlation with creativity and novelty influences creativity more than usefulness does. Also, novelty and usefulness have a low correlation, indicating that they are characteristics that independent of each other.

Finally, we calculated the correlation between the correlations obtained using designers experienced method and the proposed method. The high correlation between designers' intuitive method and the

proposed method (0.95) indicates that the proposed method represents the intuitive notion of the designers well.

6   CONCLUSIONS

Creativity should be measured directly in terms of novelty and usefulness of the outcomes. It is noted that product characteristics can be employed to ascertain the relative degree of novelty of products. The FBS model has been used first for determining novelty of products and SAPPhIRE model then to assess the relative degree of novelty of these products. A method for finding the relative usefulness of products is developed that uses the importance of usage, popularity of usage and rate of use as the criteria for assessing usefulness of products.

Based on these two measures, a method for the degree of creativity of products is developed. The proposed methods are evaluated using comparative studies involving experienced designers. The proposed methods are also compared with other available methods, and it appears that these can predict a designers intuitive notion better than the others available methods. Further research includes assessing the creativity of problems and evaluating parameters.

7   ACKNOWLEDGEMENT

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