STUDYING ENGINEERING DESIGN CREATIVITY[1]

Developing a Common Definition and Associated Measures

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Abstract. A commonly accepted definition and related, reliable measures for creativity are pre-requisites to understanding influences on creativity, and developing validated aids for enhancing creativity. Literature, though abound with definitions and measures for creativity, has little in terms of a shared definition, and the measures proposed rarely related to any definition. The objective of this paper discuss the methodology adopted to study design creativity in order to propose such a 'common' definition, for creativity in general as well specific to engineering design, to develop related measures for creativity for engineering design, and to validate these measures.

1. Introduction

A commonly accepted definition and related, reliable measures for creativity are pre-requisites to understanding influences on creativity, and developing validated aids for its enhancement. Cross-examination of results is not possible unless it is shared across the research as to what is meant by creativity, and what measures can be used to operationalise this definition. Literature, though abound with definitions and measures for creativity, has little to offer in terms of a shared definition, and the measures proposed rarely relate to a definition. As a result, while many influences to creativity are proposed, and many methods suggested for its enhancement, it is unclear how well these findings relate to one another and to creativity. Here are some excerpts from a growing body of literature echoing similar views.

Eder (1995) argues that even though much research is published, it is still unclear what constitutes creativity, how creativity operates, what conditions

[1] Published in the Proceedings of the NSF International Workshop on Studying Design Creativity'08 - Design Science, Computer Science, Cognitive Science and Neuroscience Approaches: The State-of-the-Art , University of Provence, Aix-en-Provence, 10-11 March 2008

should exist for creativity to thrive, how creativity interacts with engineering design and what measures for creativity can deliver valid assessments. Urban and Hauser (1993), and Eder (1995) stress that research to ascertain the definition, factors and measures of creativity are essential.

However, the creative process is still not well understood and the specific determinants of creativity are not known (Urban and Hauser 1993). Though creativity has been used in education for over 50 years, we struggle to define and identify it (Forum, 2002). Frankenberger and Birkhofer (1995) state that, ‘A definition of creativity relevant for engineering design is still difficult despite enormous amount of research on creativity in the last decades.’ This in turn makes identification of a suitable method to measure creativity difficult (Christiaans 1993). According to Jarvis and Hauser (2000), and Lobert and Dologite (1994), creativity is difficult to define and quantify; inadequate understanding of creativity by engineers leads to its exclusion in their education. Eder (1995) and Jarvis and Hauser (2000) argue that defining and measuring creativity will help the research community, especially engineers in their education.

The objective of this paper is to discuss the methodology adopted to study creativity in order to: develop such a ‘common’ definition, for creativity in general as well as specific to engineering design, develop related measures for creativity for engineering design, and validate these.

2. Developing a ‘Common’ Definition

Development of a ‘common’ definition hinges on being able to clarify what is meant by a ‘common’ definition. Developing the definition then becomes an activity of operationalising this meaning. A ‘common’ definition, we feel, must find what is common across existing definitions. Therefore, research started with an effort to collect a comprehensive list of creativity definitions (see Ideaslab 2007 for the list) from literature. We saw two possible meanings for ‘common’ definition. The first is, since it should reflect the views of the majority of the researchers in the domain, we should develop an approach that uses, in the ‘common’ definition, those concepts that are most frequently used across the current definitions. The second, alternative meaning is based on the argument that the above - *majority based* - definition may not capture the rich, underlying relationships among the concepts used in the various definitions, and hence may not provide a ‘common’ definition that *represents* all the definitions. The list of creativity definitions were therefore analyzed using two alternative approaches, based on these two meanings. The first is called *Majority Analysis*, and the second *Relationship Analysis*. The results from these two analyses were then compared in order to develop the proposed definition.

2.1. MAJORITY ANALYSIS

In majority analysis, a comprehensive set of existing definitions of creativity is synthesized into a single common definition, using the features that are *common* among the majority of these definitions. Its steps are as follows.

2.1.1. Further Selection of Creativity definitions

The initial review of creativity literature revealed many definitions of creativity: a total of 164 definitions of creativity were identified. It is important that any proposed common definition of creativity should reflect its shared understanding within the research community on creativity. This led to focusing on only those definitions whose authors worked in the area of creativity, design or innovation and have formally published their work (e.g. in conferences, journals or books). Fifty definitions (see Ideaslab, 2007) that satisfy these criteria were identified and reviewed, showing that:

- Authors highlighted a variety of attributes in their definitions of creativity. Some of these are ‘new’, ‘novel’, ‘useful’, and ‘uncommon’.
- Creativity has been defined using some of the following means:
    - A set of *abilities* or personal traits: e.g. fluency, originality, flexibility, elaboration. These, however, seem to measure creativity-supporting abilities rather than creativity itself.
    - A special *process* or activity that makes someone creative.
    - A product or *outcome* with a set of characteristics.

Outcome-oriented definitions seem to link more *directly* to creativity since, even if one possesses a creative talent and even if a special process is followed, unless the outcome is seen as creative, creativity might not be said to have occurred. However, even outcome-oriented definitions are not without issues, such as: How to assess the creative elements of the outcome? Should the creative elements have to be unique to the whole of society or only to the creator? In particular, the presence of the variety of attributes has made the meaning of the term ‘creativity’ rather poorly defined and understood. The current definitions are either too general or too application-specific, making creativity appear as a highly ambiguous concept.

2.1.2. Initial Analysis

Initial analysis showed that each definition uses a (verb or noun) phrase to express the essence of the definition, and its corresponding qualifiers to express something specific about the phrase. Definitions shown in Table 1 (refer to Ideaslab, 2007 for all fifty definitions), illustrate how verb and noun phrases have been used in defining creativity.

2.1.3. Identifying Commonality

Each definition was divided into its primary phrases (verb and noun) and the frequency of their occurrence across definitions was counted in order to identify underlying commonality across definitions:

- Phrases occurring in two or more definitions were considered.

TABLE 1. Initial Analysis of Definitions

Author	**Definition of creativity**	**Verb/ Verb phrase**	**Qualifier**	**Noun/ Noun Phrase**	**Qualifier**
Amabile	The process by which something judged (to be creative) is produced			Process	something judged is produced
Charles Thompson	Creativity consists of coming up with many ideas, not just that one great idea	coming up with many ideas	not just that one great idea		
Heikkila	Creativity is the ability to produce new ideas and solutions			Ability	produce new ideas and solutions
M. Stein	Process that results in a novel work that is useful			Process	results in a novel work that is useful
Rollo May	Creativity is the process of bringing something new into being			Process	bringing something new into being

- Phrases having no commonality with other phrases were ignored.
- The verb phrases, noun phrases and their corresponding qualifiers were analyzed and clustered, clustering together phrases having similar meanings. Noun phrases, being more in number, have many clusters. The simplified data was tabulated. Commonality among all verb phrases and noun phrases were identified separately.
- Next, statistical frequencies of occurrence were determined for each cluster and the core phrases/words and core qualifiers were identified.
- These were combined to construct a common definition of creativity.

2.1.4. Finding Commonality among Phrases

Only five definitions expressed creativity using verb phrases. Only one verb phrase (occur) was found more than once. Table 2 shows the distinct similar clusters of noun phrases. Unlike verb phrases, analysis identified a number of non-identical sets of noun phrases with high frequency of occurrence. Four major clusters were identified. The phrase with the higher number of occurrences was selected to be a part of the common definition.

Note that though the terms ‘ideas’, ‘products’ and ‘solutions’ have similar meanings, they differ in the concreteness of the outcome. ‘Products’ are more concrete than ideas and solutions. The word ‘work’ is interpreted as similar to ‘solution’ or ‘product’. If we construct a definition of creativity using the selected phrases, then the first part of the definition could be:

Creativity occurs through a process by which a person uses his/her ability to generate ideas, products or solutions. To avoid terms like 'his/her', we replace the word 'person' with 'an agent', reframing the first part of the definition as: **Creativity occurs through a process by which an agent uses its ability to generate ideas, products or solutions.**

TABLE 2. Clustering of definitions- the noun phrases

	Noun/ Noun phrase		**What selected**	
	Part A	**Part B**	**From part A**	**From part B**
Cluster 1	Persons(2)	-	Person	
Cluster 2	Process(8)	some thing judged is produced (2)	Process	-
Cluster 3	Ability to (5)	Bring something into existence (2)	Ability	Occur (has already been considered)
Cluster 4	generation of (11)	Products (5), ideas (6)	Generate	products and ideas
	problem solving (5)	-	(same as generation of solution)	-
	production of (6)	something (2), ideas and solutions (2), work (2)	-	Solution and ideas (work can be taken as a solution)

2.1.4. Finding Commonality among Phrase Qualifiers

TABLE 3. Clustering of definitions- the noun phrases

	Qualifier of Verb/ Verb Phrase	**What selected**
Cluster 1	New, with many ideas, original	New (Novel -see discussion below)
	Qualifier of Noun/ Noun phrase	**What selected**
Cluster 1	New(11), original(2), novel(13)	Novel (new and original)
Cluster 2	Socially valued (valuable) (9), useful (5), appropriate (4)	valuable

Qualifiers are used after the verb or noun phrases to express something about the phrases (Table 3). Like the verb clusters, the verb qualifiers are few in number. The cluster with the most number of entries is shown below. Similar to the verb qualifiers, noun qualifiers are also clustered, see Table 3.

Using the most frequently used terms from the clusters, the qualifier part of the definition of 'creativity' can be stated as **'that are novel and**

valuable'. Thus using Majority Analysis, the common definition of creativity is constructed as: '**Creativity occurs through a process by which an agent uses its ability to generate ideas, products or solutions that are novel and valuable**' **(Definition 1).**

2.2. RELATIONSHIP ANALYSIS

In the Majority Analysis of definitions, the definitions of creativity were analysed by identifying the essential attributes or features that the *majority* of these definitions use, for integrating them into a 'common definition'. However, this does not take into account the *relationships* between the attributes or features used, and may miss the potential, underlying unity among the features. In Relationship Analysis, we analyze how the essential features of these definitions *relate* to one another so as to link them together in hierarchies of similar features, in order to identify the *overarching, high level features* that represent *all* the features in the hierarchies. A 'common' definition of creativity that integrates these high level features would also *represent* the definitions that use the related, lower level features, thus creating a more representative definition of creativity than possible by using the criterion of simple majority. Its steps are as follows.

3.1.1. Identifying Commonality

This step is carried out after compilation of creativity definitions. First, each definition of creativity is analysed to identify the underlying structure of the definition and its constituent features. Take the following definition as an example: 'Creativity is the ability to produce new ideas and solutions'. In this definition, creativity is seen as an *ability* 'to produce', with 'ideas' or 'solutions' as *outcomes* having the *properties* of being 'new'. Such analysis of each definition leads to the following conclusions:

- As found in the earlier Analysis, in each definition, creativity is referred with respect to person, process/ability, or outcome;
- There are *seven* generic types of definition identified (Table 4). Each current definition can be categorized into one of these types. For instance, Type 'A' refers to creativity of outcomes and defines this in terms of certain kinds of outcome (X) having certain kinds of property (Px); Type 'B2' refers to creativity of a process or ability, and defines this in terms of the kind of process/ability (Y) with the kinds of outcome (X) with properties (Px). Most definitions are of Type B2.
- Except for Type B1 definitions, all other definitions refer directly to *outcomes* with *properties* as the means of establishing creativity. Even for definitions related to Type B1, the process properties can be translated into outcome properties. We conclude that a definition of creativity should include the *types* of outcomes and their *properties* (e.g., 'ideas' that are 'new') as *essential* features of the definition, This makes

sense, since whether one refers to creativity of a person, process, ability or outcome, the most *direct* means of accessing creativity is through *properties of its outcomes*. Hence in this analysis we focus primarily on outcomes and their properties.

TABLE 4. Clustering of definitions- the noun phrases

Type	**Reference**	**Process/ability**	**Outcome**	**properties**
A	Of outcome is		Outcomes X	with Properties Y
B1	Of process/ ability is	Process/ability Z		With properties θ
B2	Of process ability is	Process/ability Z	With Outcomes X	With properties Y
B3	Of process ability is	Process/ability Z	Outcome X	With properties θ (for X) and these properties are having properties Y
C1	Of a person is	Process/ability Z		With properties θ?
C2	Of a person is	Process/ability Z	With Outcomes X	With properties Y
C3	Of a person is	Process/ability Z	Outcome X	With properties θ (for X) and these properties are having properties Y

Next the meanings of the various feature terms used (e.g., X, Px, Y, Py in Table 4) are identified, either from the authors' explanations, or from common, relevant meanings of these terms across four major dictionaries.

3.1.2. Linking Novelty Features

Based on the relationship between their meanings, the features are placed in hierarchies of features having related meanings. This allows each definition to be interpreted as a combination of features spread across the hierarchies. The outcome features formed three hierarchies, one for outcome type and the other two for their properties. The first hierarchy (Figure 1) was formed by linking all the features relating to novelty. The features are shown in the boxes. An arrow from feature A to B shows that A influences B. Equality sign is used between terms having similar meaning.

Note that there are features that relate to the *surprise*, *interest or stimulation* created by an outcome. What kind of surprise could an outcome create? Vest (2004) in his MIT presidential address spoke of two different kinds of surprises that Robert Gallagher experienced on the work of Claude Shannon. The first kind is illustrated, when confronted with Shannon's concept of information channel and his theory of information, by Gallagher's reaction "How did he ever think of that? I would never have!"

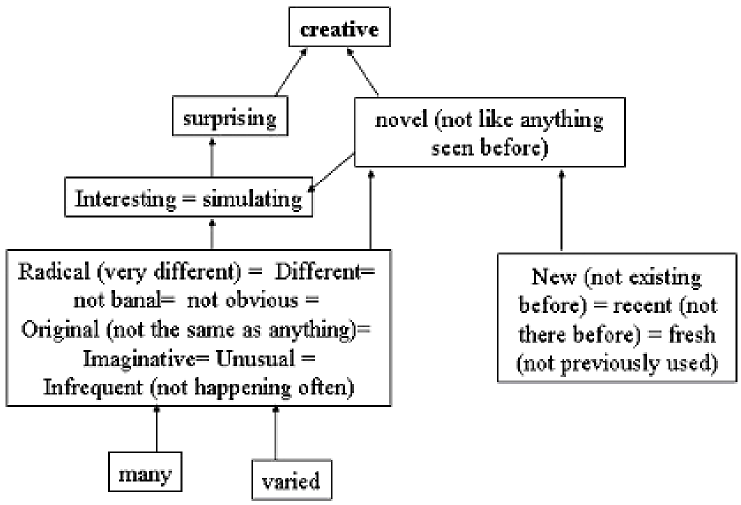

Figure 1. Hierarchy for novelty and Related Features

The second kind of surprise is illustrated by the common reaction on Shannon's application of Boolean algebra to describe computing – 'I wish I had thought of that!' Morris (2006) spoke of similar kinds of surprise: the big surprise ('AHA') and the small surprise ('Oh Yeah'). Bruner (1962) spoke of 'effective surprise' as an element of creativity. An effective surprise is created, not merely by an idea being novel, but being effective in solving the problem or meeting the need while being novel. In other words, *both* novelty and value play a role in creating the surprise. We argue that the first kind of surprise (i.e., big surprise: "How could he ever think of that!") is due to a high degree of novelty, and therefore it is primarily 'novelty' that contributes to this surprise. Since surprise must be preceded by *interest* or *stimulation*, we argue that something being 'novel' can contribute to it being 'interesting' or 'stimulating', which can contribute to producing 'surprise'.

3.1.3. Linking Value Features

In the hierarchy in Figure 2, all features that relate to the value of the outcomes are linked. The second kind of surprise ("I wish I had thought of that!") could now be explained with respect to the 'value' feature. We argue that surprise of this kind is due to the high degree of value or usefulness that was possible to achieve by tweaking the existing ideas only slightly, giving the feeling that the observer could well have thought of that idea, since it appears so similar to familiar ideas! Here the contribution to surprise comes not so much from its novelty, as from its apparent familiarity and yet fulfilment of the purpose! Hence Surprise is linked *also* to value (Figure 2).

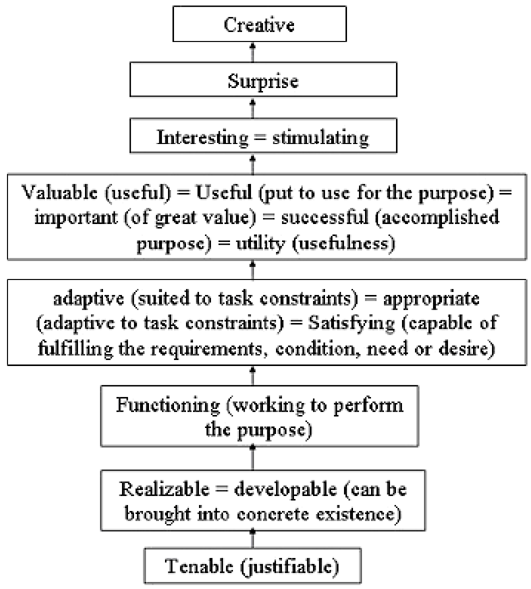

Figure 2. Hierarchy for Value and Related Features

Surprise seems a matter of degree of impact that the outcomes make – to the *degree* of creativity, and *not as an essential feature distinguishing creative from the non-creative*. Hence while we include both novelty and value, we *do not* include surprise as an essential feature in the combined hierarchy (Figure 3) or in the definitions we propose; we feel that its nuances are accounted for in the degree of creativity attained by outcomes.

3.1.4. Linking Outcome Features

The third hierarchy (not shown) links the types of outcome used in the various definitions of creativity. The broad types of outcome found are: ideas (i.e., thoughts, concepts, and perceptions), problems, products (or artefacts), solutions, inventions, discoveries, and evaluative statements or evaluations (e.g., points of view and judgements). We view inventions as artefacts or solutions with a high degree of novelty – as equivalent to 'solutions' or 'products'. 'Discoveries' could be 'artefacts', solutions, problems, evaluations, or that of natural systems. All of these could be described as 'something'; hence 'something' is taken the most abstract form of outcome, and placed at the topmost node of the hierarchy. Note that, in the context of design creativity, all forms except some forms of discovery (e.g. discovering natural systems) are *designed constructions*.

3.1.5. Developing Common Definition of Creativity

Now, the features appropriate to be included into a 'common' definition of creativity and into that for design creativity, are selected from the common hierarchy. In order to qualify as a common definition, the features should be at the topmost nodes of these hierarchies.

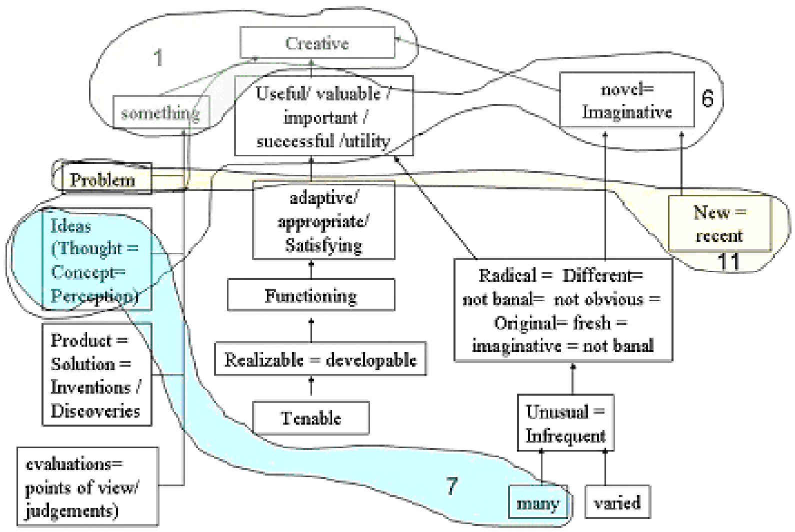

Figure 3. Combined hierarchy and definitions of creativity overlaid on them

If the two outcome-property hierarchies (Novelty and Value) are merged with the hierarchy of outcome-types, and the feature combinations that represent the original definitions are superimposed on this, three distinct kinds of definition emerge: a few in which features from only 'novelty' hierarchy are used; another few that include features only from the 'value' hierarchy, and the third kind, within which *most* definitions fall, that use a combination of features from both these hierarchies. In order to be inclusive, we need a definition of creativity that includes terms from both 'novelty' and 'value' hierarchies, and put them as essential features for the most generic outcome-types. This could then be related to product, person, ability or process to be inclusive. The combined hierarchy is shown in Figure 3.

Based on this analysis, the following is proposed as a 'common' definition of creativity: **Creativity of 'Something' lies in its 'novelty' and 'value'. Creativity is an ability or process using which a person (or agent) generates 'something' that is 'novel' and 'valuable'. This 'something' can be a 'problem', 'solution', 'work', 'product', 'statement', 'discovery', 'thought', 'idea' or judgement (evaluation) depending upon the context. For design, 'something' could be taken as 'problem', 'solution', 'product', 'idea' or 'evaluation' (Definition 2).**

2.3. COMPARISON OF THE DEFINITIONS

The definitions created by the two analyses are different in the meaning of ‘something’. While in Majority Analysis, ‘something’ encompasses ideas, solutions and products, in Relationship Analysis it encompasses a greater variety – in particular problems and evaluations. Since identifying problems and carrying out evaluations are essential tasks during any creative activity. It can be argued that, both problem finding and finding evaluation criteria are subtasks to the goal of generating creative ideas, solutions or products. Thus, focusing on generation of ideas, solutions or products should provide a more direct measure of creativity. The general definition of creativity from Relational Analysis is simplified hence as: **‘Creativity in design occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable’ (Definition 3).** It is the same as the definition proposed in Majority Analysis (Definition 1).

The general attribute of social ‘value’ can be further *specified* in the context of engineering design, where it becomes *utility* value – or ‘usefulness’. Thus for engineering design, the definition could be further specified as: **‘Creativity is a process by which an agent uses its ability to generate something that is novel and useful, where ‘something’ refers to ‘problem’, ‘solution’, ‘product’, ‘idea’ or ‘evaluation’ (Definition 4).**

This definition for design creativity (Definition 4), together with the more generic definition for creativity (Definition 3), provides a more inclusive framework for creativity than provided by Majority Analysis. This is because the features used in the definition now represent, and not eliminate the indirect features not directly represented in the definitions.

It also provides a justification for the various measures proposed and used by earlier authors for creativity, and how directly these relate to creativity. For instance, Torrance (1979) used fluency and flexibility as two measures for creativity, which in the novelty hierarchy are represented by ‘many’ and ‘varied’. Shah and Vargas-Hernandez (2003), and Lopez-Mesa and Vidal (2006) use ‘infrequent’ as a measure of novelty. ‘Non-obviousness’ has been used as a measure in assessing patent documents (Franzosi 2006). Amabile (1996) uses experts to identify what is ‘creative’. Shah and Vergas-Hernandez (2003) measure usefulness using the ‘satisfying’ feature, which could be used as an indirect measure, as viewed from its placement at a lower level in the hierarchy in Figure 4. Except for the measure used by Amabile who leaves the onus of defining creativity as felt appropriate by ‘experts’, all other existing definitions are subsumed and represented by the above two definitions, and at a greater level of directness.

3. Developing 'Common' Measures

Operationalisation of the proposed common definition of engineering design creativity requires being able to assess its two core components: 'novelty' and 'usefulness'. For this, two sets of information must be available:

- Potential measures for novelty, usefulness and creativity, where the creativity value is some function of novelty and usefulness values.
- Some means of independent evaluation of novelty, usefulness and creativity as a benchmark for evaluating the potential measures.

While literature has many measures of creativity, often the second information – some means of independent evaluation is missing. What is also missing is any proposed relationship between the measures and creativity. Both are crucial for the results to be valid. An ideal means of independent evaluation would be using competent people with knowledge of all existing products from all domains. The next best alternative to such utopian means, we feel, is the collective knowledge of experienced designers from the domains to which the newly generated products belong. In a design firm, creativity of conceptual solutions is typically judged by experienced designers who decide whether to develop these concepts further into products. In patent offices novelty and usefulness of products are judged by experts in related areas. We argue, like Amabile (1996) who suggested the use of experts to identify what is 'creative', that ultimately for any measure of novelty, usefulness or creativity to be valid, the results should match the collective notion of experienced designers (or experts). This is what we use as the benchmark for evaluating the potential measures.

3.1. MEASURING NOVELTY

'New' is something that has been recently created. 'Novel' products are those that are socially new. Novelty' encompasses both new and original (Cambridge 2007). We are interested in a *direct* measure of novelty. Development of a measure involves development of a *scale* and a *process* of measurement. We argue that for detection of novelty of a recently developed product, the characteristics of that product should be compared (i.e. the *process*) with that of other available products aimed to fulfil the same need. The differences among these characteristics should indicate how novel the recently developed product is. If no other product had satisfied the same need before the new product should be considered of the highest novelty (the *maximum* value in the *scale*). If the product is not different from existing products, its novelty should be zero (the *minimum* value in the scale). Thus, to assess novelty of a product, one should know both the time line of similar inventions (to identify which product satisfied first the need) and the characteristics of similar products (to assess how this is satisfied). It must also be possible to determine the degree of novelty.

With a few exceptions, literature on identifying novelty of engineering products is rather sparse. Patent offices often employ experts to determine 'novelty', 'usefulness' and other aspects of patent applications, but they are interested in identifying whether the patent is novel and useful or not, and not in their *degree of novelty*. Determination of the degree of novelty is essential to identify the slight differences among recently developed products. Existing research on measuring novelty (Saunders 2002; Shah and Vargas-Hernandez 2003; Chakrabarti and Khadilkar 2003), deals mainly with identification of novelty of products.

Saunders (2002) deals primarily with aesthetic novelty of patterns. Shah and Vargas-Hernandez (2003) proposed two measures of novelty. The first is based on grading of the functions that a product or idea satisfies, and the second on posterior classification and counting of distinct solution ideas with respect to prior knowledge. Redelinghuys (2000) define invention gain as a differential contribution, which is the difference between system achieved and previous state-of-the-art projected values, but suggests no method for measuring this. Chakrabarti and Khadilkar (2003) propose a metric for assessing product novelty that combines the contribution from two criteria: the level (Need, Task, Subsystem structure, Technology, Sub technology and Implementation) at which, and the importance of the functions for which the product to be evaluated differs from existing ones. Lopez-Mesa and Vidal (2006) propose a method to identify the novelty of solutions generated by design teams '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)'. This method is similar to that of Shah and Vargas-Hernandez (2000). The current methods seem to have the following inadequacies:

- Some methods are based on the assumption that less frequently generated ideas are more likely to be novel; this is, at most, indirect influence.
- Some methods are based on the assumption that new solutions for fulfilling more important functions are likely to be more novel. We disagree: importance is relevant for usefulness, and not for novelty.
- Most methods assume that there is a hierarchy of levels of abstraction in an idea, and being novel at a higher level is more novel. We agree.
- All use some Function-Behaviour-Structure model (FBS) of the artefact for the hierarchy. We feel that FBS models are not sufficiently detailed to enable adequate assessment of degree of novelty. We use FBS model as well as SAPPhIRE model to achieve this.
- Two elements are missing in the current methods: history of ideas is not taken into account, and the scale without mention of its maximum possible value is potentially incomplete.

3.2. PROPOSED NOVELTY MEASURE AND ITS VALIDATION

To determine novelty of a new product with respect to available products, comparison of these products is carried out by comparing their features or characteristics. FBS model (Chandrasekaran 1994; Qian and Gero 1996; Goel 1997) is suitable for this. Since novel products are new and original, if the functions of a new product are different from those of available products, the new product must have the highest degree of novelty. We ascribe the qualitative degree of 'very highly novel' - the need it fulfils was not fulfilled by other products at the time of its introduction. Next, if the structure of the new product is same as that of any other product, it cannot be considered novel; otherwise it should be taken as novel.

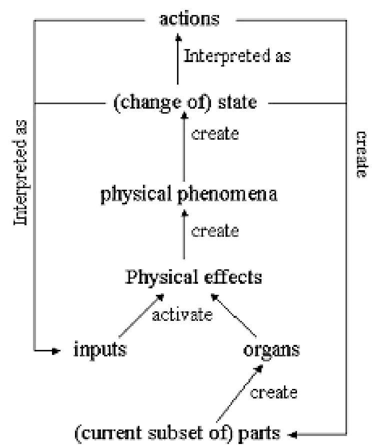

Figure 4. SAPPhIRE Model of Causality

This approach should help identify very highly novel products, or whether a product has some degree of novelty. However, it will not help assess the relative degree novelty of these products, which is required for distinguishing between similar products in terms of their novelty. Thus, a more detailed model for describing the causality of products was needed. We used SAPPhIRE (standing for State-Action-Part-Phenomenon-Input-oRgan-Effect) model of causality Chakrabarti et al. (2005) to assess the relative degree of novelty of products. It has seven elementary constructs. Action is an abstract description or high level interpretation of a change of state, a changed state, or creation of an input. State refers to the attributes and their values that define the properties of a given system at a given instant of time during its operation. Physical phenomena are a set of potential changes associated with a given physical effect for a given organ and inputs. Physical effects are the laws of nature governing change. Organs are the structural contexts needed for activation of a physical effect. Inputs are energy, information or material requirements for a physical effect to be activated. Parts are the physical components and interfaces constituting the system and its environment of interaction. Parts are necessary for *creating* organs, which with inputs *activate* physical effects, which are needed for *creating* physical phenomena and state change. State changes are *interpreted* as actions or inputs, and create or activate parts. Activation, creation and interpretation are the relationships between the constructs.

For detection of relative degree of novelty in products that are not 'very highly novel', state change and input constitute the next level of novelty ('high' novelty), physical phenomena and physical effect the next level ('medium' novelty), and organs and parts constitute the next level ('low' novelty) at which a product can be different from other products. Based on these, a method for novelty detection has been developed which employs FBS model initially (to find if a product is very highly novel or not) and later SAPPhIRE model to assess (relative degree of) novelty with respect to other products. The method was evaluated in terms of the degree to which its output (that is the degree of novelty of products as determined using the method) matched with the output of experienced designers (the degree of novelty of the same products as perceived/determined by these designers). This evaluation was carried out using a comparative study of various novelty measuring methods and the proposed method with the collective, intuitive evaluation of novelty of 3 product sets by 16 experienced designers (Sarkar 2007; Sarkar and Chakrabarti 2007). The product sets, each with 3-5 products, historically organised, were devices for: (1) writing, (2) room temperature control, and (3) personal communication. The experienced designers were from consumer goods and automobile industry, with a 2-year Master in Design degree and an average of 4 years of industrial experience.

TABLE 4. Correlation: Experienced Designer's Evaluation and Proposed Method's

	Methods	**Correlation**
For product set 1	Experienced- Proposed method	0.8
For product set 2	Experienced- Proposed method	1
For product set 3	Experienced- Proposed method	1
Average correlation	Experienced- Proposed method	**0.9333**

Note: 'experienced' represents 'designers' intuitive method' and 'proposed' represents the 'proposed method'. Note: Level of significance of the above correlation: $p<0.1$ 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.

The results from proposed method (Table 4) correlate highly with that of the designers' collective intuition. Similar comparison with Shah and Vergas

Hernandes' and Chakrabarti and Khadilkar's method yielded little correlation (<0.16), indicating the greater potential of the proposed method.

3.3. MEASURING USEFULNESS

A product may be perceived as useful and yet this could be validated only if this is supported by results from its actual use - it is the *actual* use of the product that validates its usefulness. Thus, we argue that the usefulness of a product should be measured, whenever possible, by its *actual* use, and when this information is not available value of its potential use can be used. We could develop a broad notion of the use of a product, with which to assess the degree of its usefulness – the second criterion for judging creativity – by comparing products in terms of their usefulness.

Patent offices employ experts to determine both novelty and usefulness to ascertain validity patentability of applications, but there are no explicit measures available for these. *Usability* is the closest to usefulness that we have found in literature that have some measures. It denotes the ease with which people can employ a particular tool or other artefact in order to achieve a particular goal. There are several measures of usability (Green and Jordan 2002; Nielsen 1994; Gramam 2003). Various norms exist for its assessment such as ISO and SIS. Review of literature, however, *did not yield any direct measure for usefulness*. Even though several researchers define usefulness (e.g., Mumford et. al 1994; Sternberg and Lubart 1999), no measures are proposed. We argue that the methods for evaluation of designs or products (Rozenberg and Eekels 1995) are the closest available to what could be used for assessing usefulness of products. Shah and Vargas-Hernandez (2003) propose to measure 'quality' of products using a variant of the 'weighted objective method'. So, we take the 'Weighted Objective method' as a representative evaluation method for this purpose, and evaluate the method we propose (later in this paper) by comparing it with this method, against the collective, intuitive notion of usefulness of experienced designers as benchmark, with these as rationale:

- Usefulness should be measured in terms the degree of usage a product has in the society. This should overcome other potentially misleading indicators, e.g. sales, even though a product is not useful.
- The scale is provided by a combination of several elements to assess the degree of usage: the importance of the product function, the number of users, and how long they use it or benefit from it. Together these give a measure of how extensive the usefulness of the product is to the society.
- Though usefulness should be ideally judged by taking feedback from a statistically representative collection of users of the product, this is best approximated by the collective opinion of experienced designers who

are trained to understand users well. Hence, collective opinion of experienced designers is used as benchmark for corroborating results.

3.4. PROPOSED USEFULNESS MEASURE AND ITS VALIDATION

As to how important the use of a product is depends on its impact on its users' lives. Some products are indispensable; products that are more important to the society should have a higher value for their usefulness. We identified five levels of importance of products: extremely important (e.g. life saving drugs), Very highly important (e.g. compulsory daily activities), Highly important (e.g. shelter), Medium importance (e.g. machines for daily needs), Low importance (e.g. Entertainment systems). All other parameters being the same, the products that are used by a larger number of people should be more useful to the society. We argue that *rate of popularity* should be assessed by the number of people using a product within a given period of time. Products that are used more frequently or have longer duration of benefit are likely to have been more useful to the society, assuming that the 'level of importance', the 'rate of popularity' for a set of products is same, the rate of usage increases the usefulness of such products. Rate of duration of benefit is defined as duration for which a user gets benefited by using a product per usage of the product. The *rate of duration of benefit per person time* is defined here as the *product* of the *frequency* of usage and the *duration* of benefit per usage person, in a given unit of time.

TABLE 5. Correlation: Experienced Designer's Evaluation and Proposed Method's

	Inter-method	**Group 1**	**Group 2**
Product set 1	experienced-weighted objective method	0.4	0.8
	experienced-proposed	0.8	0.8
Product set 2	experienced-weighted objective method	0.6	0.9
	experienced-proposed	0.9	0.975
Product set 3	experienced-weighted objective method	-0.5	0.5
	experienced-proposed	1	0.5
Average	experienced-weighted objective method	0.167	0.733
	experienced-proposed	0.9	0.758

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 the product in that community. When designing a new product, a designer could use the values of these parameters which may be extrapolated from data of other similar products in the market and predict the usefulness of the new product. Taking the above parameters into account we construct Equation 1 below for assessing the usefulness of a product.

$$U = L (F D) R \tag{1}$$

L stands for level of importance; F for frequency of usage (how often people use it); D for duration of benefit per usage; R for rate of popularity of use (how many people use it). The unit of time for R, F and D should be same.
Unlike for the ‘weighted objectives’ method, the ranking of products using the proposed method has *consistently* high correlation with that using ‘designers' intuitive method’, for all three product sets, for both the groups who evaluated usefulness using the methods. This shows that the proposed method reflects better the designers’ intuitive notion of usefulness (Table 5).

3.5. PROPOSED CREATIVITY MEASURE AND ITS VALIDATION

With the argument that ‘novelty’ and ‘usefulness’ of products should be taken as the only two *direct* influences on creativity (as in the common definition), it should be possible to express creativity as a function of these two. For a list of creativity measures see Sarkar (2007). We propose that the relationship be reflected as a product of the two influences, embodying the notion that absence of either will lead to seeing no creativity in the outcome (C stands for creativity, N for novelty, and U for usefulness):

$$C = N X U \tag{2}$$

In order to assess the validity of this relationship, the following steps are used to assess the relative degree of creativity of a product in a given set:

1. Assess novelty of each product on a qualitative scale: ‘Very high novelty’, ‘High novelty’, ‘Medium novelty’ and ‘Low novelty’.
2. Convert the qualitative novelty value of each product into a quantitative value as below: ‘Very high degree of novelty’ is taken as 4 points, Very high novelty = 4 points, High novelty = 3 points, Medium novelty = 2 points and Low novelty = 1 point.
3. Give relative grading to each product. For example, if five products are compared with one another, allocate 1/5, 2/5, 3/5, 4/5, 5/5 points to those ranked 1-5 respectively.
4. Assess the usefulness of each product using the method described before.
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, 5/5 points respectively.
6. Calculate creativity of a product as a product of its degree of novelty and usefulness using Equation 2.

Creativity ranks obtained using experienced designers’ collective opinion is compared with that using the proposed method. The results (Table 6) show consistently high correlation between these, corroborating the proposed method. Further analysis shows *no correlation* between usefulness and novelty, indicating their independence, corroborating our results further.

TABLE 6. Correlation: Experienced Designer's Evaluation and Proposed Method's

Product sets	**Correlations**	**Group 1**	**Group 2**
Product set 1	experienced-proposed	0.6	0.6
Product set 2	experienced-proposed	1	0.9
Product set 3	experienced-proposed	1	1
Average	experienced-proposed	0.867	0.833

4. What this study tells about studying creativity

We argue that a 'common' definition of design creativity with empirically defendable measures is essential for research in this area. We learnt these:

- Success of a 'common' definition would finally hinge on agreement within the community on what is acceptable as the 'common' definition. Operationalisation of this definition is needed for assessing creativity. This needs corroboration, which should come from expert opinions.
- Creativity measures are based mainly on human traits and abilities, which we argue are more indirect than those based on the outcomes. While indirect measures might be useful for developing and assessing aids for creativity, any such measure should be accepted and used only after their worth in influencing creativity is empirically tested and validated against direct, outcome-based measures, such as those described in this paper, that reflect the 'common definition.

Research reported in this paper opened up many avenues for further work. More product sets need to be evaluated for enhancing confidence on these measures. Applicability of the measures can be extended to other areas (e.g. aesthetic creativity), and to assessing creativity with more abstract or incomplete product descriptions. The definition and measures need to be utilised in assessing or identifying potential influences on creativity, and on developing and assessing aids for enhancing various aspects of creativity.

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