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DEFINING AND SUPPORTING DESIGN CREATIVITY

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1. Goal

Creativity is an essential element in designing. Definitions of creativity, however, are multiple and varied, and factors influencing creativity myriad and various. Moreover, the definition, the influences and their measures are not linked in a systematic way. Consequently, metrics for estimating creative potential of agents or methods are few and only as sound as the theories on which they are based. The goal of this paper is to provide a broad and quick overview of work in this area and analyse them to speculate on what should be reasonable as the:

- Essential aspects of a creative idea or solution
- Essential factors influencing development of creative ideas or solutions
- Metric for evaluating methods for their potential in supporting creativity
- Some means for supporting creativity under development at Ideas Lab, IISc.

Please note that unless explicitly stated, all references are quoted from Davies [1999].

2. Characteristics of a creative idea or solution

Literature has seen multiple attempts on qualifying and quantifying the main characteristics of a creative idea. Many authors see novelty as the sole essential characteristic of a creative idea, e.g., to Newell, Shaw and Simon, "creativity appears simply to be a special class of psychological activity characterized by novelty." For Rhodes, "Creativity… is a noun naming the phenomenon in which a person communicates a new concept."

Contrary to these, many other authors like Davies argue that an idea must have novelty as well as some sense of "appropriateness, value or social worth" for it to be considered creative. Perkins states that a "creative person by definition..., more or less regularly produces outcomes in one or more fields that appear both original and appropriate." Hennessey and Amabile argue that "to be considered creative, a product or response must be novel… as well as appropriate." In earlier papers we defined [Chakrabarti, 1998; 2003] creative outcomes as "new as well as interesting".

We feel that to be creative, an idea ought to be novel, purposeful and resource-effective. This conclusion is more of a generalisation of others' work; the claim to novelty is in clarifying the characteristics that should constitute what is "appropriate", "useful" or "interesting". The definitions of these are:

- Novelty: degree of difference from other existing ideas (the higher the better)
- Purposefulness: degree of satisfaction of the task, or solution of the problem (the higher the better)
- Resource-effectiveness: amount of resources used (the less the better)

A novel idea becomes creative in one of the following cases:

- It is as purposeful and resource-effective as existing ideas (enabling competition with protected ideas)
- Compared to existing ideas, it is more purposeful yet as resource-effective, or more resource-effective yet as purposeful, or better in both.

3. Examples Illustrating Novelty, Purposefulness and Resource-Effectiveness

The following three sets of examples illustrate primarily these three aspects of a creative solution:

3.1 Novelty

We take the following cases as examples of Novelty:

1. Tunnelling Accelerometer,
2. SMA Key Ring

While existing concepts of accelerometers are based on principles of capacitance, inductance and resistance, this new accelerometer is based on tunnelling effect in how movement of a mass in response to acceleration is electrically sensed; it also has comparable performance characteristics to the existing accelerometers. As another example, take the concept of a key ring made of shape memory alloys; when heated to its transition temperature it assumes its 'memorised' shape, thereby allowing keys to be inserted.

3.2 Purposefulness

We take the following cases as examples of Purposefulness:

1. Adjustable steering column,
2. Brush with Soap Filled Handle

In both these cases, the concepts are not only novel, but also more purposeful. An adjustable steering column of a car can be used by users of a wider variety of dimensions than a single size steering column. A brush with a handle for filling with soap supports scrubbing as well as dispensing of the soap during scrubbing. Both utilise similar amount of resources as that used by their competing concepts.

3.3 Resource-Effectiveness

Examples of Resource-Effectiveness:

1. Engine 'Nose' Concept,
2. Acid Tester Concept

The pointed front 'nose' of some the Rolls Royce engines act as a nucleus for snow and subsequent ice formation that leads to breakage of the ice and pitting of the surface of the turbine blades. The common and not so resource-effective solution to this problem is to heat the 'nose' continuously. A more creative solution is to consider the 'nose' as a separate element, periodically wiggled by a motor, so that snow has no time to become ice but to break away with no harm to the engine blades. As another example, a common problem for an acid bath is the corrosion of its walls. In these baths material specimens are dipped in an acid for a given time to measure their susceptibility to corrosion by the acid. Common solutions to the problem are replacing the bath or repairing its surface – neither is resource-effective. A more creative solution is to shape the specimen as a small bath in which to pour acid, thereby eliminating the acid bath altogether – a far more resource-effective solution!
Similar ideas of choosing the simplest (interpreted here as more resource-effective) among competing proposals often is an unwritten rule used in natural science disciplines. A 14th century logician William of Occum proposed one such rule – Occum's Razor - "Given two competing solutions to the same problem, the simpler one is the better".

4. Essential Factors Influencing Creativity

A wide variety of factors are cited in literature as influencing creativity. Rhodes [1961] group over fifty definitions of creativity into four Ps: product, people, process and press, the product characteristics being influenced by the characteristics of the other Ps. Afterwards, various authors identified various factors related to each of these Ps, e.g., strong motivation (people), incubation (process), or relaxed work environment (press).

Several authors describe creativity as a special kind of information or knowledge processing [e.g., McKim, 1980], and argue that information or knowledge must be a prime ingredient for creativity. For instance, Gluck [1985] sees as essential the "…possession of tremendous amount of raw information…", as does Read [1955; cited in Davis, 1999, p. 44] who describes this as "scraps of knowledge" in describing creative people who "…juggle scraps of knowledge until they fall into new and more useful patterns." Note the act of juggling in this description – one proposed to be described here with the generic name of 'flexibility'. Also note the mention of "new" and "valuable" patterns - the two aspects of creative outcomes. Various authors have also stressed the importance of flexibly processing knowledge. McKim [1980] speaks of flexibility in "levels, vehicles and operations", and argues that seamless use of and transfer between these are important in creative thinking. Gluck [1985] describes as essential in creativity the "ability to combine, order or connect" information. In C-K Theory [Hatchuel et al., 2004], the authors distinguish two different kinds of creative ideas: those that are dominated by knowledge requirement, and those that operate within existing knowledge but require imagination for conception. We interpret the first category as primarily requiring new knowledge while the second primarily requiring flexibility in thinking. In TRIZ [Terninko et al, 1998], children are described as capable of connecting all ideas to each other, while common adults connect only few – that too in the existing ways. In the light of flexibility and knowledge requirement for creativity, the act of children can be interpreted as having great flexibility in thinking with little knowledge of the constraints among them, while adults having far less flexibility with far more knowledge. In the four stage model of the creative process by Wallas [1926, cited in Davis, 1999, p. 44], the first stage - preparation is interpreted here as accumulation of knowledge, the "scraps" as described by Read [1955]. The second stage - incubation is one of transferring the task to the hand of the subconscious - a sign of flexibility [McKim, 1980]. The third stage – illumination – is when these two come together to create the idea. Note that 'mental blocks' [Adams, 1993] are blocks against using knowledge in a flexible way.

We propose knowledge, flexibility and motivation (i.e., encompassing all motivational factors and indicators such as challenge, energy-level, single-mindedness and aggression) as the three factors essential for creative thinking. McKim has spoken of similar factors "for productive thinking" - information, flexibility and challenge. Perkins [1988, cited in Davis, 1999, p. 45] describes creative people as "motivated", have creative "patterns of deployment" or "personal menuveurs of thought" (both of which are interpreted here as flexibility) and have "raw ability in a discipline" (seen here as knowledge). Echoing similar notions, Torrance [1979; cited in Fox & Fox, 2000, p. 15] argued that "prime factors" on creativity of people are their "abilities, skills and motivation".

The specific ideas proposed here in this regard are the following:

- Motivation, knowledge and flexibility are the broad, primary factors influencing creativity
- The factors are not independent of each other. Knowledge influences motivation, motivation may lead to acquiring of new knowledge; flexibility leads to development of new knowledge that may lead to more flexibility; motivation to utilise knowledge in a flexible way may lead to further flexibility leading to more motivation, etc. This idea of interdependence of factors is influenced by Lewis' model [1981] of influences on intelligence in children. Lewis sees intelligence as the ability to see and solve problems – at a broad level not very different from designing. In his model, motivation, self-image and attitude are all linked to a child's problem-handling skills, and vice-versa.
- Among these factors knowledge and flexibility are the ones that directly affect the outcome of a creative problem solving process, motivation assuming an indirect influence. Other factors, from the categories of people, process and press influence one of these factors, which in turn influence the novelty, purposefulness and resource-effectiveness of the product. This proposed model of influences is shown in Figure 1.

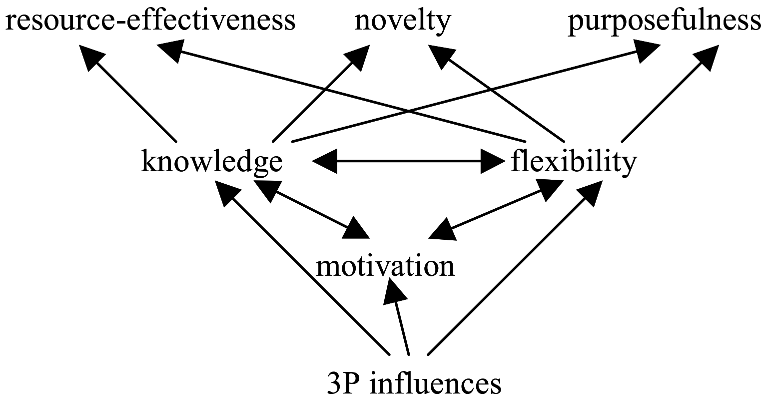

Figure 1. Proposed Model of Influences

Sometimes it is difficult to see the influence of knowledge as separate from that of flexibility. An instance where their separation is quite clear is the acid tester example. No additional domain or solution-specific knowledge than already provided in the current product is necessary for creating the novel "specimen as bath" concept – as long as the current knowledge is processed in a flexible way!

5. Evaluating Creative Impact of a Creativity Support

Knowledge and flexibility, the two major direct influences on creativity, could be used to intuitively explain the major potential impacts of a creativity support. For example, brainstorming methods would primarily influence flexibility of idea generation, and only indirectly provide some knowledge by virtue of being a group method that displays the knowledge created. However, it does not help clarify or solve a problem for more purposefulness or resource-effectiveness, and hence the ideas generated have no more than a statistical chance of being purposeful or resource effective.

In Synectics, another method for group ideation, several steps are used to first clarify the problem, then systematically generate ideas analogically connected to the problem, and eventually use these ideas to solve the problem. Apart from help in clarifying the problem, its problem solving focuses on finding solutions to particular aspects of the problem, and is likely to provide more novel and yet purposeful or resource-effective solutions rather than merely associative ideas as in brainstorming. Here too, knowledge is primarily provided by the group, while flexibility by the method.

Consider also the case of using the 'contradiction method' for solving problems in TRIZ. It is an approach for developing alternative formulations of a problem by providing support to flexibility in clarifying the purposefulness of the problem, and by using contradiction tables that provide both knowledge and flexibility in resolving contradictions in the problem. The result is a space of concepts that are novel and purposeful. A further illustrative case is the 'ideal design' approach in TRIZ – supporting the ideal definition of a problem (i.e., solving the problem with no resources!), and gradually compromising to the extent necessary to find a close-to-ideal solution. Here, the primary focus is on finding novel and resource-effective solutions, and the method provides knowledge and flexibility for solving such problems.

How can we categorise these intuitive evaluations into a common, overall evaluation framework? We propose to do this by putting together three aspects of evaluation. The first is, a creativity enhancement support should be useful in either exploring the problem or generating solutions, since both these have a bearing on the eventual creative value of the solution. The second is, it should be helpful in enhancing either flexibility or knowledge necessary. Finally, a support should enhance novelty, purposefulness, or resource-effectiveness. Putting these three aspects together, we have an evaluation matrix, see Table 1. Within this matrix, we could now place a given support by highlighting the areas of its likely influence, and the relative strength of these influences. We assume therefore that the influence of all creativity methods have the goal of finally providing either flexibility or knowledge in exploring problems or generating solutions for novelty, purposefulness or resource-effectiveness. Creative synthesis agents must provide both knowledge and flexibility in some form or the other.

Table 1. Creativity Evaluation Matrix

	Novelty		purposefulness		Resource-effectiveness	
	problem	solution	problem	solution	problem	solution
knowledge						
flexibility						

6. Examples of creativity support work at Ideas Lab, IISc

At the Innovation, Design Study and Sustainability Laboratory (IdeasLab) founded and directed by the author at the Centre for Product Design and Manufacturing (CPDM) of Indian Institute of Science (IISc), Bangalore, design synthesis and creativity is a major theme of research. Various aspects of synthesis and creativity investigated include: understanding what influences creativity, role of exploration and triggers on creativity, automated and interactive computational synthesis of engineering systems, biomimetics, structure sharing, product design principles, and design affordance.

We believe that creativity could be influenced at three levels: at a skill level, at a procedural or methodical level, or at a stimulus level. Note that this distinction is not crear-cut and static: a procedure applied over a period of time may become part of the skill of the designer, a procedure may primarily help provide stimuli that over time becomes part of the knowledge of a creativity agent, etc.

6.1 Skills influencing creativity

A skill, according to Cambridge Advanced Learner's Dictionary is "an ability to do an activity or job well, especially because you have practised it". Note that it is a kind of knowledge that can only be acquired through *practice* of the discipline, something that distinguishes it from procedures/methods and stimulii. Skills, we believe, indirectly influence creativity of agents. The broad categories of skill we recognise are individual skills and team skills. Individual skills are those possessed by a person for use for working alone, while team skills are those necessary during working in teams.

McKim [1980] defines a skill-combination that he finds important for creative thinking: relaxed attention. In order to attain this, one needs to relax first, and then attend. According to Siler [1997] fears contain energy that could have been positively used otherwise for creativity, and therefore fear interferes with creativity. McKim [1980] states that fear is the cause for excessive tension which is detrimental to creative thinking, and suggests various techniques such as deep breathing and deep muscle relaxation for relaxation. Brain researchers speak of four kinds of branwaves: beta (15-14 cps), alpha (9-14 cps), theta (5-8) and delta (1.5-4 cps). The first is associated with wakeful alertness, while the second and third with relaxed to drowsy states with associated flow of ideas, and hence creativity [King, 2005]. Some authors state that it is the alpha-theta border which is most condusive for ideation. Yoga techniques allow deep relaxation to take place, leading to alpha and beta states of the brain. We therefore feel that having the skill to alter between alpha and beta states is useful for synthetic and analytical thinking respectively, which we teach using a course of yoga and meditation. Literature also suggests that it is possible to induce these states through light and sound having a beat frequency similar to that of these states using what are called binaural beats. However, Yoga is considered a time-tested method for attaining these states, and was easier to introduce because of its cultural acceptance in India.

6.2 Methods influencing creativity

Methods or procedures are essentially process-prescriptions to help attain a task. Creativity methods, from the point of view of the two major influences postulated in this work should support enhancement of knowledge or flexibility. Most conventional creativity methods are meant to enhance flexibility, and only indirectly knowledge. Brainstorming, for instance, enhances ability to think up new ideas as an exposure to other ideas generated. It allows one to be exposed and stimulated by many ideas. Compendia of various sort on the other hand, primarily help provide knowledge of ideas which could be used for solving the task at hand. Most of these are meant to help create novel, purposeful ideas.

Here we spacifically talk about a method for supporting resource-effectiveness, one that helps create more structure-shared ideas. Structure sharing is the sharing of a structure for many functions in a product, and is one of the many forms of sharing used in a product [Chakrabarti, 2001]. A methodology has been developed which allows a computer program to create structure shared concepts for a sensor design principle (synthesised using building blocks metaphor) so as to create potential physical embodiments for the principle that uses least number of parts to satisfy the functions [Chakrabarti and Regno, 2001; Chakrabarti, 2004]. A method for use by designers is also developed [Chakrabarti and Singh, 2005], using which designers can modify a design in order to make it more structure-shared and resource-effective.

6.3 Stimuli influencing creativity

Cambridge Advanced Learner's Dictionary defines stimulus as "something that causes growth or activity". Stimulii or triggers are pieces of knowledge that could lead to larger ideation activity, potentially creating new idea spaces. Research at Ideas Lab explores two approaches for providing stimuli, In the first, formal techniques are used to automatically create a wide variety of semi-complete alternative designs for a given task, and expose the designer to these designs. The idea behind is similar to that of brainstorming – these ideas should stimulate the designer to think in previously unexplored directions. FuncSION – an acronym for Functional Synthesiser for Input Output Networks – creates designs at topological, spatial, spatial and simulational levels to provide a comprehensive variety of ideas to a designer, in the mechanical domain [Liu et al., 2000; Chakrabarti et al., 2002]. Comparison of computationally generated ideas with those produced by designers shows substantial potential for such systems in enhancing designers' creative ideation potential.

The other route explored is that of using analogically relevant biological and artificial systems available as potential stimuli for satisfying a given task. In this case, a softare called Idea-Inspire with large databases of natual and artificial systems is created with the behaviour of the systems described using a novel generic behavioural language called SAPPHIRE model of causality. Techniques have been developed to represent a problem in a generic sense and search the databases for suitably relevant entries. Comparative tests in design experiments in which designers ideate first without and then with the help of the entries searched from the software as stimuli – show a substantial increase (100-200% additional ideas) in the number of ideas generated after designers' own ideas got exhausted [Chakrabarti et al., 2005].

7. Discussion and summary

The thoughts reported here are largely speculative; many are based on analysis of product cases and findings by other creativity researchers. The main points proposed are:

- A creative idea or solution has three related aspects: novelty, purposefulness and resource-effectiveness.
- Creativity has three mutually related major influences: knowledge, flexibility and motivation. Only knowledge and flexibility are direct major influences; all other influences affect these two directly or indirectly (e.g., by influencing motivation).
- An evaluation matrix is proposed for positioning the influences of a creativity support in terms of whether it affects problem or solution generation by enhancing flexibility or knowledge.

- Creativity methods are taken here as divergent methods that assist in finding problems or solutions.
- Flexibility requires knowledge that is generic and guides change in a domain- and solution-neutral way, while ‘knowledge’ is largely domain- and solution-specific.
- A number of creativity-enhancing means are being explored at Ideas Lab, IISc, at skill, method and stimuli levels, where some are beginning to show substantial potential.

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References

Adams, JL. Conceptual Blockbusting: A Guide to Better Ideas, 3rd Ed., Addison-Wesley, MA, 1993.

Chakrabarti A. A Measure of the Newness of a Solution Set Generated Using a Database of Building Blocks, and the Database Parameters which Control its Newness, CUED/C-EDC/TR64-April 1998, University of Cambridge, 1998.

Chakrabarti, A. Towards a measure for Assessing Creative Effects of a Creativity Technique, Intl. Conf. on Eng. Design, Stockholm, 2003.

Chakrabarti, A. Towards Hybrid Methods for Synthesis, Proc. of the Intl. Conference on Engineering Design (ICED01), Design Research – Theories, Methodologies, and Product Modelling, pp-379-386, Glasgow, 2001.

Chakrabarti A. A new Approach to Structure Sharing, ASME JCISE, 1, 1, 2004

Chakrabarti, A. Some Thoughts on Definition, Influences and Measures for Design Creativity, in Engineering Design, John Clarkson (Ed.), London, 2005.

Chakrabarti, Amaresh, and Singh, Vishal. A method for structure sharing to enhance resource effectiveness, International Conference on Engineering Design – ICED05, Melbourne, August 18-20, 2005.

Chakrabarti, A., Johnson, A.L., and Kiriyama, T. An Approach to Automated Synthesis of Solution Principles for Micro-Sensor Designs, Intl. Conf. on Eng. Design, 2, 125-128, Tampere, 1997.

Chakrabarti, A., Langdon, P., Liu, Y-C., and Bligh, T.P. Supporting Compositional Synthesis on Computers, Engineering Design Synthesis: Understanding, Approaches and Tools, pp-179-197, Springer, London, 2002.

Chakrabarti, A. Sharing in Design: Categories, Importance and Issues, Proc. of the Intl. Conference on Engineering Design (ICED01), Design Methods for Performance and Sustainability, 563-570, Glasgow, 2001.

Chakrabarti, A., and Regno, R. A New Approach to Structure Sharing, Proc. of the Intl. Conf. on Engineering Design (ICED01), Design Methods for Performance and Sustainability, pp-155-162, Glasgow, 2001.

Chakrabarti, Amaresh, Sarkar, Prabir, Leelavathamma, B., Nataraju. B.S. A Behavioural Model For Representing Biological And Artificial Systems For Inspiring Novel Designs, International Conference on Engineering Design – ICED05, Melbourne, August 18-20, 2005.

Chakrabarti, A., Sarkar, P., Leelavathamma, B., Nataraju, B.S. A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas, Accepted for AI EDAM, 2005

Davis, GA. Creativity is Forever, 4th Ed., Kendall Hunt, Dubuque Iowa, 1999

Fox, JM, and Fox, RL. Exploring the Nature of Creativity, Kendall Hunt, Dubuque Iowa, 2000.

Gluck, FW. “Big Bang” Management: Creative Innovation, 49-59, The McKinsley Quarterly, Spring 1985.

Hatchuel A, Le Mason, P, and Weil, B. C-K Theory in Practice: Lessons from Industrial Applications, International Design Conference, Dubrovnik, May 18-21, 2004.

Kirton, MJ, Adaptors and Innovators: Styles of Creativity and Problem Solving, Routledge, London, 1994.

Lewis, D. You Can Teach Your Child Intelligence, Souvenir Press Limited, London, 1981.

Liu, Y.C., Chakrabarti, A., and Bligh, T.P. Further Developments of FuncSION, , Artificial Intelligence in Design’00, J.S. Gero (Ed.), pp- 499-519, Kluwer Academic Publishers, 2000.

McKim, R. Thinking Visually, Dale Seymour Publications, 1980.

Prince, G. The Practice of creativity, Harper and Row, 1970.

Shah, J, Hernandez, NV. Metrics for Measuring Ideation Effectiveness, Design Studies, 24, 111-134, 2003

Terninko, J, Zusman, A, Zlotin, B. Systematic Innovation: An Introduction to TRIZ, CRC Press, 1998.

Wallace, KM. The Eng. Design Process, 1st Year Lecture Notes, Dept. of Eng., Univ. of Cambridge, 1990.

Lord King. Creative Thinking, 2005, http://www.ahapuzzles.com/creative_thinking_1.htm

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