Role of Random Analogy in Creative Idea Generation for New Product: An Empirical Study

Submitted in partial fulfilment of the requirements
of the degree of

Doctor of Philosophy

by

Sharmila Sinha

(Roll No: 09413801)

Supervisor

Prof. B K Chakravarthy

IDC School of Design

Indian Institute of Technology, Bombay

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Approval Sheet

This thesis entitled *Role of Random Analogy in Creative Idea Generation for New Product:*

An Empirical Study by *Sharmila Sinha* is approved for the degree of Doctor of Philosophy

Examiners

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-Declaration-

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Date: October 2020

Abstract

The rapidly changing world scenario and its implications on social needs and behaviours in this new century have stirred the focus of organizations towards the fostering of new ideas. Research pursuits on the phenomena of idea generation have been on in the field of cognitive psychology, to understand the working of the mind. Substantial innovations often result from transferring solutions from one industry/domain to another by forming correspondence between elements of representation, creating a path for cross transfer. Analogies possess the potential to juxtapose knowledge from one domain to another following the principles of making "the strange familiar and the familiar strange" (Gorden, 1961).

In the creative field of design, expert designers often use analogy for strategic problem solving and new idea generation, based on prior experiences (Dunber & Blanchettel 2001). Therefore, in the case of novice designers, inculcating this way of thinking can be a way to surmount linear patterned thinking and expand the boundaries of creative exploration. This stems from the tendency to search for solutions that have previously shown results or search for results within area of expertise to override the fear of failure. This has led most design by analogy studies to focus on data patent mining (Altshuller 1984) using computational support for big data management and retrieval. While studies reveal that analogy usage is pervasive in many disciplines, there are very few studies that show how and why novice product designers face challenges to use analogy inspiration for ideation.

This research study is scoped to objectively assess the phenomenon of random analogy triggered generative ideation conditions and discover the key challenges and opportunities, both at the individual's cognitive level, as well as design application level, to develop key insights for new product idea initiation. The objective of the research was to demonstrate and describe how and why random analogies, when used during idea generation, can increase the probability of success towards creative and paradigm-changing product design ideas even by novice designers. Though analogies seem to be commonplace in the design domain/practice, the spontaneous use of random analogy is yet to be studied, mainly when it comes to creative ideation. Following a qualitative research method a 3 stage exploratory study is carried out to seek the causal relationships involved between the creative parameters and its effects on the

phenomenon of random analogy triggered idea generation. This has helped obtain the relevant evidence and insights that would help build a strong base for design practice.

The methodology of random analogical association in the various stages of new product design has enhanced generation of creative outputs. Random analogy helped as idea starters that further catalyzed multiple points of association and analogies. This steered abstract thoughts that allowed radical exploration through force-fitting attributes from source to domain (Sinha and Chakravarthy 2013). Educational institutions and corporations need to take initiatives and lead changes through integrated pedagogic interventions by creatively rethinking about the highly complex society and business scenario.

Key words: Random analogy, idea generation, new product, phenomenology

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Chapter 1
Introduction

1.1 Research Background

The changing social and behavioural needs in this new century have been compelling organizations to focus upon new product development and the fostering of new ideas. The key differentiator in keeping abreast of current trends is through creativity and innovation. Thus, the application of creativity to the innovation process is the way forward that can help product design firms effectively ride the creative economy.

Studies about the phenomena of idea generation have seen a lot of research activities in the field of cognitive psychology to understand the working of the mind - which has better revealed the process of analogical reasoning through associative thinking. Vosniadou and Ortony, in their work on '*similarity and reasoning*' brought out the fact that "the ability to perceive similarities and analogies is one of the most fundamental aspects of human cognition". It is crucial for recognition, classification, and learning, and it plays an important role in scientific discovery and creativity. Successful learning often depends on the ability to identify the most relevant bodies of knowledge that already exist in memory so that this knowledge can be used as the starting point for learning something new." (Vosniadou & Ortony 1989). The wide interest in this field of study has brought out radically different points of views based on varied focus areas: from the development of psychological processes involved in reasoning by similarity and analogy, and the conditions that promote the application of analogical reasoning; to solving the computational problems involved in simulating analogical processing in problem-solving situations.

Since it is not natural to think illogically, normal thought processes are not optimized for creative thinking. Rather, they are related to pattern recognition as the mind processes data from the senses to recognize people, objects, situations, and places. An analogy is a

fundamental cognitive mechanism of retrieving this existing knowledge and applying it in a new context (Hargadon 2003). This is to drive the continuous need for improvement and innovation.

Studies show that the process of idea generation uses the rich resource domain of external sources of information to generate new ideas. Various external stimulants in the form of tools, techniques, and methods are used to stimulate the generation of ideas. Substantial innovations often result from transferring solutions from one industry/domain to another by forming correspondence between elements of representation, thus creating a path for cross transfer. Analogies possess the potential to juxtapose knowledge from one domain to another following the principles of making "the strange familiar and the familiar strange" (Gorden, 1961). Retrieving solutions and generating ideas from analogies result from the fusion of pieces of knowledge to make new connections. According to the theory of bounded rationality, the search field of a developer – the same as any other individual – is constrained. He/she, when developing solutions, is only able to notice a limited section of the environment, because of his/her limited cognitive abilities. (Simon, 1957; 1982; 1996) In addition, the retrieval of solutions from very distant domains can be constrained by established thinking patterns. Most people search for solutions in the nearer context of the problem as they are led by already fixed thinking structures. As it is seen, most people were having great difficulty to think outside their areas of expertise; thus, functional fixedness based on experiences of former projects can block the way to innovative solutions (Schild, Herstatt and Lüthje 2004). Equal importance is to be given to both knowledge acquisition and skill development for creative solution generation. Analogical reasoning is one such strategic skill. Many expert designers often use the analogy for strategic problem solving and new idea generation. Therefore, in the case of novice designers, inculcating this way of thinking can be a way to surmount linear patterned thinking and lead to open radical idea generation. The use of analogy in creative thinking has brought about many breakthrough innovations, as new product ideas often result from recombining existing know-how and analogies, e.g., sailboat + steam engine = steamboat. Empirical work by Dahl and Moreau, show that originality during idea generation can be enhanced by encouraging the extensive use of analogies, especially far analogies that can lead to original designs, as an analogy connects two previously unrelated ideas and allows the two to be interpreted from a new

perspective (Dahl and Moreau 2002). Analogical reasoning in problem-solving operates by recognizing and exploring the similarity between the source and the target and mapping knowledge from the source area to the target problem. The general relevance and utility of analogical thinking in problem-solving is advocated through psychological models, where it has been demonstrated that analogies are effective in the combination of two matrices of thought leading to creative solutions (Koestler 1964).

When engaging in creative activities, the designer has to expand the boundaries of the semantic domain of the problem, in order to create new instances of the concept. Despite this, most problem-solvers have a tendency to fixate on their mental representation of the existing solution, hence inhibiting their capability to form new ideas (Hekkert, 1997). When investigating the problem space for possible solutions, most people choose methods of inquiry similar to those that have previously shown results, or they search for results within their area of expertise. Thus, the significance of analogical problem-solving has been demonstrated through psychological theories (Gentner, 1989). Considering design as a task involving some sort of problem-solving leads to the assumption that the methodical use of analogies can lead to a greater variety of idea exploration, and consequently, more creative products. Furthermore, many research projects in the field of engineering design and Bio-inspired design have shown how cross-disciplinary databases organized by functional and structural features are presented as an especially potent source of analogies in design. This is due to the various types of interpretation the analogies allow. Structural alignment is proposed to explain property interpretations where property from one concept is asserted on the other. The structural alignment process is essentially analogical structure-mapping (Gentner 1983). Studies in the fields of linguistics and psychology have shown analogical reasoning as a central aspect of the design process (Holyoak & Thagard 1997), which is akey driver of analogy inspired design practice. The practice of analogy-driven design is thus recognized as one approach to innovation but remains an area of active research in the overall design methodology.

Design research, too, is in pursuit of disseminating new knowledge and approaches to generate creatively - compelling product design ideas and concepts. Today in the fields of Psychology, Computational Sciences, Engineering, and Management Studies, intense

research efforts are going on to develop analogy methods and computational tools to aid creativity. Analogical thinking is frequently found to be used in the lab and classroom-based studies involving creative design activities for assessing the effect of new tools and cognitive processes. To describe the role of analogical input and the impact it has on the real world, projects on innovation are being carried out. To make innovation by design meaningful, the process of analogical stimulation - along with its advantages and limitations - needs to be understood and applied towards generative idea production; so as to harness the full potential of the workforce in the growing economy within the creative industry and have the novices fulfilling a productive engagement process.

1.2 The Research Problem

Even though the design is recognized as one approach to innovation, it remains an area of active research as cognitive inertia to free exploration becomes an inhibitor for idea generation. As a result, they are putting the focus on the quality of examples retrieved during the design process. Purcell and Gero, too, stated that the retrieval of high quality, innovative design examples as analogies are considered to be a potential source for developing high quality creative ideas and solutions (Purcell & Gero, 1996). Leading most design by analogy studies to focus on data patent mining (Altshuller 1984) using computational support for big data management and retrieval. While studies reveal that analogy usage is pervasive in many disciplines, not many studies have shown how and why novice product designers face challenges to use analogy inspiration for ideation. Today, the practice of analogy driven design is recognized as one approach to innovation but remains an area of active research due to the cognitive inertia of analogy retrieval and mapping. Often, existing design ideas or solutions are reused interestingly as components for new design ideas or in different contexts to trigger the generation of creative ideas. Brown counter argues this by suggesting that it is important to experiment with objects in many different ways and to look at them from different points of view that are likely to free objects from specific roles, thus rendering them more useful as tools for more varied applications. Even though experiences can enhance flexibility and lead to increases in transfer, a counter to this is with regards to how the habitual use of an object to perform a specific task produces a lower rate of transfer (Brown 1989).While studies reveal that analogy usage is pervasive in a variety of design disciplines,

not many studies have shown how and why novice designers retrieve different types of examples for solution inspiration or the challenges they face. This study explores the development of a design framework for random analogy triggered creative product ideation and the overcoming of implementation challenges.

1.3 Research Aim and Objective

For designing new products, idea generation sessions - commonly known as 'brainstorming' - are conducted for finding multiple solution ideas to an existing problem. This makes the idea generation process not only a key initial step for the development of novel products, but also provides an opportunity to explore the ideation process further. This study aims to understand the operational phenomenon of idea generation.

Aim:

1. Objectively assess the phenomenon of random analogy driven idea generation by applying psychological concepts and theories of associative thinking, memory search, and knowledge representation

2. Find out the perceptual and operational perspective of retrieval and representation of analogous inferences towards creative product design ideas.

3. Explore and assess specific structures and patterns in the phenomenon of idea generation with random analogy triggers. Initiate the implementation of random analogy triggered generative framework for supporting uninhibited generation of creative ideas.

Objectives:

1. Enhancing the creative idea generation potential of novice and less experienced product designers with random analogy triggered stimulation.

2. Demonstrate and describe how and why random analogies (which are used during idea generation) can increase the probability of success towards creative and paradigm-changing product design ideas.

1.4 Research Relevance & Limitation.

Based on studies done by the Synectics group on innovative product development, it has been reported that a non-rational idea produces evocative metaphors, images, and unfinished dimensions that can be built upon. This kind of non-rational interplay of thought can be used in a generative way towards increasing coherence. The starting point is to take 'psychological chances' by abandoning familiar ways of looking at things and defying all logic (Gordon 1961). Various inventive discoveries and innovative products designed through analogical associations have motivated the field of inquiry. Though analogies seem to be common place in the design domain/practice, the spontaneous use of random analogy is yet to be explored, mainly when it comes to creative ideation.

The scope of this study lies in:

1. Through the forced random analogy guiding framework, abduct patterned thinking and allow generative catalization of idea output for designing creative products

2. Enhancing new product idea generation in the early stage of designing, primarily for novice and less experienced designers, and the creative economy at large.

This gives rise to the following overarching questions that are used to structure the design and analysis of this study.

1.5 Research Question

RQ1: How do novice designers generate creative ideas and what role do analogy triggers play in it?
RQ2: How are random analogy triggers sourced and used for the generation of creative new product ideas and what are the implications on the idea output process?
RQ3: How can forced random analogy trigger creative idea exploration and lead to Creative and Paradigm modifying new product ideas?

1.6 Research Study

The research study of the phenomenon is designed in explorative stages to answer the research question for evolving some confirmatory findings on the creative idea generative

potential of random analogies for new product design by less experienced designers. The research defines an analogy based ideation framework to guide novice and amateur product designers to mitigate domain-based ideation through forced analogy triggers. This is done by putting to use the operational mechanism of Gordon's Synectics (Gordon 1961), DeBono's PO and random input tools (DeBono 1970, 1972), alongside Osborn's SCAMPER (Osborn 1957) for analogical thinking and associational representation.

The exploratory studies investigate the limitations associated with analogy drivers for idea generation as well as the quantity, novelty, diversity, and quality of idea outputs. Normative design theories favour divergent solution searches as a strategy in the early phases of design (Pahl and Beitz 1984), though Guilford and Torrance proposed that for effective idea generation, one should generate a large number of ideas from as many categories as possible: emphasizing the fluency and flexibility of the generation of ideas (Guilford 1950, and Torrance 1974). The experiments include qualitative assessments of the ideas and their relation to various parameters. Qualitative assessment refers to analyzing the content of the idea generation process - from idea words, scribbles, idea maps, sketches and idea presentation along with the researchers' observational notes and categorization of the idea outputs in relation to the research variables.

1.6.1 Qualitative Phenomenological Study

The research followed a sequential evolutionary process through three studies conducted to build, refine, and clearly articulate the phenomenon:

Introductory Observational Study: To address RQ1 and gain insight into the phenomenon of idea generation in 2 varying conditions of analogy usage.

Exploratory Study 1: To address RQ2 by feeding in the insights gained from addressing RQ1 and gaining a deeper understanding of the phenomenon to establish new findings. The idea output triggered by forced random analogy and forced mapping to target versus random analogy triggered idea generation with very rational mapping was helpful in developing the 2nd exploratory study.

Exploratory Study 2: Using the understanding of the phenomenon from the previous studies, this study evolved to address the generative potential of forced random analogy in creative idea generation as well as the challenges encountered in suspending reality while ideating by incorporating a guiding framework, thus answering RQ3: How does forced random analogy trigger creative idea exploration and lead to Creative and Paradigm modifying new product ideas? This helped in establishing the confirmatory findings and bring out new results.

1.7 Structure of the Thesis

The general flow and structure of the thesis is presented as a guiding factor by weaving each chapter into the other in a systematic manner. The thesis consists of eight chapters to conclusively fulfill the objective of the study following the specific flow of content from chapter to chapter.

Chapter 1: Provides an overview of the research study, investigating the idea generation phenomenon and the role of analogy in it.

Chapter 2: Reviews the various theories and concepts pertaining to the area of the research study. The creative process of ideation and generation of creative product ideas, the underlying principles and functioning systems of analogical thinking and representation for creative application are reviewed to set the base and direction of the research in the following chapters in the thesis. A key problem in using analogies for idea generation is to override them instead of finding relevant analogies. The method of accessing analogies has limited resources and can have the potential of exploration to bring value to specific knowledge inthe context of creative problem ideation. The research bases itself on the idea of producing potential of analogies and its constraint of being able to apply it right and see how it can be overridden and leveraged. But most research has been concentrated on modeling the processto generate the best analogies. The researcher feels that this in itself becomes kind of self-defeating and contradictory to the concept of out-of-domain stimuli, especially in the case of new product design ideation. This gives the scope of exploration of forced unrelated analogy usage for radical idea generation study. Also, very little work has been reported regarding Product design in relation to the use of analogy other than anecdotal incidents.

Chapter 3: The research study design outlines and discusses the approach and the specific research methods used to gather and analyze meaningful data specifically to argue the role of random analogy in idea generation. The methodology used and the procedure to be followed are presented in the three-step sequential procedure of inquiry, allowing for the building of new knowledge. The research has primarily focused on inference finding to ground the assumption of the creative driving potential of random analogy in idea generation. Taking into account the whole research process based on the objective of the inquiry, the methods used specifically aid in analyzing and reporting data to draw conclusive insights for addressing the unresolved gaps.

This research design has been developed to fundamentally collect information that can fulfill the exploratory requirement of the study objective. This is achieved by answering the `why' questions to seek the causal relationships involved between the factors and its effects on the phenomenon – thus, obtaining the relevant evidence and insights to help build a strong base for design practice.

Chapter 4-6: Contains all the studies carried out for data collection. The Introductory Study that checks out the working of an analogical trigger's effect on the idea generation phenomenon, which leads to Exploratory Study 1 and observing the effect of the suspension of reality in idea mapping. Finally, the Exploratory Study 2 that drew learnings from methodological elements in chapters 4 and 5 are integrated to propose a guiding framework of operation. The concept was to use a structured, attribute-triggered stimulation process that further work as analogous triggers to generate creative ideas for designing new products. This process is then implemented, keeping in mind the experience and barriers faced by novice and mid-level designers.

Chapter 7: The findings elucidate and evaluate the results produced to draw certain conclusions. A clear articulation of the phenomenon and a positive direction to the ways of mitigation of barriers to radical ideation for novel idea output with forced random analogy triggers is seen. The understanding of the challenges and opportunities underlying the analogy driven idea generation phenomenon helped develop a random analogy based idea generation guiding framework for new product design to facilitate novice designers better

and provide positive results. Also through weighing the scope and limitations of the findings, future work recommendation is proposed.

Chapter 8: The conclusion chapter outlines and summarizes the contribution of this research study in the field of product design, explicitly articulating the implications of the findings on design practice and design pedagogy. The findings revealed deep insights and factors of influence and deterrence that were dovetailed into the subsequent study to finally bring tothe forefront the requirement of a guiding framework, its development and its implementation. The results from the research revealed that a random analogy generative framework facilitated creative idea generation for novice and mid-level product designers and design engineers.

Chapter 2
Literature Review

2.1 Introduction

This chapter elaborates on the specific selection of literature – from the theoretical, empirical and methodological aspects of design ideation and thinking in association to analogy triggered design, and the various ideation methods popularly used in these fields of study. The specific areas of study were narrowed down to by setting clear search parameters to build the research on.

Table 2.1: Literature Review Process

Search starter	Key words to find key people in the field of study and build from referencing.
Sourcing method	Search Database and previously known articles.
Sources used	ACM, Journal of Psychology, Science Direct and Design studies and Design issues etc.
Population	Non specific
Studies taken	Empirical research including interviews/surveys, action research, case studies, observational studies, and experimental studies.
Inclusion criteria	Serious peer reviewed research articles on empirical studies of creative new product designing from cognitive science, design disciplines, and analogical reasoning and thinking in the design process.
Language	Only English.
Article dates	Non-specific.

The sourced literature as stated in Table 2.1, was categorized to gain a clearer understanding for building discourses and arguments by addressing the following views:

Theoretical view- The theoretical base takes into account the design cognition aspects and the emergence of certain methods and deductions. As idea generation and the use of analogy falls into the purview of thinking and comprehension, explorations in the fields of psychology and linguistics are used to understand and operationalise the process. Analogical reasoning is knowledge-based and is dependent on relational familiarity rather than analogical ability. Gentner in his structure mapping framework stated that the most useful analogies involve relations; in particular causal relations (Gentner, D. 1983). Thus, great importance is given to sourcing the right analogy. Even within the theory, there is a conflict between congruity and incongruity. Thagard's study states that a major part of what makes an analogy effective in creative leaps is the surprising combination of congruity and incongruity (Thagard 1998). It's not about the semantic fit of target and source; the surprise is when an unexpected relational fit presents itself. The unusual mapping produces the surprise, as it connects together elements not previously mapped, yet it has to be done in a way that is still highly coherent. This has helped re-identify the gap for exploration and its scope to understanding the idea generation phenomenon and the role of analogy in it within the Product design domain.

Empirical view- A systematic review of empirical studies conducted in the area of analogy driven design was carried out. This includes previous studies in creativity with analogy for design; observations conducted in experimental as well as actual conditions, real life product analysis and their deductions, as well as giving focus to word association and other methods popularly used in prior study. Ideation with random analogy is an important generative stimulator for creative ideas, but as a conscious cognitive process it is avoided due to the fear of rejection of unconventional representation. As stated by Lakoff & Johnson, literal interpretation is due to our culturally imposed thinking and presumptions of dichotomous relationships which blinds us to the possibilities of alternative explanations (Lakoff & Johnson 1980). Most literature deals with the difficulty aspect, thus ensuring the focus goes towards the development of process tools.

Methodological views- The predominant methodology uses experimental methods to study causal effects of treatment as well as case based studies to achieve a deep understanding of the process and interaction. As research in the area of creative thinking and associative thinking involves verbal, textual and visual data that are both internally as well as externally represented, in-depth analysis of the inceptions and current use of methods are carried out. From behavioural data collection on real and hypothetical projects using protocol analysis and content analysis, the process and output measures of content have been studied.

The research follows exploratory studies using content analysis and reflective protocol for data collection and analysis.

Thus the research study focuses on the following as depicted in Figure 2.1:

i. New product ideation.
ii. Use of analogy for design ideas.
iii. The phenomenon of analogy driven idea generation.

Full-text articles were obtained through author search of known researchers who are active in the area of study. A variety of aspects of problem domains, populations and research techniques were studied. . A fair mix of qualitative and quantitative methods were observed to be used in both real world and experimental scenarios. These methods have been studied to assess the use of analogies within and across domains and understand their relationship with creativity.

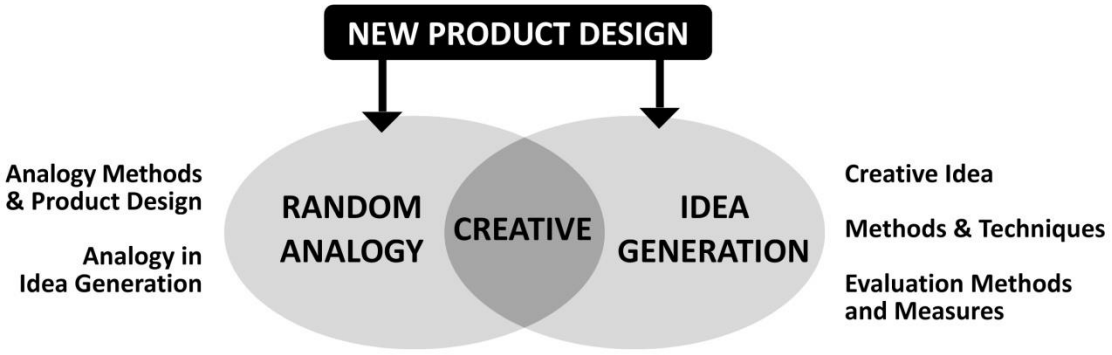


Figure 2.1 Core areas of literature review

2.2 Overview of Creativity in Design

Creativity and Design issues can be seen to predate human civilization as a necessity for survival and evolution. Thorough studying of these aspects came much later, with the central factor being the relation between originality and effectiveness. Further studies have ensured the vital aspect of creativity as originality, but it is not sufficient in itself and there must be some form of effectiveness as well. As analyzed and defined by Ranco, ‘‘Originality is vital, but must be balanced with fit and appropriateness’ to justify creativity” (Ranco 1988). Here, the word balance suggests leaving room for contextual flexibility while imparting value that actually heightens creativity. This has been expanded to being worthwhile (Cropley 1967), appropriate (Jackson and Messick 1965), relevant (Kneller 1965), adaptive to reality (Barron 1955), and ratifying the creative process as a highly organized system of responding in an original act. This set the ground for establishing creativity as a systematic learned process with different facets and parameters, playing a unified role and not an esoteric thing. This ambiguity in imparting the value perception impels people to interpret situations for themselves, it encourages them to start grappling conceptually with systems and their contexts, and thus to establish deeper and more personal relations with the meanings offered by those systems (Gaver et. al. 2003)

Guilford further took the thought forward in setting the act of balance by saying, ‘‘Creative work that is to be realistic or accepted must be done under some degree of evaluative restraint.” Too much restraint, of course, is fatal to the birth of new ideas (Guilford 1950). Stein further elucidated, saying, “the creative work is a novel work that is accepted as useful or satisfying by a group at some point in time”. By ‘novel’ I mean that the creative product did not exist previously in precisely the same form. The extent to which a work is novel depends on the extent to which it deviates from the traditional or the status quo. This may well depend on the nature of the problem, the knowledge base or experience that exists in the field at the time, and the characteristics of the creative individual and those of the individuals with whom he or she is communicating. In speaking of creativity, therefore, it is necessary to distinguish between internal and external frames of reference, (Stein 1953) explaining the personal, social, and historical creativity. Thus, making creativity a purpose to a means.

Design too is a purposeful process of systematic problem solving through scientific inquiry in an iterative way.

Design activity, as defined by Treffinger, is a want or a need for a new option for the open ended and ambiguous situation and carrying out its solution successfully in a planned way (Treffinger 1995). Bonnardel pointed out that in a creative design context, the design solution must be both new and adaptive to the characteristics of the situation or context, including future user and usage (Bonnardel 2006, 2012). Sternberg & Lubart defined the twofold requirement of creative design as the ability to produce work that is both novel and appropriate (Sternberg & Lubart, 1999). To maintain the dual requirement of the creative design, it employs both divergent and convergent thinking.

2.2.1 Creative Thinking

The creative thinking process of design is carried out to expand, explore, and create new ideas. In this exploration, designers are known to draw inspiration from the analogous situation and build connections to the design domain. Which allows the divergent nature of the process to manifest. This kind of creative association acts as a powerful tool when trying to understand a new situation or solve a new problem and build unexpected design solutions (Yanowitz, 2010). Analogical thinking helps transfer elements from one or more sources, to trigger design solutions for the target domain, to build design concepts with the clustering of multiple ideas. This associative thinking process is also useful to propose and communicate non-communication formative ideas that are in contrast to the source.

Today more than ever, the surge is seen in the need for understanding the process behind the creative act and output so as to foster a creative attitude and mindset. Organizations today are putting emphasis on the creative potential of individuals to be adaptive to change and open to new ideas. Torrance has worked to devise a set of tests and testing parameters to judge levels of creativity (Torrance 1994, 1995).

2.2.2 Creative idea

Since ideas are vital for any creative endeavor, it would be helpful to understand what an idea is. Dictionary.com defines an idea as *"any conception existing in the mind as a result of*

mental understanding, awareness, or activity". Jack Foster's discussion in his book entitled "How to Get Ideas" (Foster 1996) looks at how others have defined ideas. James Webb Young', author of the book "A Technique for Producing Ideas," says an idea is *"nothing more nor less than a new combination of old elements"* (Young, 1992). Arthur Koestler, stressed on the fact that-*"creative originality does not mean creating or originating a system of ideas out of nothing, rather out of a combination of well-established patterns of thought-by a process of cross-fertilization*", where one "*uncovers, selects, reshuffles, combines, synthesizes already existing facts, ideas, faculties, and skills*" (Koestler 1964). All these definitions highlight new ideas as a recombination of elements of others ideas. Using the dictionary definitions, one can deduce that ideas come from people (not machines or computers) are a result of mental activities. Thus, it can be stated that new ideas are formed as a result of mental activities where previous knowledge, information, facts, or ideas are recombined and associated in some way or other. Vandenbosch, states that "*ideas and opportunities are intertwined. Recognizing or creating an opportunity is an occasion for generating or testing an idea; an idea may lead to an opportunity and it may require an idea to capitalize on an opportunity*" (Vandenbosch, et al. 2006).

Creative ideas are potential solutions gained through inspiration sources or transforming a product and extending beyond it. Often they are used as indicators to judge individual creative capacity or success of methods and processes. Four factors were set by Torrance to measure creative ideas and thinking:

- Fluency: the total number of relevant responses.

- Flexibility: number of varied categories of relevant responses.

- Elaboration: amount of detailing in the responses.

- Originality: The rarity of the response.

Research by Amabile has refuted the test's generic aspect as creativity in design is task specific. But subsequent research has seen the application of these parameters on the finished design in relation to other factors influencing it (Amabile 1996).

2.2.3 Source of Ideas

While debating about the creative measures of ideas, it's important to always know "where new ideas come from?" or "what are the most likely sources for new ideas". As idea generation is a cognitive process, it is none other than people who are the sources of ideas; computers, or machines cannot create ideas – but they facilitate the generation process by creating connections from existing patterns (an article in MIT Technology Review has described a computer algorithm that created novel patentable designs of antennas (Williams, 2005).Without people, there are no ideas. Manufacturing plants running totally autonomously; software programs executing code on a server; machines punching parts - none have never been known to create an idea by themselves. Individuals may look at things and come up with new ideas, but things are not the source of the ideas - they are the stimulus. As the stimulus is controlled, the exploration by the individual can be instrumental in bringing out the power of association in the plurality of thought.

People are the source of ideas and activities and - through tools and techniques – ideas are produced. Activities in the brain involving association, recombination, creativity and so on, are necessary to create ideas. People may create ideas while sleeping because their brains are active and are actively recombining things in unique and often irrational ways. By looking at it this way, some insights can be grasped.

2.2.4 Effects on Ideas

As people are a source of ideas, the effect on ideas will have to be related to them. The factors affecting ideas and their production can be seen as follows:

1. Stimulation: This has a 'positive' effect on idea generation by consulting external material prior to or during the process. The stimulation is believed to help designers get started with the ideation process, and help create ideas that are similar to the stimuli, but heterogeneous stimuli presenting multiple categories have been found to facilitate the production of more diverse ideas (Finke, Ward & Smith1992; Howard-Jones et al., 2005).
2. Fixation: It's the reversal of stimulation, and refers to the negative impact. A number of studies on 'design fixation' have tried to characterize it as a tendency to reproduce

parts of the given examples to independent work unknowingly. It can also happen that the person gets fixated on the stimulant itself as well.

3. Time: A key component in the process of idea creation from the point of view of constraints as well as advantages. It is not directly correlated.

2.3 Idea Generation: An Overview

Idea generation is a key component in new product development that can give the highest leverage to the business of a firm. Thus, generating innovative ideas is a critical requirement in the designing of products. The process of idea generation entails multiple domain explorations - from aspects of technology, processes, socio-cultural trends, user needs, etc. to evolving new out-of-the-box product designs. In the fast-changing business scenario, the field of design too has evolved into a multi-domain synthesis process. Designers today seek inspiration from existing designs, often transforming, combining or adapting elements from them for generating new ideas.

To study the process of idea generation in designing, it is important to look into the realm of creativity studies. Most of the investigation in the area of creative idea generation has been done outside the design domain; from the field of psychology, philosophy, physiology, sociology, management, etc. with each shaped by their own problems and lines of investigation. Thus it is important for designers to develop methodologies of design research (Cross 2000) to counter the danger of non-designer approaches to importing methods that are not appropriate to the field of design, and to develop a framework to define and support the practice.

In the 21st century, creative competence is of utmost importance in the domain of product development. Thus the methods in managing the early phases of product design need revisiting by understanding the phenomena of generation of ideas in the design process. This starts by reviewing the existing literature on design idea generation, general theories of idea generation and empirical studies of theoretical development: with the goal being, to expand the perspective of design into the science of design and help both educators and practitioners to advance their acumen towards effective designer-centered practices.

2.3.1 Characteristics of idea generation studies

Idea generation studies are mostly reported through the following experimental processes:

i) By comparing the experimental and controlled condition of ideation by individuals or groups.
ii) By individual documenting the act of ideation in real-time.

The data generated from these studies are:

a) Design idea output in visual or written form.

b) Video recording of the total designing activity along with activity sheets.

Though both have their merit of drawing inferences from the working of the mind, they have their limitations as well in capturing the free-flowing spontaneity of a creative act.

Design idea generation studies have assessed hypotheses and have operationalized independent factors, with the most common variable - being the number of ideas produced - which is also addressed as quantity or productivity of ideas. Counting is done of unique, non-repetitive ideas only. This is a simple figure that is often complemented by some measure of creativity, even though creativity is difficult to define (Mayer, 1999) and measure. Typically researchers consider either the novelty or quality of the idea. Novelty, diversity, or un-commonality are measured in several ways, usually by creating an index of the commonness of an idea, while quality is addressed as functionality, feasibility or even usability (Shah, Vargas Hernandez et al., 2003).

2.3.2 Methods of idea generation

In the face of numerous new design methods, and with the constant pressure to become a more creative practitioner, the need for objective information to help steer the development of design practices with the right choices is important. Idea generation includes activities that aim to produce a large number of variants, without selection, evaluation, or reflection on the ideas. During the early stage of the design process, the ideas are preliminary, abstract, and often not very convincing. A common term that is mentioned in the literature in relation to

idea generation is divergent thinking. Divergence refers to spreading or branching - to a process that opens up many new directions. Sometimes it is equated to associative thinking.

Literature reveals methods associated with ideation in design to facilitate the discovery of ideas. From a basic research point-of-view, they might be labeled as tools for creativity, like lateral thinking (De Bono 1970), dissociative (Koestler 1964), divergent thinking (Guilford1950), Brainstorming (Osborn 1957), TRIZ (Altshuller 1984), Synectics (Gordon 1961), etc. Different kinds of stimuli in a design idea generation process have been quite extensively investigated (Shah, Kulkarni, & Vargas Hernandez 2000). Several investigators have studied how related products and unrelated stimuli included in design idea generation sessions can influence the design process. When this thinking is applied to design ideation, it becomes necessary to find a framework for describing the design activity as a whole; in depicting the steps in this activity, and presenting a theory of design knowledge. Some recent theories of idea generation have been inspired by the Creative Cognition approach (Finke, Ward, & Smith1992), which goes beyond the problem-solving view of design to creating something new from previous experiences and acquired knowledge.

Table 2.2: An over view of the most popularly used methods

	Method	Functions	Commonality
Osborn's Brainstorming, checklist, APS	Exploring random ideas through direct and indirect associations.	Adapt, modify, rearrange	Associative adaptation
Gorden's Synectics	Use of analogies, direct, personal, symbolic and fantasy assumptions.	Transpose, symbolize, abstract	Analogical transfer
DeBono's Lateral Thinking	Random stimulation, forced provocation and challenging assumptions.	Compare, borrow, distort, randomize	Taking analogy
Altshuller's TRIZ	Attribute listing, attribute splitting and forced connections.	Adapt, associate and other use	Analogical mapping

In comparing the most common ideation methods in Table 2.2, it is observed that the core operation mechanism was focused on analogical and associative adaption; with the research study aimed at investigating this core function in the context of early phase of idea generation for new product design. Thus, further literature was reviewed to identify deeper insights to set the parameters, structure and methods of investigation.

2.3.4 Issues and Problems with Idea Generation

Several concerns arise regarding the process of idea generation. Foremost, despite the many books and articles on idea generation, it is still relatively in its infancy and is often less understood as part of the whole innovation process. To help new product designers, idea generation is an imperative activity in the innovation process and its conceptual workings must be clarified. This research attempted to address several problems which are preventing designers from using analogies effectively from coming up with innovation design ideas and the challenges of the idea generation processes.

2.3.4.1 Stimulation and Fixation in Idea Generation

The general findings on studies related to ideas is that some form of stimulation is needed for the production of ideas, which can be internal or external in nature. Studies have shown that stimulation under some circumstances can increase ideational fluency in terms of number of ideas generated. It has also been reported that stimulation occurs mostly within categories, and thereby does not increase the flexibility of idea production (Nijstad et al. 2003). This negative effect is known as design fixation that has been observed in design idea generation (Jansson and Smith 1991). Fixation during ideation refers to conformity effects that result from exposure to examples, which reduces the flexibility of idea production. Or even abandoning further exploration of alternatives that could have generated ideas with high fluency.

The concept of fixation is important for understanding the difficulties faced in solving problems, and on how to overcome impasses reached due to the same. Three general patterns of fixation are typically acknowledged: Functional Fixedness (Duncker 1945), Entrenched Mental Set (Luchins 1942), and Memory Blocking (Smith 1995). Fixation happens when a person is ‘fixated’ by the common functional properties of objects (Duncker 1945). Idea

fixation thus becomes a hindrance to design idea generation, which limits the diversity and originality of subsequent idea generation. (Purcell & Gero1992, 1996, Gero & Purcell 1993).Some factors to consider in this regard include:

1. There are very few comprehensive lists of idea generation activities and techniques which one can utilize. More importantly, the literature confuses activities and techniques, when in fact they are distinctly different. Thus, there is a need to categorize them and see their optimization of usage and maximization of their results to build our study.

2. The research on sources of ideas is often confusing and contradictory. Several articles mix idea generation activities with sources of ideas, which leads to more confusion. A comprehensive review of the sources of ideas is needed and will be of value to innovation practitioners.

3. There are no reviews of the major idea generation processes. There are several famous idea generation processes, but none which have been reviewed or critiqued for their ability to create ideas. Each process is very different and there are no guidelines to help practitioners select the process which is most appropriate for their needs. Thus, the popular idea generation processes need to be described, reviewed, and compared in order to address this issue.

4. A great need to control and manage the idea generation process has lead to the exploration of a frame-work, which has become important to analyse the idea generation processes. Consequently, there is a strong need for an analysis tool to assess the effectiveness of the overall idea generation process.

2.3.5 Idea Generation and Design

Designers should generate a variety of conceptual solutions, as generating several ideas increases the chances of finding better ideas (Shah, Vargas-Hernandez, & Smith, 2003). Herman Herzberger once said that, “Everything that is absorbed and registered in your mind adds to the collection of ideas stored in the memory: a sort of library that you can consult

whenever a problem arises. So, essentially the more you have seen, experienced, and absorbed, the more points of reference you will have"(Herzberger 1991).

Questions arising from this are:

i. How is knowledge stored and retrieved from memory to aid in ideation?
ii. Is knowledge always useful in design, or are there instances when it can actually constrain thought?

Idea generation involves retrieval processes, as new ideas cannot be developed without existing knowledge (Amabile 1996). Here the role of the cues used to probe relevant memories in the design process becomes important. These cues can be either self-generated or provided as an external stimulus in the form of design examples.

2.4 Overview of Analogy based Associative Thinking

Analogical thinking is considered an important aspect of cognition, involving the act of accessing past knowledge that can be in the form of objects, attributes or relationships as a source to understand, define or solve the problem at hand which is usually referred to as the Target (Ball & Christensen 2009). This process of accessing and applying information from one source to a targeted problem is called Mapping (Gentner 1983). Scientific Inventions have largely drawn from analogies. Besides their multitudinous roles one important role of analogies have been to understand and communicate concepts by making the strange familiar and also solve problems innovatively by making the familiar strange (Gordon 1961). Research in the field has shown that experts are able to more correctly transfer elements when the source has underlying similarities and surface dissimilarities (Novick, 1988) compared to novices. The main process is based on retrieval from memory and representation into the mapping. Studies in the field have shown analogy sourcing from within the domain- that is both the target and source are from the same domain - while inter-domain analogy is when the source and target are in two different domains. These are also called near and far analogies. Though both are used to solve problems, studies have revealed the potential of far analogies towards more innovative solutions (Christensen & Schunn, 2007). Dahl & Moreau found that when encouraged to use multiple domain analogies and distant analogies, the

design outcome showed a partial improvement in originality of ideas in parts (Dahl & Moreau 2002).

For the base foundation studies used to understand analogy, their application and implication are from the field of Cognition and Linguistics. The former explains the process and the latter gives certain models of understanding. Thagard and Shelley theorized that analogies can generate emotions by directly relating to a perception of the thing e.g., happiness is like a butterfly; or abstractly express the essence (Thagard & Shelley 2001). Observing and mapping attributes from analogy allows simple representation of abstract concepts as well as abstract representation of simple attributes. The most intriguing role of analogy is its capacity to integrate diverse knowledge sources to create a novel situation.

To observe the use of association in analogical thinking we need to refer to the works of Mednick, where he outlined and operationalized the associative basics of the creative process in the remote association test (Mednick 1962). The basic elements of his theory are that ideas are different from neurological studies of connectivist theory. Association is about activation of one element as a result of the activation of another. When looking at both analogy and ideas it is seen that both are generative processes. It can be an interesting study to see the role of the generation of analogy and its relation to the generation of ideas. Boden's view on creative ideas is that truly novel ideas are associated by thinking generative systems (Boden 1990) and that creativity is based on tacit and explicit knowledge reference to the generative systems. Weisberg defined creative thinking as the mechanism that involves problem solving processes within the creative process and he talked about the use of analogy and its selection on salient similar clues and the association chain that are triggered by environmental events and result in unexpected ideas (Weisberg 1993). Factors creating individual differences are argued by Weisberg as being domain specific expertise, environmental support, chance, motivation and commitment.

Gordon's Synectics is a process of joining together of different and apparently unrelated elements to find new solutions, as he found that solutions to problems were most often restricted due to the problem of being too familiar or too strange. So by understanding the mechanism of idea generation process, he came up with the use of analogy and metaphors as the means to turn the familiar into strange and strange to familiar – a kind of play with

irrelevance. He developed a framework of systems for the use of problem solving ideation by using four types of analogies (Gordon 1961).

2.4.1 Ideation with Analogy

Understanding the cognitive process involved in the formation of analogies is important for understanding the idea generation process. Analogy can be viewed as a mapping of knowledge from one situation to another enabled by a supporting system of relations or representations between situations (Gentner, 1983; Falkenhainer, Forbus and Gentner, 1989; Chiu, 2003). This process of comparison fosters new inferences and promotes construing problems in new insightful ways. The potential for innovative ideas is evident when the two domains being compared are very different on the surface (Gentner and Markman, 1997), which can help draw new inferences and construe problems in more insightful ways.

Research has been carried out in the field of psychology to understand the cognitive processes people use to create and understand analogies (Falkenhainer, Forbus and Gentner, 1989; Gentner and Markman, 1997; Gentner, Holyoak and Kokinov, 2001; Blanchette and Dunbar, 2001; Hummel and Holyoak, 1997; Gick and Holyoak, 1980). Figure 2.2 shows the basic processing steps involved in reasoning by analogy - the most cognitively challenging step - and the design methods that are available to support each step.

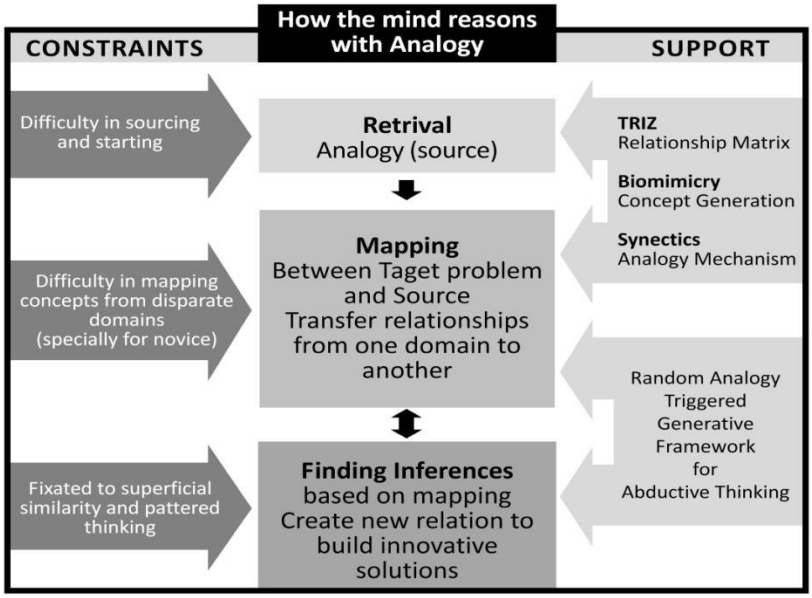


Figure 2.2: Steps in how the mind reasons with analogy and supporting methods

Analogy has traditionally been viewed as a comparison between two items in which their relational or causal structure match, but not the superficial attributes (Gentner, 1983; Gentner and Markman, 1997). For example, an airplane wing and a hydrofoil can be viewed as analogous because of how they work; the colours they are painted is irrelevant for this particular relationship. This process of finding comparative elements fosters new inferences and promotes construing problems in new, insightful ways.

In psychological literature, there has been a great deal of interest in the roles of analogy and expertise in problem solving. Gick and Holyoak, when working with undergraduate students who have no specialized domain knowledge, found that analogies are helpful in solving insight problems, but are difficult to retrieve from memory (Gick and Holyoak 1980). Whereas research with experts showed a tendency to use analogies often (e.g., Dunbar, 1997; Leclercq and Heylighen 2002; Casakin and Goldschmidt 1999), thus reflecting on the fact that experts can see the deeper, logical structure of situations while those without domain expertise are mainly aware of only the superficial features (Chi, Feltovich and Glaser 1981; Gentner and Landers, 1985; Novick 1988).

2.4.2 Analogical Transfer

The spontaneous accessing of analogy is influenced by a number of factors, like the explicitness of relational similarity, domain knowledge, etc. Access involves both noticing and retrieving a source. Where the noticing involves recognizing or selecting a particular earlier example, retrieval concerns the actual remembrance of this earlier example.

To successfully map aspects of the source on to the target it is important to:

i. Construct a mental representation of source and target.
ii. Select the source as a potentially relevant analog to the target.
iii. Map components of source and target that play corresponding roles in the two situations.
iv. Extend the mapping to new implications.

These steps interact in multiple ways with select sources and to iterate various levels of abstractions also helps to conceptually organize the analogy process.

2.4.3 Methods using Analogy

There are a few formal methods to help use analogy for problem solving, such as Synectics, Biomimetic concept generation, TRIZ, CPS etc.

Studying these methods from their process points and applications in product design idea generation, brings to light certain constraints and challenges, which include:

i. The requirement of a facilitator to steer the analogies.
ii. The difficulty in finding the right analogy.
iii. The need of experience/domain knowledge to leverage analogical relationships and mapping beyond the surface level.
iv. Complexity of ad hoc tools dither the maximization of the analogy.

Thus, a lot of effort is given in generating computational aid for systematically mining and leveraging analogy for design. For example the automated tool to provide inspiration to designers as part of the idea generation process, does so by providing analogies from nature or other devices based on the function or behaviour of the device (Chakrabarti, *et al*. (2005a&b), and Word-Tree (Linsey 2007).

2.4.3.1 Role of Analogy in Synectics

The term Synectics comes from the Greek word *synectikos* which means 'bringing forth together' or 'bringing different things into unified connection.'

"Since creativity involves the coordination of things into new structures, every creative thought or action draws on the Synectics method of thinking. Creative behaviour occurs in the process of becoming aware of problems, deficiencies, gaps in knowledge, missing elements, disharmonies and bringing together new relationships in available information; identifying the missing elements, searching for solutions, making guesses or formulating hypotheses" ~ E Paul Torrance (Roukes N. 1988).

"Creativity is the marvellous capacity to grasp mutually distinct realities and draw a spark from their juxtaposition" ~ Max Ernst (Roukes N. 1988).

Buckminster Fuller summed up the essence of Synectics when he said that all things, regardless of their dissimilarity, can somehow be linked together either in a physical, psychological or symbolic way (Roukes N. 1988).

Synectics method of thinking is the process of discovering the links that unite seemingly disconnected elements. It is a way of mentally taking things apart and putting them together to furnish new insight for all types of problems. It encourages the ability to live with complexity and apparent contradiction to stimulate creative thinking and mobilises both sides of the brain, the right brain (the dreamer), and the left brain (the reasoner), providing a free-thinking state of consciousness. The Synectics Trigger mechanism catalyse new thoughts, ideas and inventions by using disruptive thinking with the use of analogies. Its analogical thinking base motivates the fusion of opposites to create a synergistic whole.

Excessive logical thinking can stifle the creative process, stimulus input or analogical cues can turn ordinary perceptions into extraordinary ones. To breakout of our logical thinking pattern, disruptive inputs are necessary. Thus, the Synectics way of forced analogy is a very useful method of idea generation. The idea is to compare the problem with something else that has little or nothing in common, and gain new insights as a result. The role of the Synectics mechanism is to go beyond Gordon & Prince and use a simplified process at the individual level.

Synectics research hinges on the following assumption: that the creative process can be correctly described; and that a sound description should be usable in teaching methodology to increase creative output. Synectics has attempted to illuminate the creative process - resulting in seven working hypotheses which are useful for practice and have markedly increased the creative output. (Gordon 1961)

Synectics research has looked into the psychological mechanisms basic to creative activities by gaining concrete insights and testing the validity of these mechanisms in problem stating and problem solving situations, as depicted in the spectrum of thinking in Fig. 2.3.

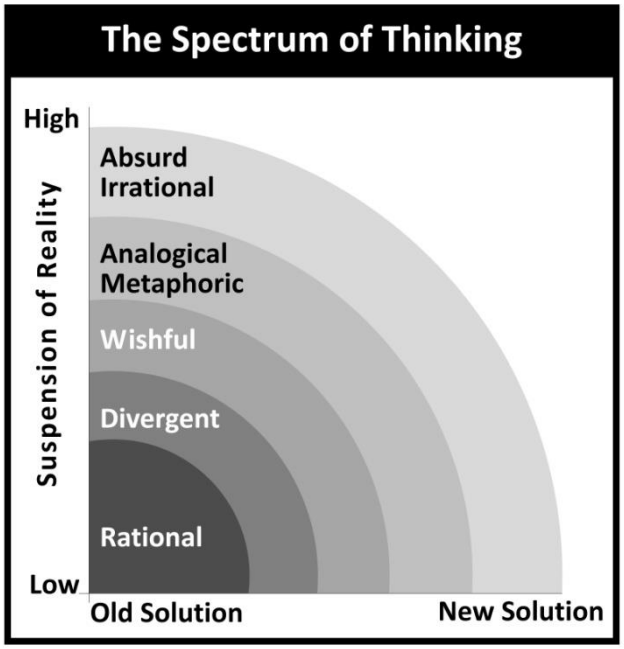


Fig 2.3: The Spectrum of thinking as presented in Synectics (Nolen & Williams 2010)

Synectics theory holds that-

i) Creative efficiency can be markedly increased if they understand the psychological process by which they operate.

ii) In the creative process, the emotional component is more important than the rational.

iii) It is the emotional irrational element that needs to be understood to increase the probability of success in problem solving situations.

A non-rational idea produces evocative metaphors, images and unfinished surfaces that can be built on. This kind of non-rational interplay is part of the process which spirals up towards increasing coherence.

Figure 2.3 shows that to achieve radical approaches to one's problems, it is essential to take the "psychological chances" to abandon familiar ways of looking at things and defying all logic. (Nolen & Williams 2010)

What is the new point of departure? This comes from not limiting the domain of the problem at the ideation level. In later imparting of feasibility, expert input can be sourced to get

further knowhow as well as pointing out of weaknesses. One of the important expectations to exert the correctness of the principle is to achieve some level of implementation of solutions. To judge the effectiveness of the theory, the value of the hardware output becomes an important input.

The theories comprised in Synectics are proposed as hypotheses designed to increase the probability of success in creative activities. As the major component of the creative or idea generation process are subconscious thought associations and retrievals, the creative outcomes traditionally hold a high probability of accident quotient, making it difficult to purposely repeat; while Synectics attempt to make the explicitly conscious the subconscious workings of the mind so as to evoke it when the need arises. It is an almost on-demand process, as the Synectics mechanism can induce appropriate psychological states that can promote and sustain creative activity- by making the strange familiar and making the familiar strange. To solve a problem it is important to understand it and analyse the fundamentals of the problem. For any work on the problem to get started, some concrete assumptions must be made. The psychological workings of the mind, when faced with strangeness, attempt to force it into an acceptable pattern or break barriers to incorporate the strangeness by 'abducting' the mind. By the tapping into previous knowledge, the mind familiarizes itself to the strangeness. Synectics has delved into the different states of the creative activity from the conscious, preconscious and subconscious psychological states. Creative activity lays in balancing the analytical and problem detailing to avoid yielding superficial solutions. Though the problem might not be new-the perspective of looking at it can be new, as novelty demands fresh viewpoints which in turn embodies the potential for a new solution.

Novelty is in the pursuit of strangeness by distantly inverting or transposing the everyday ways of looking and responding to the world. It is not just a search for the bizarre and out of the way, but a conscious attempt to achieve a new perspective on people, the world, ideas, feelings etc. as the starting point of a new invention. But to sustain this condition brings with it anxiety and insecurity of failure. This drives the mind towards the most superficial solution; the natural impulse to master the strange by making it familiar. Thus to gain a new point one has to shed the protective legacy, and take risks. To understand the mental

tolerance towards temporal ambiguity that is implicit in risk taking, the four mechanisms of making the familiar strange as identified in Synectics process are:

Personal Analogy: To make personal identifications with elements of the problem in terms of its previously analysed elements (act like the element). The role of empathic personification is the inertial feature in productive thought by helping in developing insights for new representations (eg. Benzene molecular structure). Often when a Solution is not arrived at, the main mechanism for making the familiar problem strange is Personal analogy. The metaphoric experience of being the element can be understood after some exposure to Synectics. It brings out all the nuances that need to be expressed.

Direct Analogy: It is the actual comparison of parallel fields, knowledge or technology. A lot of Biomimetic work is based on this mechanism (eg. Ear function and Telephone). It is quite straight forward, but is able to uncover comparisons conceptually. Recordings of scientific discoveries as well as years of working on practical inventions of the Synectics group indicates that biological perception of physical phenomena produces generative viewpoints. Using diverse knowledge sources provides the richness that is essential for the successful application of the mechanism of Direct Analogy. The disparate comparison of two varied fields tend to force an expression of a problem in a new way. One must source adequate citations of the new knowledge so as to do justice to the intrusion of alien ideas and their subsequent shifts and matches. It can be stated that the mechanism of Direct Analogy functions as a constructive agent of the creative process.

Symbolic Analogy: Uses objectives and impersonal images to describe the problem. The analogy is used as a poetic response (metaphoric in nature).It is known as a compressed description of the functional elements of the problem as viewed by the designer. Symbolic Analogy is immediate it's a blurting of association-it's a Gestalt response where the physical, neural and mental patterns of activities are suddenly integrated into a compressed articulation (Kohler W. 1930). The cultural grounding and curriculum grounding in the education scenario makes it difficult for technical graduates to understand or use the qualitative aesthetic mechanism. It takes some amount of learning and practice to break apprehension and work to produce rich viewpoints and solutions, ensuring the willingness to use such mechanism also increases.

Fantasy Analogy: Psychologists like Freud have termed creative works as 'fulfilment of a wish' (Freud 1933). The wish fulfilment Theory reveals the connection between creators/thinker motives and the chosen method of gratifying them. The challenge towards success lies upon the ability to not get consumed by the wish in-fantasy, but in realizing the wish by embodying it in the task (Freud 1949). It is a forced absurdness in play and common sense outlaws such fabrication which foolishly flies in the face of established law (Gordon 1961). It pushes the mind to tolerate the irrational and naive inconsistencies. This irrational mechanism usually operates in the subconscious because our rational character tends to deny its inherent irrational nature. If used first in the process of making the familiar strange, it can be particularly effective. It actually acts as an excellent bridge between problem stating and problem solving. Primarily, it is about restating the problem in a imaginative way. This in turn evokes other mechanisms (eg. from Fantasy, to Direct to Personal, etc.). It is about using the freedom to innovate by using the right to imagine the best (fantasy) solution to the problem by temporarily disregarding the laws of logic. It can be called, a 'conscious self-deceit', where one can be aware of the law - that conflicts with the ideal solution, yet be willing to ignore it. Our trained mind tends to be super rational and feels threatened by any thinking which attacks the logical universe, thus inhibiting breakthroughs. Therefore, the mind has to be abducted from this logical status quo.

Synectics experiments have repeatedly used these mechanisms for successful implementation of problem stating and problem solving. These can be regarded as specific and reproducible mental processes or tools to trigger the creative process of generation while sustaining and renewing it.

The starting can be a superficial perception but it has to be backed by technological insight, without which no new viewpoint can be possibly realized. Multiple examples of analogy show that the most common form of Direct Analogy is biology. Synectics can be called a constructive mechanism of balancing necessary variables; as a mere stringing together of metaphors is non-productive. It is like moving from an apparently irrelevant analogy and fitting the analogy with elements of the problem/task. The test of validity comes from valuable solutions to the problems-suggesting effectiveness and productivity. It is not about a complete grasp of the operational mechanisms that will lead to successful project

implementation; it is about going beyond intellectual insights and in embracing the emotional component (that which lays underneath).

Synectics techniques are based heavily on metaphors and their rich contribution, so it is important to enrich the inventory of a suggestive assumption and use random triggers. In Synectics, the ideas are presented in terms of' processes', from which the ideas are born.

To break out into creative action, it is necessary to twist ‘out of phase’ whatever conventional laws appear to hold stable. It is not about defying all phenomenology-but defy them apparently. Then, through the gaps which show up due to the twisting of the perspective, things can be seen in a new way. Here, more important than the product, is the interplay of information collaboration in contributing to the concept. First, it is important to make the strange familiar- this understanding results in metaphor and compassion, which lead to a constructive viewpoint. It is a theory about how the creative process operates. Over the years, the process has been broken down to operative mechanisms which can evoke novel viewpoints that lead to solutions to the task. These mechanisms are made up of various types of analogies to the problem at hand and constitute potential new ways of looking at the problem.

2.4.3.2 Analogy in lateral thinking

Forced analogy being an exploratory and generative process is very useful, but can also be an exciting way of generating ideas. The bizarre juxtaposition and combination of bringing out new insights is intriguing in itself. The power to force relationships between almost anything, and make a sensible output that is novel is the need of the hour today.

2.5 Analogy and Design

Analogical thinking, also known as associative thinking, uses both analogies and metaphors to build relations or share attributes between two entities. It is about the relational similarity as well as the number of attributes shared. (Gentner and Markman 1997)

In the realm of design, metaphors help to frame and define the design problem for the designers, and are commonly used to map users’ understanding, activities and reactions to a product. Analogy mainly maps the causal structure from source product in one domain to the

target design problem being solved. Analogies from nature have been used effectively for inventions. There are enough anecdotal examples to support the use of analogy. When problem solving, analogy can be used to generate new and novel representations by recognizing and exploiting some significant similarities between the target and source. The real challenge is in how to recognize these 'significant similarities'. Lakoff and Johnson stress on how even multi-source domains can contribute to a single expression quite common in language expressions; that is various source analogs define different aspects of the problem by complementing each other. This can help in developing more abstract notions that can be used to build, embellish, transform etc. The generative mechanism of analogy depends on the efficiency of source analogy and choosing the relevant properties of the source to transfer (Lakoff and Johnson 1980). In this study both metaphor and analogy are referred to as analogy.

Nature has been a source of inspiration for many a creative pursuit and a strong guide for design by providing profound solutions in unexpected places and drastically different contexts. Other than analogies from nature, analogies between devices are commonly used in effective ways. This phenomenon is observed in history e.g. the early design of a reel lawn mower was based on the nape trimming machines for carpets. Identifying innovative use of material for 'Jaipur foot', was inspired by the analogy of the bicycle tyre (Pralhadh 2010).

2.5.1 Supporting Design ideation with Analogy

There is no doubt that analogy plays an important role in the mental process of creative thinking (Holyoak & Thagard 1995). The base working has been expressed as domain transfer from source to target, where analogies connect the two domains by familiarizing the unknown with the known working on similarities between objects or behavioural relationships and further similarities of relationships between relationships. Usually the typical use of analogy starts with the selection of a source analogy and retrieving analogous information from memory and mapping it to the target to generate inferences which are then adopted to bring out a different inference leading to creative ideas.

As the mind channels the direct flow of incoming information so as to associate different contexts, we see that when we are thinking about one thing the mind naturally invokes

thinking about another thing. To catalyse this process, several methods use stimulation and provocation of the mind to abduct the thinking from its routine thinking (DeBono 1993), creating connecting links of unconnected pieces of content to build new ideas.

"*Analogy lies at the core of human cognition*", (Holyoak et al. 2001) stresses that analogies underlie creative thought and problem solving, and are implicated in virtually all aspects of human life. Use of analogies are found in science (e.g. comparing an atom with the solar system), in politics (e.g. the first President Bush comparing Saddam Hussein with Adolf Hitler), and in everyday living. It is not altogether surprising, that analogy is an equally powerful force in cognitive development and comprehension building. Children use analogy to extend their knowledge about the biological, physical, and psychological world and to solve problems (Brown & Kane 1988; Holyoak et al. 1984; Pauen & Wilkening 1997). Spontaneous analogies have been observed in very young children (Pauen & Wilkening 1997; Tunteler & Resing 2002), and there is even some evidence that infants are able to reason by analogy from around their first birthday (Chen et al. 1997).

Studies in the area of analogical problem solving have been carried out in the field of Psychology, Management, Engineering, Education and Design. The papers were studied to understand the method and draw inferences to design the research towards developing a conceptual model and formulating the research inquiry. The studies on creative cognition have revealed that the creative thinking process is largely governed by associative thinking and, on in-depth analysis, through analogy as its core.

In investigating the relationship between design thinking and emotional content, Irina states that memories of emotional experience along with other kinds of experience and knowledge contribute to the construction of the image-banks that serve as a source of design ideas. Memory registers and stores meaningful experiences and impressions, beliefs and emotions, as well as any modifications that may take place under the influence of new experiences (Blanchette 2006). Designers utilize the knowledge and emotional impact contained in their memorable experiences in order to assist them in the creative design process. They combine, abstract and distort the past through acts of imagination in order to fuel images of some possible future. From an evolutionary standpoint emotions are 'older' and faster than other responses. Frequently, we have, if not the answer, then a predisposition toward solving a

problem in a particular way before cognition begins to have an effect. This predisposition is due to emotion. Emotions are expressions of the way a person understands an experience, because they filter and structure the person's perception of the situation and information (Robinson 1996) when they focus attention (Carroll 2001), and they greatly influence construction of memory. Memories of emotional experience constitute a separate, valuable and large part of a person's knowledge bank. Unavoidably, then, emotion has to be one of the sources for conceptual ideas in design, as well as for both creative processes and decision making in other fields of science, art and everyday life.(Solovyova 2003)

The empirical evidence supports the use of analogy for design, but is less extensive. Design teams frequently use close-domain analogies, in the form of references to past designs (Eckert, Stacey and Earl, 2005), for more than just conceptual design. Analogies to similar products are also used for process planning, cost estimation, and evaluation of a new product.

A few controlled experiments have explored the use of analogy. Casakin and Goldschmidt studied visual analogies and how it improved design problem solving for both novice and expert architects (Casakin and Goldschmidt 1999). Ball, Ormerod, and Morley investigated the spontaneous use of analogy with engineers (Ball, Ormerod, and Morley 2004). They found experts use significantly more analogies than novices do and the type of analogies are significantly different from the type used by novices. Novices tended to use more case-driven analogies (analogies where a specific concrete example was used to develop a new solution) rather than schema driven analogies (more general design solutions derived from a number of examples). This difference can be explained because novices have more difficulty retrieving relevant information when needed and have more difficulty mapping concepts from disparate domains due to a lack of experience (Kolodner, 1997).

The key ingredients for innovation and increasing breakthrough ideas are the primary research goal that is the driver of this research. The focus is on how it happens by first developing a deeper understanding of the cognitive processes that drive the successful generation of breakthrough ideas at the individual and group levels. Innovation begins with an individual having an initial idea. This idea will likely be added to, modified, and enhanced. The focus of this research is to improve the ability of individuals and design teams to create innovative solutions that fulfill the technical, cultural, and user needs.

The use of analogies in the tools reinforced the potential of training to tap memory and experience to generate creative solutions.

The categorization of the methods and functions of the creative techniques helps to identify the approach of analogy based thinking for idea generation as most prevalent. Though analogy is recognized for its effectiveness, limited formal method guidance is provided. When the thinking is removed from the immediate problem space by the use of random stimulation and Synectics, a strong skill based on creative intuition is required to make a fruitful connection with the problem and create novel ideas. Some major characteristics of the above techniques show the use of analogy to bringing together unrelated ideas.

Drawing analogies between situations helps form a better understanding of novel situations and to make predictions about them through the extended inferences, as analogical reasoning confers the ability to determine similarities and to make inferences from one situation to another. This creates higher-order relations that bind one relation to another and thus give depth to a relational structure.

2.6 Summary of Literature Review

In summary, we can see there is a strong need for systematic idea exploration at the fuzzy front-end to initiate innovative ideation right from the beginning of the product lifecycle. This requires the innovation processes to generate or obtain ideas, as ideas result from the brain's activities in which previous knowledge or ideas are recombined in the way of forming a new concept - giving ideas leverage to create novelty due to the potential of newness. Very often, during this stage, an impasse is reached, which creates fixation or an idea block and needs facilitation to move towards the fresh generation. Intrigued by these phenomena, much research has been going on to give a constructive explanation to the pattern of thinking and externalizing its application algorithmically through AI replicating the associative working of the mind through computed data.

The cognitive function for comprehension and communication requires the forming of analogy as a tool for understanding a new situation or solving a new problem. Extending this cognitive model to product design has also led the process of finding relevant analogies for problem-solving, which poses its own difficulties. Analogies are used to project a structural

relation from one domain to another, revealing new information and insight - further catalyzing new analogies to move further out of the problem and help map radical new solutions. According to Gero, unexpected design solutions are a product of the confluence of two schemas mediated through an analogy (Gero 1992). Schema is defined here as "a mental template that automatically or intuitively guides our perceptions and interpretations of our experience" (Myers, 2002). It involves deconstructing the problem, then redefines the solution space of the problem. This process of adaptive abduction in the way analogy can beused generatively and expand the potential of the process as well as the individual is an area of great scope as having limited resources. There seems to be great potential for exploration to bring value to specific knowledge in this context of creative ideation and problem-solving. As most of the work is from the field of psychology and technology-aided computational tools using precedents of studies in language and their application for engineering design, it has left a great scope in the field of New Product Design.

Although the use of analogical reasoning has been investigated in many domains, empirical studies on its use in design education and teaching of creativity are also limited. Affirmative effects of analogy over creativity would be observed when one uses the analogy to understand the problem or to draw ideas from past designs. Negative effects of analogy over creativity have been observed when it limits designers' imaginations to specific solutions and leads them to filter out potential creative solutions. This is called the Fixation Effect of Analogy (Eckert et al., 2005; Schwert, 2007). Often visual clues are used as triggers to bring out the surface similarity to the design problems which help novice students to understand the problem correctly, but they may also get fixated to the visual solution, which in turn can inhibit exploration.

2.7 Scope and Gap

The literature reveals that stimulation, fixation, time, and parameters have subsequent effect on idea generation as a whole in positive as well as negative ways. It is stated that to set the flow of ideas and start the process of ideation, external stimulation can be helpful and particularly more heterogeneous stimuli from multiple categories are found to facilitate the production of more diverse ideas (Howard-Jones & Murray 2003)

Idea exploration, with the use of analogy, has a good effect in designing. It can give a physical representation to conceptual thought and translate abstract emotions into tangible forms. This helps to break predetermined perceptions and transcend to the next level. It can be manipulated to have a different association in differing contexts, as the same theme can be represented in a radically different manner from the use of different analogies or the same analogy can be applied in a different context to initiate new perception. Analogies operate from different levels of directness to abstractness and simplicity to complex meaning makers. The use of direct analogy helps as an idea starter by offering a direct surface point of association. It helps to steer from direct to abstract thoughts, leading to the radical representation of symbolic ideas.

The research bases itself on the idea of producing potential of analogies and it's constrain of rational bounding of being able to apply it right and see how it can be overridden and leveraged. Most research has been concentrated on the difficulty aspect of the use of analogy and furthered research in modeling the process to generate the best analogies. The researcher feels that this in itself becomes kind of self-defeating and contradictory to the concept of out of domain stimuli, especially in the case of new product design ideation. This gives the scope of exploration of forced unrelated analogy usage for radical idea generation study.

The goal is to set a flexible analogy application process for product design by harnessing the ambiguity ambit of random analogy trigger with the ambiguous scope design exploration offers. Additionally, to contribute to design pedagogy and design practice is also seen as a positive outcome.

Chapter 3
Design of the Research Study

3.1 Introduction

For research, a structure or design is needed to ensure that the evidence obtained helps to answer the initial question in a convincing way. To obtain relevant evidence, it is important to specify the type of evidence needed to answer the research question, to test a theory, to evaluate a program, or to describe some phenomenon accurately.

The Research Design is qualitative in nature to understand the process of analogy triggered idea generation by novice designers and mid-level designers, though certain quantifiable values are used to categorize generated ideas into the parameters of creative output based on the Torrance creative parameters (Torrance 1974). Taking into account the whole research process and based on the objective of the inquiry, the methods used specifically aid in analyzing and reporting data to draw conclusive insights for addressing the unresolved gaps. Starting with outlining and describing the field of study, the choices of what data is to be collected and how they are set. Based on this, the research approach used in the thesis is articulated and discussed.

The researcher starts with the two fundamental types of research queries:

1. What is happening in the phenomenon (observatory research)? A good description provokes the `why' questions of explanatory research by forcing the ‘WHY’ of the happenings. Thus, setting the facts and dimensions of the context of study is very important, or else the description can degenerate into mindless fact gathering or what Mills called `abstracted empiricism' (Mills 1959).

2. Why is it happening in the way that it is (explanatory/exploratory research)? To develop an explanation about why something is happening, the total scenario's observation and understanding is necessary. This in turn can aid a more conclusive 'HOW' to alter the phenomenon.

This research design has been developed to fundamentally collect information that can fulfill the exploratory requirement of the study objective. By answering the `why' questions to seek the type of causal relationships involved between the factors and its effects on the phenomenon as shown in Figure 3.1. Thus, obtaining the relevant evidence and insights to help build a strong base for design practice.

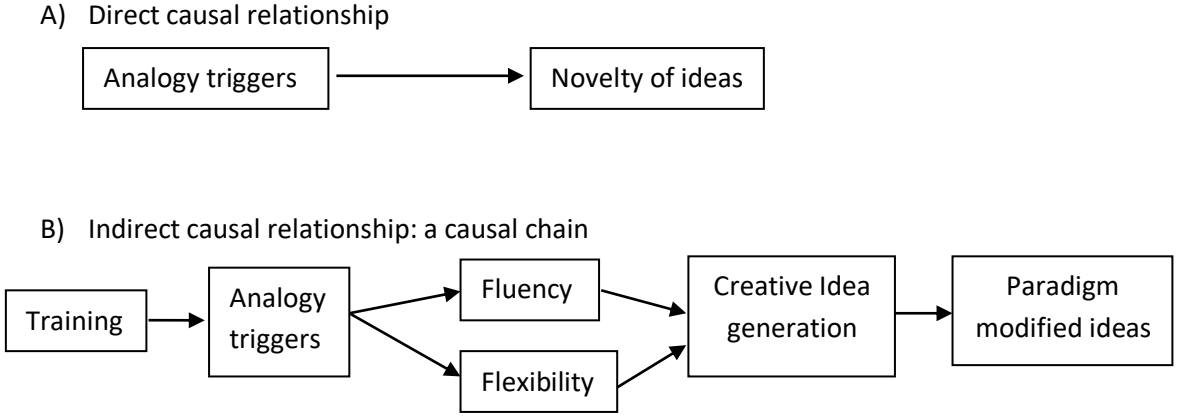


Figure: 3.1 Two types of analogy triggered causal relationships

To set the research query, the following research questions were asked:

RQ1: How do novice designers choose analogy triggers to generate ideas for new products?
RQ2: What are the roles of solution driven analogy trigger and non-solution driven analogy trigger on generation of creative new product ideas?
RQ3: How does forced random (non-solution driven) analogy trigger creative idea exploration leading to creative and paradigm changing new product ideas?

The design of the research study was therefore set in three stages to conduct an empirical study of the phenomena in the context of inquiry. The three stages of study were conducted to move our understanding from a broad base of the phenomenon of analogy stimulated idea

generation and to arrive at a more convergent view about specific implementation process along with a guiding framework, which are consequently detailed in Chapters 4, 5 & 6.

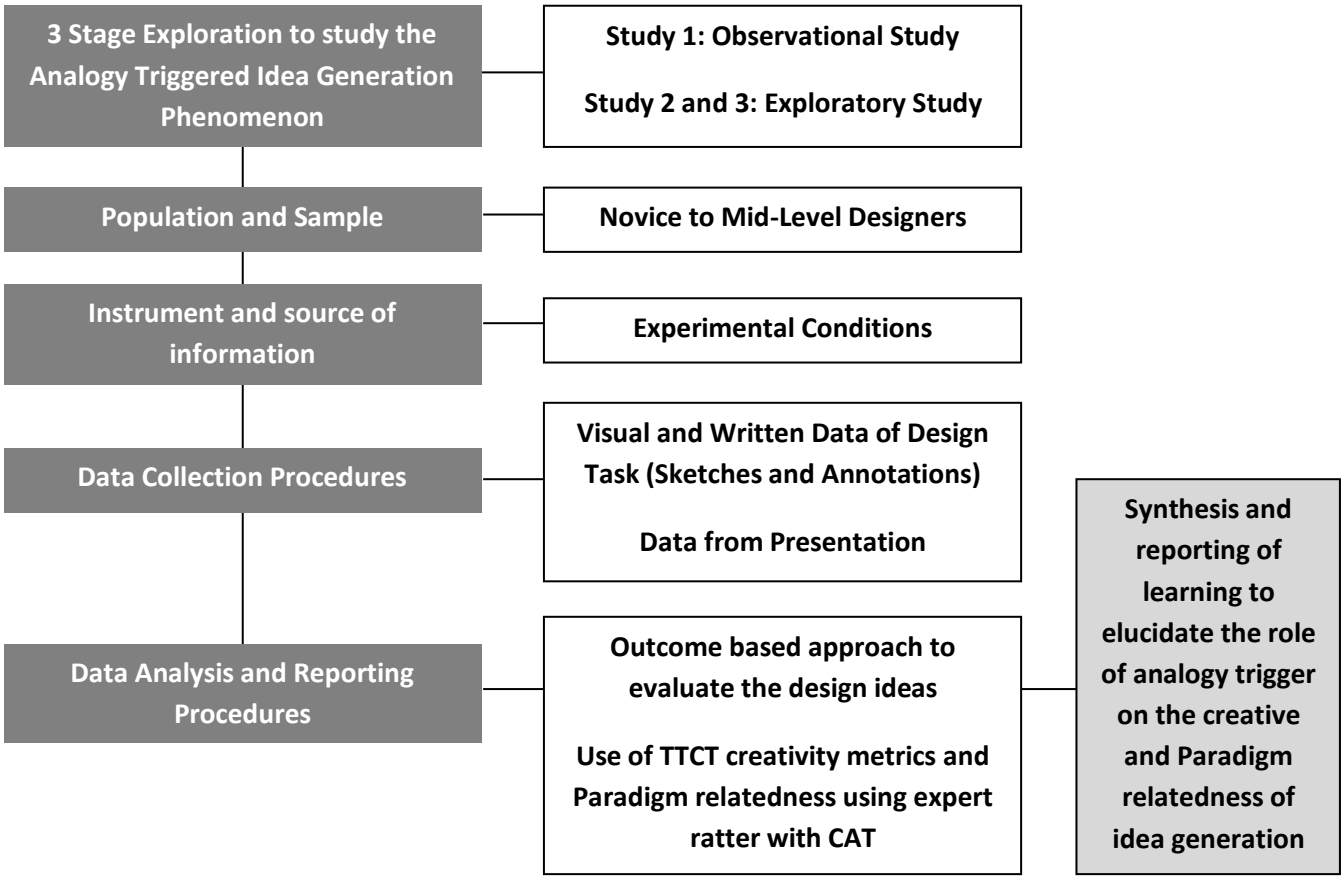


Figure: 3.2 Design of the Research Study

3.2 The Experimental process

Study 1: The introductory observational study was conducted with undergraduate engineering students taking a course in Design Issues in a classroom scenario. A two condition test treatment was administered to study the novice designers' choice and use of analogy triggers for creative idea generation. The objective being to check out the working of analogical triggers and their effect on the idea generation phenomenon in two conditions. The findings and insights were introduced into a subsequent 2nd study for further explorations.

Study 2: An exploratory research study with Mid-level design engineers and designers was conducted in a workshop scenario. The study was designed from the insights gained from the

introductory study to create a better understanding of the effect of the suspension of reality while idea mapping by using random analogy triggers. This also allowed us to see the relationship between the basis of random analogy choice and abduction of the mind towards a generative exploration of creative idea links.

Four groups were studied in which two groups were assigned random analogy triggers by the trainer (the control group), and the two other groups were instructed to choose their own random analogy. All the teams were then asked to proceed with the idea generation for the given product brief. The creative idea generation phenomenon in both cases was studied to develop further understanding and build a more conclusive discourse, to bringing forth the operational aspect of the use of random analogy triggers in the process of new product idea generation.

The learning helped build the 3rd study to explore operational challenges and paradigm relation to analogy triggering and creative idea generation. The idea triggering trends and biases brought to light, fresh insights that were further useful inputs for the third study.

Study 3: An exploratory study with a mixed group of novice and Mid-level design engineers and designers was conducted in a workshop scenario.

Based on key insights gained, learning gathered, and further theoretical support that literature offered, a guiding framework for new product idea generation with random analogy triggers was developed. The set framework was administered with a brief demo explanation. It was made mandatory to use the framework for the idea generation process. The empirical data generated was used to analyse and bring out the core tenants operating within the random analogy triggered, idea generation phenomenon. In addition, the role of analogy trigger on the creative and Paradigm relatedness of idea generation was analysed for developing a guiding framework for further enhancing the new product idea generation.

3.3 Sample Population

The participants were engineering students learning design, design students, and mid-level design engineers and product designers. These novice to mid-level engineers and designer

participants were chosen to understand the challenges posed within the phenomenon of new product idea generation using analogy triggers.

3.4 Instrument and process of sourcing information

This research study focuses on observing the phenomena of analogy based ideation process and idea output to guide the product designers in a step by step ideation through random analogies so as to catalyze unrelated association for novel new product ideas. The process is founded on the operational mechanism of Gordon's Synectics and DeBono's PO and random stimulus, method of analogical thinking, and associational representation.

To set the scene for fruitful data gathering, a workshop mode with a task-based process was carried out. This seemed suitable to break the rigidity of an experimental situation, thus allowing free-thinking for the task given. Specific treatments were applied to check emerging assumptions and ground the learning. To fulfill the quest, the research data was collected from worksheets, comprising of sketches and annotations, models, idea maps, and presentations along with close observation notes of the workshops and ideation activities. A base survey of the participants was taken to understand their inhibitions, challenges, and competence in using analogy triggered ideation.

3.5 Data Synthesis and Reporting

The ideas from the experiments are qualitatively assessed on the Torrance parameters by expert raters using consensual assessment techniques. The ideas generated were designated to categories of paradigm relatedness.

The research chooses the outcome-based approach (Shah et all 2002) to evaluate the ideation outputs produced during the design ideation exercises. The premise of an outcome-based approach is to evaluate ideas with specific metrics. One commonly used set of metrics put forth for evaluating idea generation identifies four key parameters for evaluating a designer's expansion of design space (Shah et all 2002), which can be thought of as a hypothetical space encompassing all possible solutions to a given problem (Ullman 2003).

3.6 Summary

The sequential process followed in the 3 stage inquiry helped to collect data that could bring out the constructs of the phenomena. Further, these constructs when applied brought out key attributes and elements of operation and implementation of random analogy triggered ideation. This in turn facilitated in building the guiding framework. The use of the framework helped in confirming our assumption in an inductive way and deduce the prediction, the potential of random analogy trigger in paradigm modifying idea generation for new product design by forcing the mind to generate multiple cues that can be force fitted to form cross domain association to craft product ideas.

Chapter 4
Research Study 1: Observational study of analogy triggered idea generation by Novice

4.1 Introduction

The generative process of ideation is used to stir new ideas, which uses different triggers for stimulation. Analogies assume an important role as creative triggers for problem solving and idea generation through associative connection building. Today, more than ever, creative ideas are the key drivers for potential innovation, thus leading to market success. By way of using analogical methods, one can deduce surface similarities, structural similarities, and relations from one thing to another. Analogies also help to frame, assist, and define problems and to map users' understanding, activities, and reactions to things. In the realm of idea generation, the implication of analogy is seen in the mapping of the causal structure between the source product in one domain to the target design problem being solved; (Mayback 2012) thus aiding idea exploration in this early stage. The juxtaposition of a familiar knowledge onto an unfamiliar problem or vice versa (Gorden, 1961) can manifest radical exploration.

As the idea generation phase is a key step in the development of novel new products, clearly understanding this phenomenon of analogy triggered idea generation can bring insightful knowledge on the key potentials and challenges of its use. When retrieving and generating ideas from analogies, a fusion of pieces of knowledge that have not been connected before are carried out; but one is only able to notice a limited section of the environment, due to constraints of limited cognitive ability (Simon, 1957,1982, 1996). Similarly, when retrieving solution ideas from very distant domains, our established thinking patterns can cause constrain.

In his research, Chakravarthy extensively used the process of Synectics and analogies for ideation. Synectics was proposed by Prince & Gordon for creative problem-solving practices

to problems that are unsolved by expert knowledge and analytic approaches, making it a solution centered approach (Prince 1990, Gordon 1961). By using metaphors and analogies, one is able to create unfamiliar and unusual perspectives to find creative and novel solution ideas. In the mock case studies, Chakravarthy proposed the design strategy of developing radically new products that should be innovative in multiple fronts. The use of analogy propelled new idea exploration from the field of technology, manufacturing, etc. allowing multiple creative and novel product ideas. Taking an example of the easy shave cases, it can be observed that the analogical association has allowed the cross-domain transfer of knowledge to implement a radical idea in the target domain, eg. Laser technology - which was not so popular in the last century - was used as a knowledge base and force-fitted to confirm to the target solution at hand, 20 years from then, it is a feasible reality today (Chakravarthy 2003).

To review our assumptions drawn from the literature of studies in the field of analogy driven problem solving and solution generation, we started by conducting the introductory study to observe the phenomena of creative idea generation with the analogy. The application of the few prevalent techniques was explored and administered.

4.2 Objectives

(i) To explore and understand how novice designers choose and use analogy triggers to generate ideas for new products and how it affects the creative parameters.

(ii) To gain keen insights into the analogy triggered idea generation phenomenon in relation to novice designers.

4.3 Design Task and procedure

The observational/exploratory study was carried out in a workshop mode within the course Design Issues in a classroom scenario with UG engineering students. The students were taught how to engage in analogical ideation process (Synectics, Lateral Thinking & CPS) with various creative tasks and design problems within a stipulated time frame. The workshop introduced the participants to the use of analogy triggers in creative ideation and their design worksheets using analogy mapping and brain-writing processes were used as explicit documents for analysis. The participants' free form idea generation output was

analysed on the creative criteria of fluency, flexibility, and novelty used from Torrance Creativity Tests in relation to the type of analogy trigger while performing the design task. An individual-level idea storming was carried out, as the role of analogy triggers on the individual participants' ideation output was the focus. As argued by Diehl & Stroebe, on the advantage of eliminating productivity loss due to production blocking, evaluation apprehension, and free-riding (Diehl & Stroebe 1987), group brainstorming was not considered. Amabile's consensual response of independent judges were used to gauge the prolific range of ideas produced (Amabile 1982).

The judging process was carried out by three designers, and an inter-rater agreement was checked to help balance the judgment. Also, multiple studies on idea assessments of new product ideas have validated the CAT (Consensual Assessment Technique) as a gold standard of assessment. Based on Boden's and Shah's studies on levels of creativity being: creativity to the individual, creativity in history and creativity to the situation/society/group and keeping in mind the realm of product design creativity, the third type is what the study focused on (Boden 2004, Shah et al. 2000).

Two test treatments were administered to study the phenomena of creative idea generation amongst novice designers with analogy triggers.

Treatment 1 & 2: Idea generation for new radical products was conducted after the participants were taught idea generation techniques of DeBono's Lateral Thinking (DeBone 1970), Creative Problem solving with SCAMPER (Osborn 1957), and the use of analogy triggers through basic Synectics (Gordon 1961) as part of their course curriculum. They were set up in two groups and given specific design tasks and instructions for task fulfillment. They were required to generate ideas as per the instructions; their idea output was judged on the four parameters of Fluency, Flexibility, Novelty, and Usefulness (Torrance 1974). The task had to be completed within a stipulated time frame of one and a half hours. The task was to be done in the classroom, which was familiar to them so that it would be easier for them to ideate. A free form ideation process was followed with no constraint of cost, technology usage, etc. The only constraint was the stipulated time. The idea generation was carried out as an individual activity to eliminate three theoretical factors of productivity loss: production blocking, evaluation apprehension, and free riding (Diehl and Stroebe 1987).

a) Idea generation for new products without instruction on analogy use (Control Group).
b) Idea generation for new products with two or more analogy triggers (Treatment Group). The task given consisted of scenarios and problems that the participants were familiar with and did not require base user research or internet information. As it was a graded assignment, they were asked to keep their phones away. This would give us scope to understand their idea triggering and sourcing procedure.

Task 1: Generate radical and innovative product ideas to facilitate reading while lying down.

Task 2: Generate ideas for an innovative rain guard for Mumbai commuters during the rains with the use of analogy method and association by choosing your own analogy (minimum 2 analogies, one object and one animal).

An observation as to how schematic or abstract representation of thoughts took place to lead up to idea outputs was made and measured on the four creativity parameters of Fluency, Flexibility, and Novelty. Their brain-writing, analogy maps, and sketches were documented and analyzed.

Fluency of idea generation: Whether the participant is able to generate a greater no. of ideas/alternative solutions to the given problem (can be in the same area or outside). The participant shows the ability to use learned information for problem-solving solutions.
1 idea = Low Fluency(1), 2-3 ideas =Moderate Fluency(2), 4+ ideas = High Fluency (3)
Flexibility in idea generation: Whether participant explores a variety of possibilities and different realms of thought. The participant shows the ability to see problems and solutions from different points of view, using varied approaches and strategies to find (unique)solutions.
No variation= No Flexibility (1), 2 Variation= Moderate Flexibility (2), 3+ variation= high Flexibility.
Novelty/Originality of ideas: Whether participant is able to produce ideas that are unique and unusual. The participant shows the ability to synthesize information generated about the problem and develop a new way of solving it.

Obvious Idea or common to many in the group= Low Novelty (1), Not so Obvious Idea, could have slight similarity with 1 or 2 others= Moderate Novelty (2), Unusual Ideas not common to any one = Novel idea (3).

4.4 Sample participants

Twenty Final year and Third year B.Tech. students participated in the experiment with prior training in analogical thinking. They were from various disciplines with similar knowledge skills. They had enrolled in the Institute elective course Design Issues, which was a credit course to learn about the design process and its application. As part of the course curriculum, they were trained in the idea generation process, with an analogy that triggered the idea generation process as being one of them. After completion of each process, they were assessed, of which the experiment was one. They were randomly mixed to be in either of the treatment. Even though it was a graded project, they were told that the grades would depend on their exploration of ideas and uncommon idea outputs so as to motivate them to ideate.

4.5 Output and Observation

Participants, when asked to engage in analogical triggered idea generation, followed an iterative process as depicted in Figure 4.2, and were able to generate more creative ideas for the given task in contrast to the participants not instructed to use analogy trigger. Where as the control group followed a more linear process as seen in Figure 4.1. The forced analogy trigger steered the mind to not only generate more ideas links, but also more variety of ideas, as seem in Figure 4.3.

The documents show that Fluency, Flexibility and Novelty levels have a substantial difference. The results indicate that the mind usually follows the path of habitual solution finding in the set patterned thinking way unless strictly instructed to break out when ideating as depicted in Tables 4.1 and 4.2, thus not allowing creative exploration and inhibiting creativity. While when forced to use the analogy trigger and form radical associations and then logically force fit the associations to the task at hand (target), more novel ideas were generated. Even though forced analogy triggering showed positive effect, left to oneself, random analogy trigger was not applied as a conscious act.

This clearly indicated towards two things:

i. The mind seeks the path of least resistance as habituated pattern following way.

ii. Even when using analogy triggered ideation there seems to be some level of difficulty in breaking out of the conformist mind set to generate radical associations.

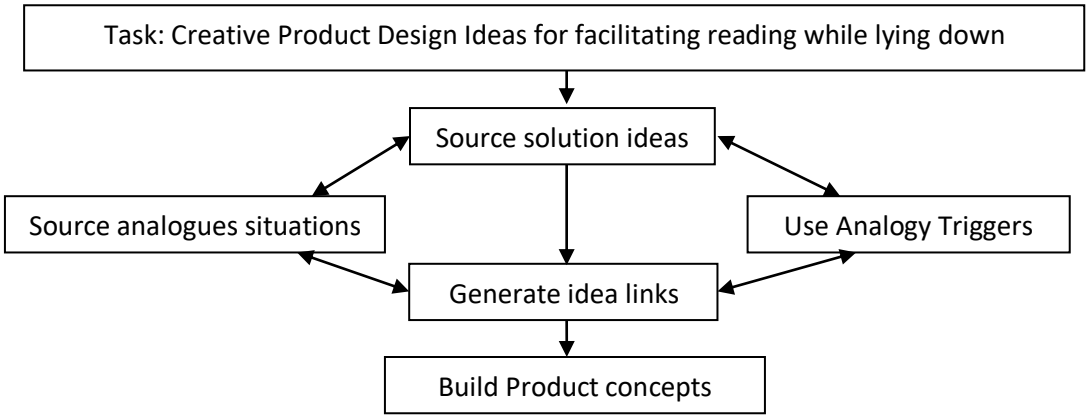


Figure 4.1 Process chart of control groups ideation activity

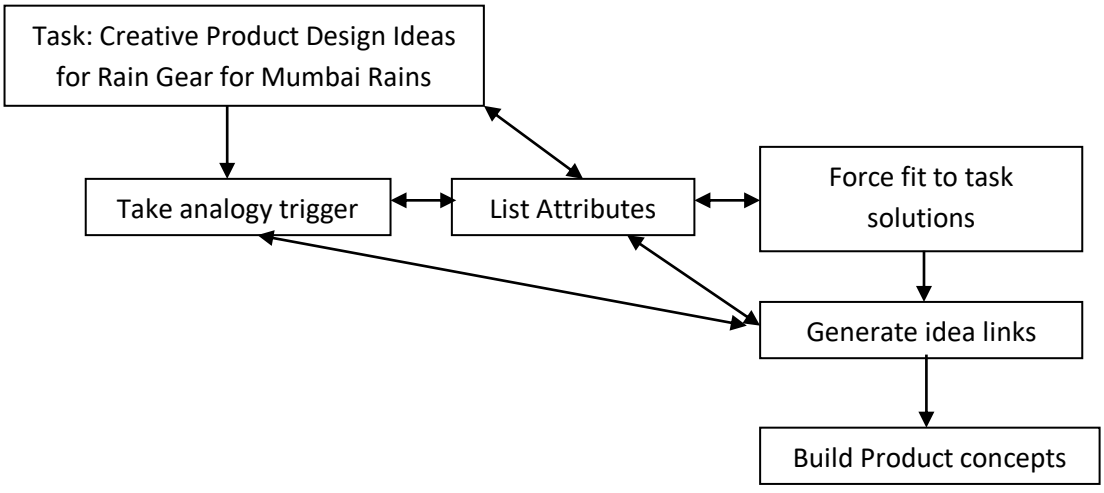


Figure 4.2 Process chart of treatment groups ideation activity

Table 4.1 Examples of The analogy triggered ideation process

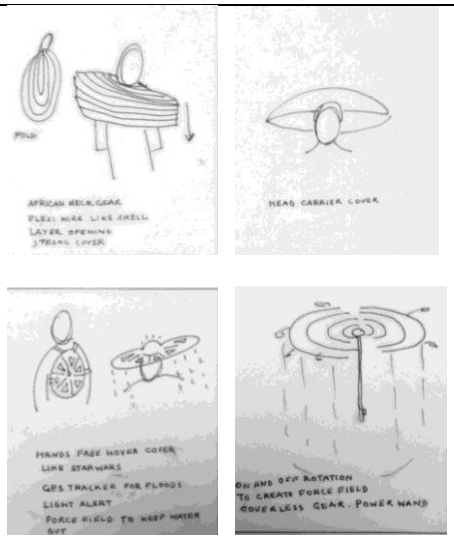
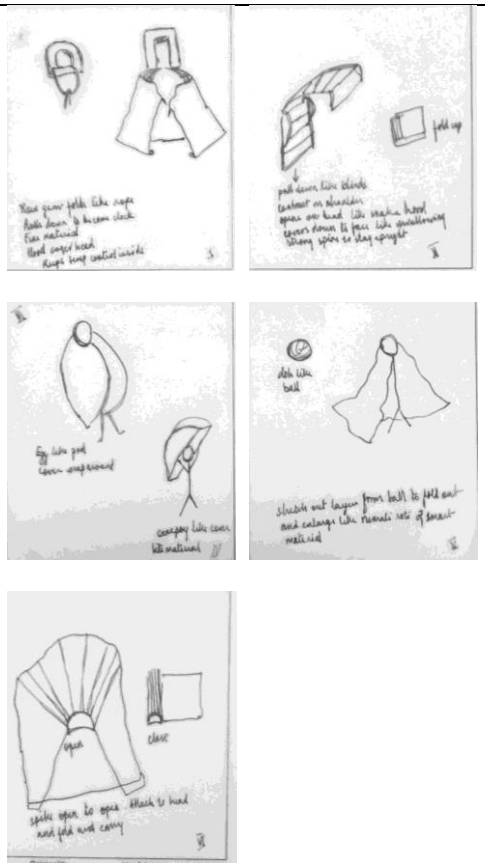
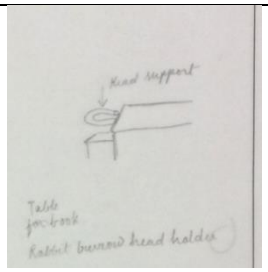
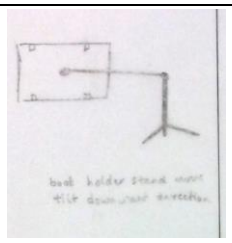
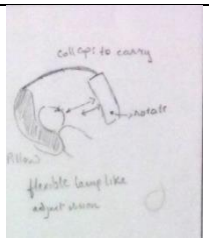
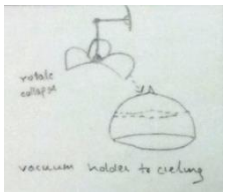
ANALOGY TREATMENT CONDITION			
Analogy Trigger	**Thought links**	**Idea Description**	**Idea representation**
Flying saucer	Sci-fi, star wars Force field Levitate Aliens, appendages	Force field to keep water away. Emergency jet mechanism to levitate in water logged situation. Powerful strong light wire structure, reinforced to withstand disaster. Like African tribal accessory Deflective dome cover head gear	
Lion	Fur, Hunt King, throne Africa No fear. power		
Snake	Rope Opens skin Cold Sense Swallow whole Scales Hood	Whole raingear folds like rope. Opens to form clock. Keep temperature cold and hot for body comfort. Scale like sections expand and contract material. A hood for the head.	
Porcupine	Spikes Defence	Sensor tip to detect rain will open fit to back.	
Rumalli roti	Soft, stretch, light Round cooking Spreads Maida doh	Smart material can be carried like ball, can be stretched to form sheet cover. A contractable and expandable round shaped cover.	

Table 4.2 Example of no analogy triggered ideation process

CONTROL CONDITION	
Solution Idea Description	**Idea representation**
1.A Bridge like structure, the book slides to position of lying down. 2.Head support to rest head and read downwards.	 
1.Stand with clip board. 2.Pillow supported devise.	  
1.Book holding stand with rotating devise. 2.Movable overhead, reverse bed table for book support.	 

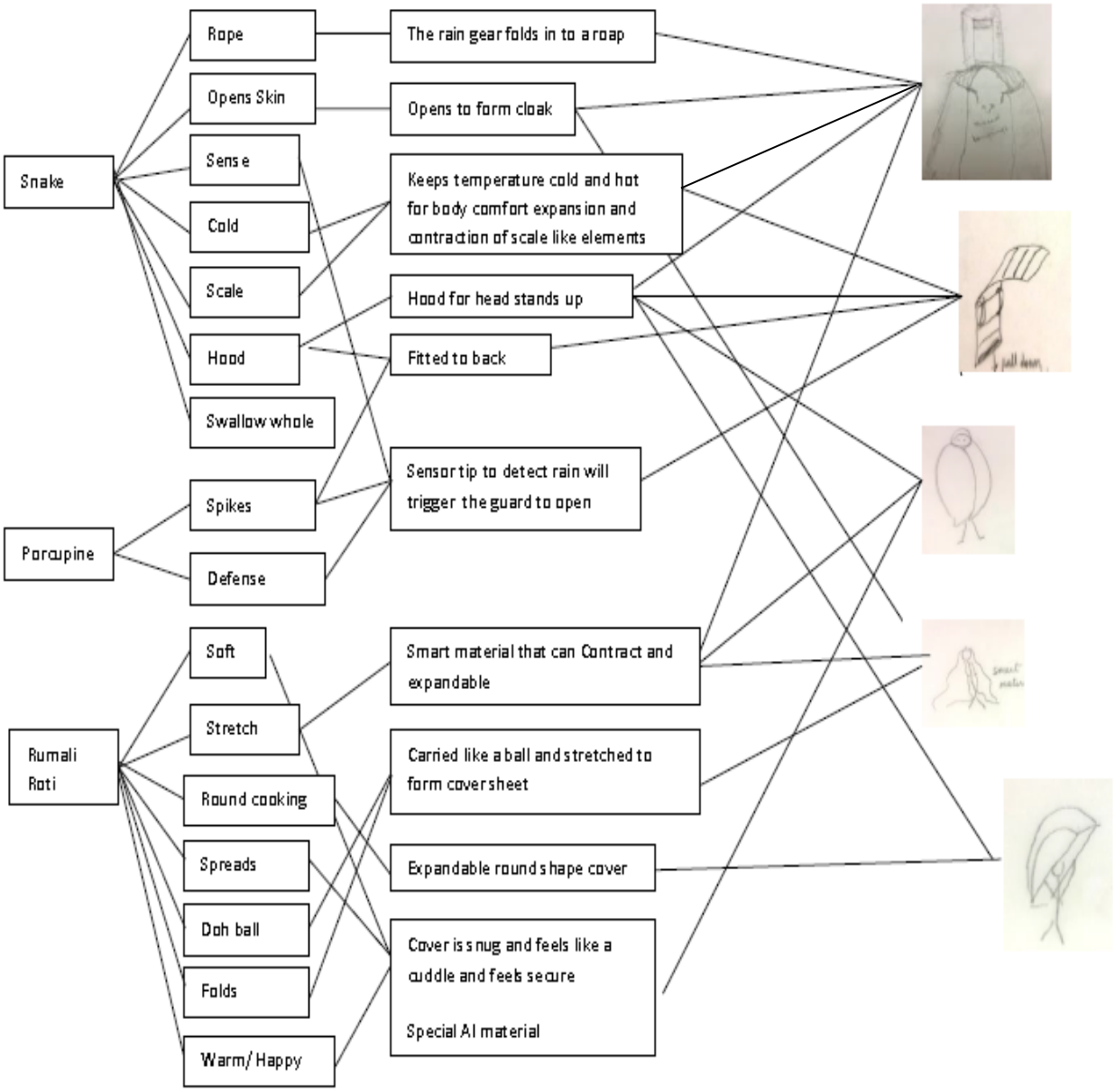
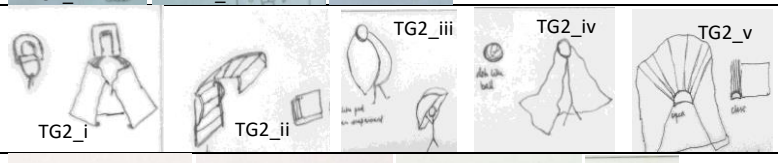
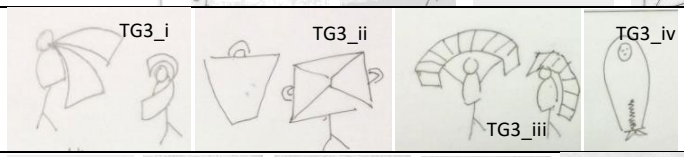
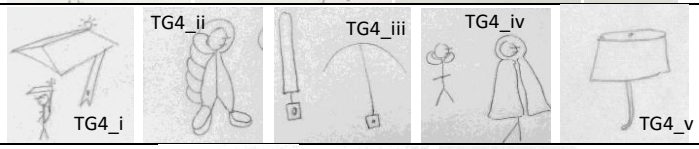
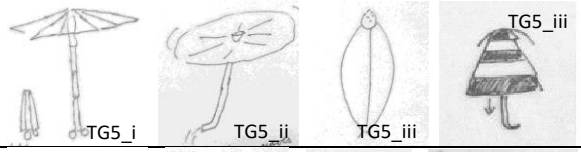
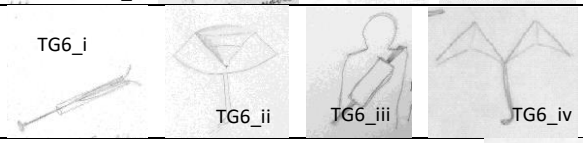
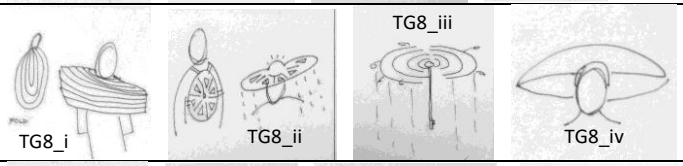
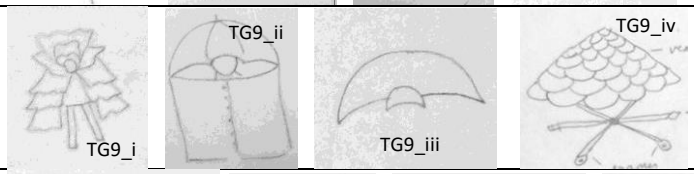
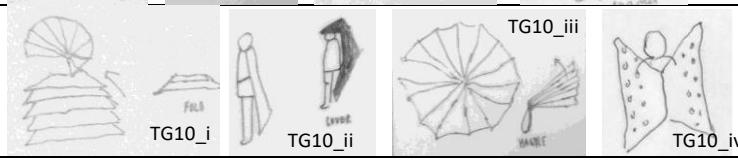


Figure 4.3 Idea trigger and idea linking

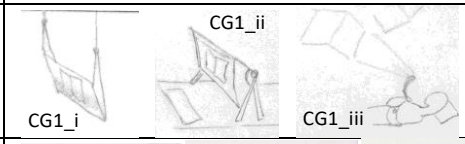
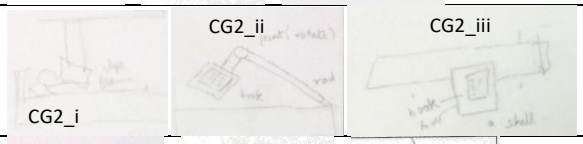
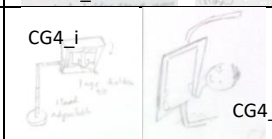
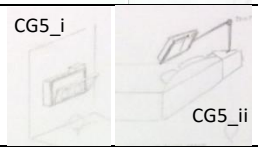
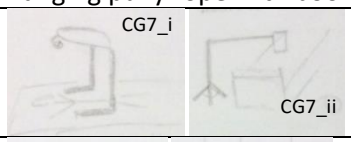
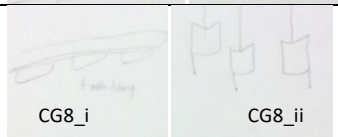
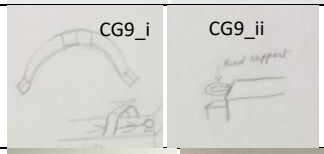
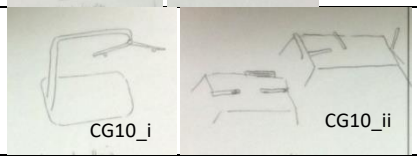
Table 4.3 Overview of ideation activity output with Treatment Scenario

	VISUAL DOODLES OF IDEAS	FLU	FLX	N	U
TG1	 TG1_i TG1_ii TG1_iii	2	2	3	2
TG2	 TG2_i TG2_ii TG2_iii TG2_iv TG2_v	3	2	3	2
TG3	 TG3_i TG3_ii TG3_iii TG3_iv	3	2	2	2
TG4	 TG4_i TG4_ii TG4_iii TG4_iv TG4_v	3	2	3	3
TG5	 TG5_i TG5_ii TG5_iii TG5_iii	2	2	2	2
TG6	 TG6_i TG6_ii TG6_iii TG6_iv	2	2	3	3
TG7	 TG7_i TG7_ii TG7_iii TG7_iv	3	3	2	2
TG8	 TG8_i TG8_ii TG8_iii TG8_iv	3	2	3	1
TG9	 TG9_i TG9_ii TG9_iii TG9_iv	3	2	3	2
TG10	 TG10_i TG10_ii TG10_iii TG10_iv	3	2	2	3
	With forced random analogy triggers, moderate to high fluency and flexibility was observed as well as high level of novelty. More radical exploration was observed.				

Colour code for the levels ☐ Low ☐ Moderate ☐ High

The numerical value is only to decipher the category of the level.

Table 4.4 An overview of Ideation Activity Output with Control Scenario

	VISUAL DOODLES OF IDEAS	FLU	FLX	N	U
CG1	 CG1_i CG1_ii CG1_iii	2	2	2	2
CG2	 CG2_i CG2_ii CG2_iii	2	1	1	2
CG3	 CG3_i CG3_ii CG3_iii	2	2	2	2
CG4	 CG4_i CG4_ii	1	1	1	2
CG5	 CG5_i CG5_ii	2	1	1	2
CG6	Hanging pully rope with bookscliped to bring down and send up	1	1	1	1
CG7	 CG7_i CG7_ii	2	1	1	2
CG8	 CG8_i CG8_ii	2	1	2	2
CG9	 CG9_i CG9_ii	2	2	3	2
CG10	 CG10_i CG10_ii	1	1	1	2
	Without being forced to use analogy triggered ideation, they followed the logical patterned route of solution finding. Thus, most of them delved in common areas, like stand and losing out on novelty value. Though there is a subconscious use of associative thinking to work out the solution ideas. This shows moderate fluency and low flexibility and partial novelty in the idea sets.				

Colour code for the levels ☐ Low ☐ Moderate ☐ High

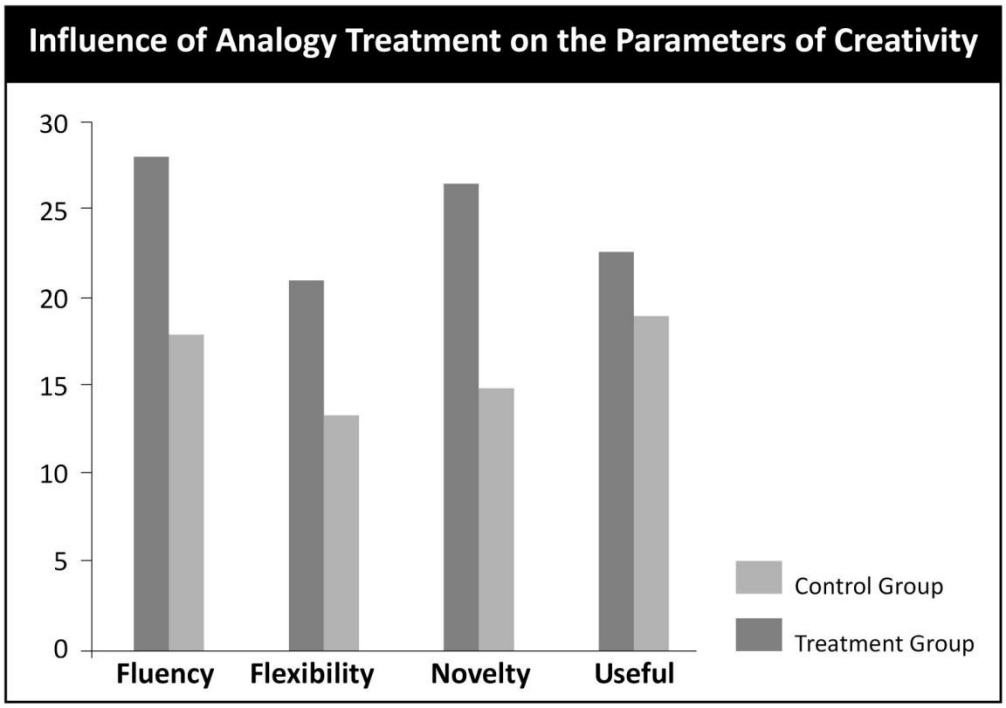


Figure 4.4 A Comparative Display of the Parameters of Creativity in two Ideation Condition

4.6 Learning from findings

The Idea Generation phenomena undergoes variance with the differing treatments as seen in the tables 4.3 and 4.4; however, it does so with a clear indication towards a positive influence of analogy-based thinking for generating new product ideas for novice design students conducting a design task. It also brought to light that the use of analogy in idea generation opens paths of exploration and enables non-design students to enhance their level of creative exploration as detailed in Figure 4.3 and 4.4. The experience in applying the analogy process with 20 engineering students from different disciplines was very positive and encouraging. In particular, these students displayed that by applying the approach they arrived at creative solutions, compared to the 'conventional' problem-solving approach (Appendix A). Further probing is needed to clearly understand the challenges of random analogy use.

4.7 Summery

The key challenges identified when not using analogy:

1. The mind does not directly use analogy triggers as an ideation starter when put through an idea generation task.

2. There is a tendency to search for analogous solution idea for various features of the task.
3. Exploring alternative lines of thought are seen to be challenging to the novice.

The key enhancers identified when using analogy:
1. The forced analogy association generated exploration of alternatives from varied routes.
2. The triggering effect of analogies helped generate multiple ideas.
3. The forced idea association with the analogy made the mind move towards deliberate new connections.
4. The novice designers were able to generate novel ideas with more ease.
5. Some inclination towards using direct surface similarity was noticed by few novices.
6. When instructed to use analogy to generate ideas, they were able to work in the domain of the analogy trigger and move away from the existing task base, while still linking to the existing task from a new perspective.

The insights gained from the study cannot be used as a conclusive finding to establish a claim, but they do provide insights into our query, "How novice designers generate creative ideas and the role analogy triggering plays in it". This gives us indicators for developing training methods and guiding structures to help participants use analogy triggers for idea generation and to stimulate novel ideas. This empirical study brought to light the relation between analogy triggered ideas generated based on the creativity parameters and its effect on the creativity level of the idea output.

It was observed that without analogy triggers for idea generation there was:
-Moderate number of ideas generated.
- Low to moderate variation in the types of ideas produced.
- Novel ideas were limiting.

With analogy trigger for idea generation there was:
- More number of ideas were generated.
- More variation in the types of ideas produced.
- More novel ideas emerged.
- An exploratory inclination to adductive thinking

The observations give a clear indication about the generative property as well as the potential to steer new association with analogy triggers for idea generation. To gain the advantages and negate the challenges encountered, the administration of random analogy triggers could be a possibility worth exploring further.

Chapter 5

Research Study 2: Exploratory study on Role of random analogy trigger on idea generation by mid-level designers

5.1 Introduction

Analogical reasoning seems to be a core driver for analogy based design that involves the transfer of relational information from a domain which already exists - referred to as the source or base domain -to the problem domain to be solved -referred to as the target domain. Thus, a useful analogy depends upon there being some sort of similarity between the source domain and the target domain, because the perception of similarity is likely to play a major role in some of the key processes associated with analogical reasoning. The case of design Synectics theory propounds that triggers responsible for producing creative thinking, comes from analogies that tap data stored in the unconscious of past experiences, while evoking the preconscious. It creates a bridge between the rational and non-rational views of the problem situation. It is an induced process, based on the theory of 'Making the familiar strange' and 'Making the strange familiar' (Gordon 1961). It is a powerful process, but a challenging one to use in order to extract the inherent paradoxes out of problems and to generate breakthrough connections for new view-points and innovative solutions. To capitalize on it, expert training is important. Many breakthrough innovations and new products are a result of recombining existing know-how and analogies, eg. sail boat + steam engine = steam boat. An analogy is a fundamental cognitive mechanism that is used to retrieve existing knowledge and to apply it in a new context (Hargadon 2003). Applying the idea of analogies opens a wide space of solutions; with a new and creative solution usually resulting from the combination of pieces of knowledge that have not been connected before (Geschka, 1992; Hargadon, 2003). Empirical research by Dahl and Moreau shows that originality during idea generation can be enhanced by encouraging the extensive use of analogies, especially far

analogies (Dahl and Moreau 2002). Creative design follows processes of activation and recombination of previous knowledge elements in order to generate new properties based on the old ones. But to create new instances of the concept, the creative activities have to expand the boundaries of the semantic domain of the problem. Despite this, most problem-solvers have a tendency to fixate on their mental representation of the existing solution, hence inhibiting their capability to form new ideas (Hekkert, 1997).

Our observations from the introductory study showed a tendency of the mind to search for a solution idea and have multiple outlying ideas adding various features to that solution idea. This challenges the exploration of alternative ideas. However, when the mind is induced with a random analogy, it can trigger forced association to make deliberate new connections. To do so, an"attribute-to-relations shift" needs to be made (Gentner 1983). As stated by Brown, “A potential solution to a problem is often not seen although it is in plain sight, because it is embedded in a familiar, but currently irrelevant, context” (Brown 1989). This suggests that it is important to experiment with objects in many different ways and to look at them from different perspectives. Such activities are likely to free objects from specific roles, thus rendering them more useful as tools for more varied applications. Yet, having an inhibitor due to the habitual use of an object in performing a specific task produces a lower rate of transfer.

This research study conducts an empirical exploration of random analogy triggered idea generation and explores Brown’s observation to set a constructive enabler on creative production. The objective remains to move out of the process of analogical reasoning for comprehension and problem solving so as to construct new processes for creative design ideation and override the concern over the potential that analogies have for leading to false or oversimplified representations. The basis of these cognitive theories has led to systematic application of carefully selected analogies, rather than random use of analogy as inspiration for idea generation. Often either problem-driven or solution-driven analogies are sourced to trigger new uses or applications for new products. The significance of analogical problem-solving as a method for expanding the solution space and overcoming personal fixations related to the problem definition can be an assumption in the idea generation phenomena that needs clarification and deeper explanation.

Synectics solicits exploration through avenues of illogical association, and force fit feasible solution actions into then. The Synectics process has specified a spectrum of thinking to show as a spectrum of new and novel as shown below in Figure 5.1 (Nolan & Williams 2010)

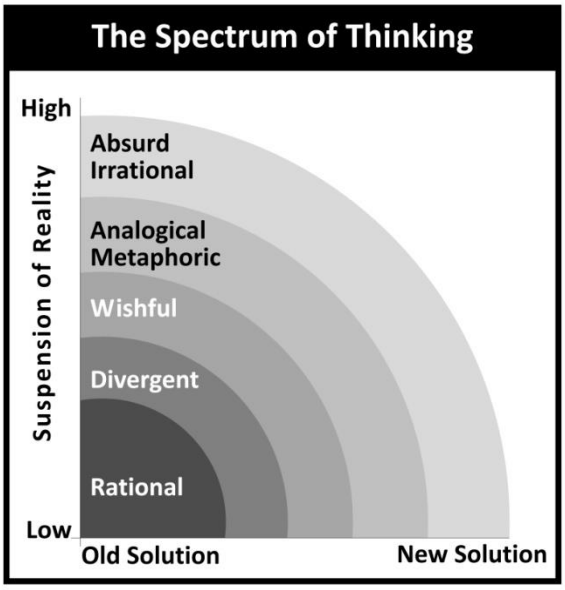


Figure 5.1 The Synectics Spectrum of Thinking

Taking the learning of the introductory study about the use of analogy in idea generation, we can learn how it opens paths of exploration and enables non-design students to enhance their level of creative exploration; even though they displayed some constraints in choosing random analogy. The second study was designed to get deeper insights into the phenomenological change that takes place in the thinking and generation of ideas from the choice of analogy and the use of it for the proposed task.

5.2 Objectives

- To explore the role random analogy triggers in pushing the realm of novel idea generation.
- To observe the inhibition and liberation experienced by designers when using random analogy for idea generation and exploration during a product ideation task.
- To observe the degree of 'suspension of reality' (Nolen & Williams 2010) in the random analogy usage within the phenomena and its effect on the ideas produced.

5.3 Design Task and procedure

This study's focuses on demonstrating the primary attribute of using analogy in design ideation; thus steering away from the course of analogy identification. The study does not base itself on testing or evaluating an analogy or its tools. But the focus is kept on the activity of design ideation with analogy and its outcomes. By documenting idea responses for the given design task, the phenomena of Random Analogical Ideation (RAI) is studied and analysed. The findings from the observation and documentation are used to bring out the degree of variance in idea responses between the two groups' treatment. This can give insights into the types of advantages that can be gained through random forced ideation and influence the idea response.

Two treatments were distributed amongst four groups of 5-4 members each as seen in Figure 5.2. The participants were first trained in the analogy based idea generation process and given a brief to generate ideas for new products by taking random analogy triggers. They were briefed and instructed about the task fulfilment and given examples and taken through warm-up exercises to understand the process. The participants were instructed to record their thought processes as sketches and annotations - which were used for data analysis – as they explored ideation both through sketches and written words. Their analogy triggers and subsequent idea catalytic processes during the exploration were documented in the worksheets and observational notes of the researcher. Group 1 and 2 were treated as the control group and were asked to choose a random analogy trigger and identify different attributes (analogy analysis) of the analogy and trigger associative idea links. Group 3 and 4 represented the treatment group and were directed by the instructor to the choice of random analogy triggers for ideation.

All the participants were instructed to force-fit similarities and relationships from the analogous domain to generate ideas for the target domain. The experiment was conducted during the workshop session. The participants were told to generate ideas by forcing the attributes to generate new and varied ideas (solution generation). While choosing the trigger analogy, the control groups thought and chose their own analogy, and the two treatment groups were told to take the thing in front of them as the random analogy trigger, and the analogy of the control team respectively, to maintain the randomness of the analogy. The

experiment was analysed through qualitative research methods from visual data of idea sketches and annotations as well as presentation and observations.

Task: To generate ideas for an innovative security device for a residential complex.
18 design executives of Honeywell from varied divisions participated in a 2 day product development workshop. They were of mid-level experience and a mix of engineering designers and product designers, having similar skill levels and experience.

Figure 5.2 Creativity workshop with Mid-level design executives at Honeywell

5.4 Output and Observation

The ideas generated were assessed for their novelty value and the level of suspension of reality achieved in the creation of the forced association based on the 'spectrum of innovative thinking' (Nolen & Williams 2010).Insights drawn from the relationships revealed were able to elucidate the reason for differences in the idea generation phenomenon (Appendix B).

After an initial simple coding process of the trigger and solutions, a categorization of the ideas was carried out by having their values assigned by three expert ratters based on Amabile's Consensual Assessment Technique (Amabile 1982). Very few studies of idea generation focus on specific ideas for products. The ones that have rated products have been involved in finished products and not early stage ideas. Studies dealing with product idea rating use various sets of criteria to define a creative product. Dean has categorized Novelty based products, with the claims that products are creative not only based on their originality (Dean 2006). To render an idea creative, it is not necessary for an original idea to be appropriate (Runco & Charles, 1993). This research used the two simple parameters to rate

the creative level and a simple two-category set was used. Table 5.1 below reveals the idea generation implication following the thinking spectrum and suspension of reality in the use of the analogy trigger.

Table 5.1: Categorizing the analogy trigger and ideas generation implication on the Levels of suspension of reality.

Treatment	Groups and analogy	Thinking spectrum applies	Ideas	Novelty
TC Control	G1 Student	Rational thinking	TC1S1	low
			TC1S2	low
			TC1S3	low
			TC1S4	low
			TC1S5	low
		Diversified thinking	TC1S6	low
			TC1S7	low
		Analogical thinking	TC1S8	medum
		Absurd and irrelevant thinking	-	-
	G2 Pen	Rational thinking	TC2S1	low
			TC2S2	low
		Diversified thinking	TC2S3	medum
			TC2S4	low
		Analogical thinking	TC2S5	medum
			TC2S6	medum
			TC2S7	medum
		Absurd and irrelevant thinking	TC2S8	medum
			TC2S9	high
TT Treatment	G3 Samosa	Rational thinking	-	-
		Diversified thinking	-	-
		Analogical thinking	TT1S1	medum
			TT1S2	high
			TT1S3	medum
		Absurd and irrelevant thinking	TT1S4	high
			TT1S5	high
			TT1S6	high
			TT1S7	high
			TT1S8	high
	G4 Student	Rational thinking	TT2S1	low
		Diversified thinking	TT2S2	medum
		Analogical thinking	TT2S3	medum
			TT2S4	medum
		Absurd and irrelevant thinking	TT2S5	high
			TT2S6	high
			TT2S7	medum

Table 5.2: Observation and learning

Conditions	**Control Teams**		**Treatment Teams**	
Teams	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Analogy used	Student	Pen	Samosa	Student
Rational for choice	It will follow orders.	It was in front.	Had to Choose an analogy from something right in front.	Control teams analogy was given.
	Their choice of trigger was logically governed.	Choose a random trigger.	They took the risk of (absurd) irrelevant trigger.	Had no role in choice.
Some observation	Carried out a very logical analogical reasoning process.	Tried to list varied attribute and explore ideas.	They abducted the rational thinking in a playful way by making illogical associations and radical exploration of ideas.	Tried to suspend logic consciously and carried out radical attribute exploration and built novel associations.
	Exploration was fixated to the analogy's direct relation to the problem at hand.	Had little difficulty in balancing logical thinking with radical thinking.	Was able to force fit the radical triggers to user benefit for product idea.	Had little difficulty in balancing logical thinking with radical thinking.
Process followed	Thought what would be an appropriate analogy and then chose.	Had a little difficulty in defying logic and choose a random trigger.	Went all out to experiment with absolutely unrelated random analogy.	Had no role in choice and was forced to use it.
	The attribute listing of the analogy trigger was fixated to generate ideas to fixed needs based on logic.	Generated a fair mix of attributes and created a mix of associations and ideas.	Generated a mixed area of attributes and force fitted to the task to explore novel combinations.	Generated varied range of attributes and force fitted them to the task to generate novel ideas.

Action	Demonstrated the limitation of analogy usage and problem fixation in the idea exploration. Was not able to trigger more links.	Demonstrated some difficulty in analogy usage, but forced the mind to create new associations and create multiple links to build ideas.	Was forced to think in a manner unrelated to the problem at hand when listing attributes. Able to explore interesting alternatives for existing needs, and also generate new needs and novel solutions. They were able to generate ideas outside the stated problem.	Was forced to think in a manner unrelated to the problem at hand when listing attributes.

5.5 Discourse of Learning

Table 5.2 shows that starting with unrelated random analogy triggers, the Control Teams took some time to reason out their choice of analogy and demonstrated resistance to breaking out of logical culmination of problem solving and the inhibiting of radical idea exploration (Dalh and Moreau 2002). Conversely, the Treatment Teams had no chance of making any pre-reasoned decision when choosing the analogy triggers. To ensure the randomness of analogy choice, they were forced to take the object in front of them and one of the analogies of the control team respectively. They were able to explore idea alternatives in various fields of the product- from material, technological, structural, intractable, etc. and generate novel solutions.

The findings of the comparative study as detailed in Table 5.1 and 5.2, can help to demonstrate a wider possibility of the radical exploration with the use of random analogy triggers for new product ideation based on the change in the phenomenon of idea generation that occurred as seen in Figure 5.3 (Details in Appendix B).

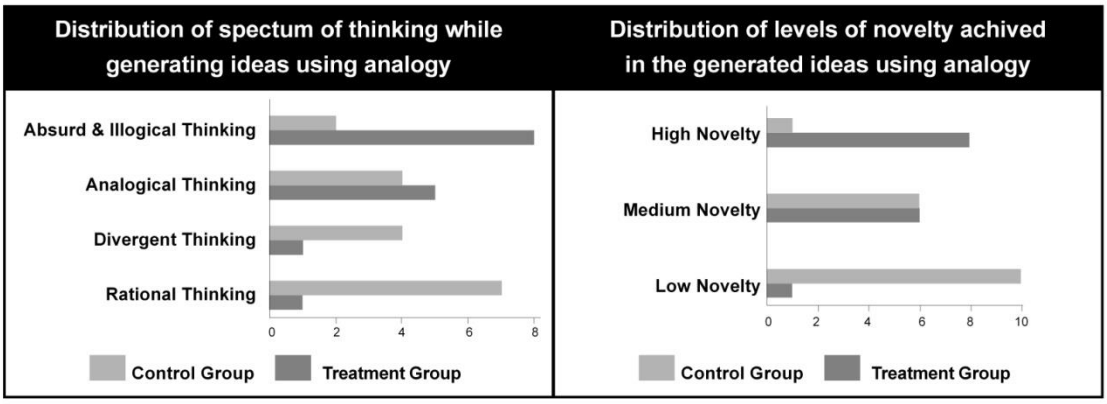


Figure 5.3 Distribution of spectrum of thinking and the level of novelty

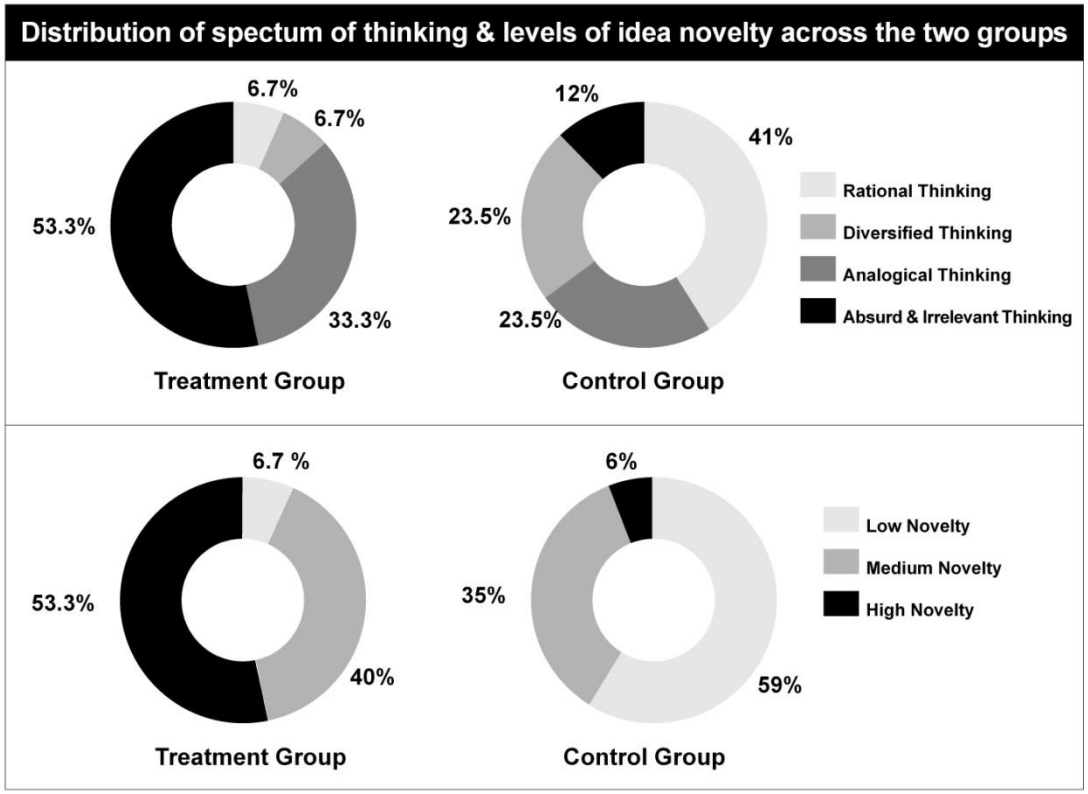


Figure 5.4 Distribution of spectrum of thinking and the level of novelty across groups

From Figure 5.4 an interesting insight in the case of new product ideas has come out; that is the fact that analogical thinking is supposed to be non-logical to bring forth the surprise of newness (Dalh and Moreau 2002). As the ideation process is in the early stage of the design process, the radical analogy trigger stirs out of fixated thinking and liberates exploration

while pushing outcomes to creative levels. Treatment Teams' responsiveness to radical analogy associations demonstrated the suspension of reality in association generation for the solution creation process. The varied approach of using analogy for the idea generation task by the two groups indicates the necessity of forcing the mind to abduct itself from logical thinking for the new product idea generation stage and refuting the need for correct analogies for appropriate idea generation in the early stage of the design process. An interesting insight that evolved was that the success of the creative output was seen in the building of far-from-logical associations. The constraint of logically choosing analogy trigger scan be overridden by the 'suspension of reality' in association building. The learning also brings to light the difficulties faced in using random analogy. Thus, the scope of this finding for productive use in new product idea generation, the observations point towards a simplified step-wise use of random analogy which can provide us with the confirmation required for the aforementioned assumption.

5.6 Summery

The two conditions of usage of self-chosen analogy and forced use of random analogy, brought out some key insights.

Challenges identified in choosing and using analogy:

1. When asked to choose an analogy the mind tends to weigh out the potential match to the target task.
2. The mind shows resistance to breaking out of logical reasoning while using analogical thinking for idea generation.
3. Exploration was fixated with the analogy's direct relation to the problem at hand.
4. Since the mind seeks the path of least resistance, the participants had difficulty in radical thinking.
5. Even after training with the use of analogy, there was difficulty in taking the radical route without direction.

The key enhancers identified when using analogy:

1. Random analogy triggers, when used to abduct logical reasoning, produced non obvious associations.
2. Illogical associations, different from the task in hand, helped build varied creative solution ideas.
3. The directed force-fitting of the illogical association to logical solutions to the task in hand leads to creative ideas.

This study provides key insights into the important role of random analogy- to abduct logical reasoning and generate multiple radical associations. To do so is not easy due to the logical watch dogs inhibiting non-obvious risk taking paths. From this study, a clear and positive relationship between the level of radical associations and the creative outputs is seen.

The observations from forced random analogy triggered idea generation process are:

- More radical associations were obtained.
- There was a playful risk taking attitude noticed.
- To move the mind towards radical thought required guiding and showed positive impact on the creative output.

The clear indication of logical interruption of exploratory thought, right from the point of choosing analogy, points towards a set perceptual conditioning. This stems from the perspective of the working of analogy, in facilitating learning and understanding to aid survival. Thus non appropriate outcomes can prove to be risky and detrimental. This mind-set being well instated in our mind, makes any unreasoned trigger challenging to implement.

For manifesting the full value of analogical thinking the logical mind must be waylaid. The forced random analogy can direct focus on new pursuits and open the mind to the exploits of radical thought. This process of suspension of logical reality has shown a flourish of radical thoughts as noted in Table 5.1.

These findings indicate the true creative potential of random analogy trigger and to help both individuals as well as organization in gaining productive creative output from less experienced designers. The insights point at the need for a conclusive guiding framework to abduct logical thinking and drive generative exploration.

Chapter 6

Research Study 3: Exploratory study of the role of Forced Analogy Ideations

6.1 Introduction

Exploratory study of the role of Forced Analogy Ideations in exploration of Creative and Paradigm Modifying New Product Ideas

The strategic use of Analogical reasoning/thinking in creative problem-solving plays an important role. In design practice, experts in the field are seen making use of analogy for problem-solving and idea finding, which has been developed through years of practice with trial and error (Dunber & Blanchettel 2006). In theory, idea generation in design is treated as a special type of problem-solving activity, having more than one solution to meet the required functionality. The functioning of the mind is driven through associative thought processes at both base levels in solving day to day problems, as well as at higher levels for great inventive discoveries (Holyoak & Thagard 1989). With the use of analogical reasoning in the design process, designers can trigger the ideation process for exploration. Much research is being done in the area of computational aided stimulation, as one of the challenges noticed in analogy usage is in making the right connection of associations and as stated by Bonnardel & Marmèche the more knowledgeable or experienced the designer, the abler they are to identify high-quality design examples and thus build better relationships. (Bonnardel & Marmèche, 2004). This has led to the belief that the creativity and originality of a designer's output is now largely dependent on the quality of examples they retrieve during the design process. Thus, retrieval of high quality, innovative design examples as analogies are seen to be potential sources of developing high-quality ideas/innovative solutions. Thus, most designs by analogy studies focus on data/patent mining (TRIZ). Purcell & Gero's assumption that if designers collect low-quality design examples, their design

outputs are likely to be uninspired (Purcell & Gero, 1996) ratifies the development of computational aid to source rich analogy.

Several research works have demonstrated the positive influence of triggers in enhancing creativity or solving engineering problems. Kletke argue that stimulus can lead to more ideas during the idea generation phase of design (Kletke et al. 2001). MacCrimmon and Wagner expressed that stimulus rich creativity technique positively impact creativity, especially when the initial ideas have been exhausted (MacCrimmon & Wagner 1994).

This can hold good for engineering design or technology ideas as it aids solution finding by mapping a solution/technology/function from one domain source to the target domain. Whereas this research explores the possibilities of radical ideation exploration in the early stage of the design process and, therefore, creating radical ideas/concepts through forced solution fitment - thus giving novice designers a head-start, by analogy, triggered thinking so as to surmount linear patterned thinking and lead to open radical idea generation. While studies reveal that analogy usage is pervasive in a variety of design disciplines, for solution finding there is scope to study the phenomenological aspects of idea generation with a random analogy by novice and young designers, so as to mitigate the challenges they face at taking the leap into unrelated exploration. This study leads in from the previous exploratory study learning in chapters 4 and 5, and sets out to test a framework of the process using a random analogy for new product idea generation and to build further recommendations and applications in design education. The use of McFadzean's creative continuum as laid out in Figure 6.1 has been carried out to plot the phenomenal change (McFadzean 1996).

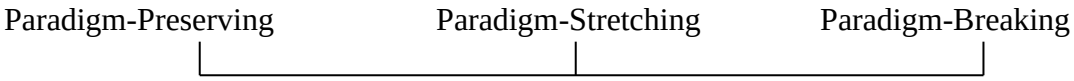


Figure 6.1: The Creative Continuum

Paradigm-preserving techniques do not force the participants to venture outside their own perspectives in exploring the situation.

Paradigm-stretching techniques encourage the participants to stretch their existing paradigms. The facilitator encourages this by utilizing unrelated stimuli and forced association. Paradigm-breaking techniques can be very powerful and can encourage participants to

develop very novel ideas. The participants produce creative ideas by bringing new elements into the problem situation and by developing new relationships between existing elements.

DeBono suggests that changing a paradigm requires lateral thinking. People can enhance their creativity by looking at a problem from a variety of perspectives and by breaking old mind patterns and forming new connections and perceptions (DeBono 1992). Several methods can encourage a change of perspective. These include using unrelated stimuli and using different modes of expression.

VanGundy suggests that the purpose of unrelated stimuli is to present a completely different problem perspective (VanGundy 1992). In fact McFadzean, Nagasundaram and Bostrom claim that this type of problem-solving technique encourages paradigm transformation. In other words, the boundaries of the problem are either stretched or broken, using paradigm stretching and paradigm-breaking techniques (McFadzean 1998, Nagasundaram & Bostrom 1993). This encourages creativity due to various factors such as:

—the presence of unrelated stimuli

—the forced association of stimuli

—the use of multiple stimuli

—the presence of an unusual mode of expression

Object stimulation is an idea-generation technique that people can use to explore the problem space and to develop ideas. The participants have to view the situation from a different perspective by using unrelated stimuli. In fact, research has shown that object stimulation is a more powerful tool in terms of creativity. Thus, the research study intends to study the relation of unrelated stimuli, the forced association of stimuli, the use of multiple stimuli, and unusual mode of expression through random analogy trigger to the idea generation output in terms of idea quantity, flexibility, creativity and elaboration.

6.2 Objective

To study the phenomena of new product idea generation with random analogy by using a framework of breaking down the object analogy into its structural, functional and behavioural aspects and using them as forced idea drivers, to study the variance to Experiment 2.

6.3 Design Task and procedure

From our understanding basis in the available literature and our findings in the previous experimental sessions with student designers and mid-level design executives on idea generation of new innovative products, we have tried to understand the phenomena of idea generation with analogy triggers. This has allowed us to observe the challenges faced by the designers in sourcing and using analogy triggers and the concern of multiple idea generation based on the Torrance creativity parameters as a structured framework of analogy triggering was devised and administered.

The design task was to generate ideas for innovative new products for a specified business domain, for which they had done a user study and problem identification on Day 1. Our study was conducted on Day 2 in generating ideas for innovative new products. A stipulated time of 3 hours was set to brief, instruct, and initiate the task fulfilment process. A structured framework of analogy attribute break up, based on Function, Structure, and Behaviour aspects, and SCAMPER heuristics, was given to facilitate random analogy triggering for new product idea generation. The participants were instructed to record their thought processes as sketches and annotations, which were used for data analysis, which they explored both through sketches and written words. Their analogy triggers and subsequent idea triggers during exploration were documented in the worksheets and observational notes of the group facilitator. The facilitators were PG Product Design students who had undertaken a workshop on idea generation with analogy triggers. They explained the use of the framework and first made each participant choose an object as a random analogy. This was deliberately done so as to keep the randomness of the analogy. Then the participants were made to breaking up the random analogy into as many attributes and associations as possible within the restrictions provided. Finally, all the attributes and associations had to be force-fitted to the task/problem/need at hand as ideas, as well as to use them as a further stimulus to generate new and novel ideas. There were no particular criteria of project choice - rather, not so complex product categories were chosen to push the boundaries of traditional approaches and bounded thinking. This would help the participants not to get overwhelmed by the problem and concentrate on the idea generation aspects of the new product development. Surely there were limitations faced in the total representation of all the thought processes.

To communicate and implement the experiment to observe the phenomena, certain functional requirements were descriptively presented to the participants.

6.3.1 Experiment Design

The Research study was designed to report in-depth, the phenomena of innovative idea generation using forced random analogy through a structured process. Eighty participants of SME organizations from varied business fields undertook the idea generation task.

There was no selection of participants; they were all part of the CII Seminar on new product innovation. The participants had managerial experience, but no prior training in the proposed ideation process. However, they have been involved in the certain development processes for new products.

The participants were divided into groups and equally distributed expertise wise. Each group was assigned a facilitator who was trained to instruct and direct the groups in applying the random analogy process within the framework as the time constraint did not allow a training session for the participants.

6.3.2 The Analogy Trigger Steps

Taking a random object/thing and breaking it down to its functional, structural, behavioural, and any other attributes and associations depicted in Appendix C. Then force-fitting the attributes and associations to the problem in hand to generate ideas by applying the SCAMPER heuristics. Finally combine and group the ideas to form new product concepts, keeping in mind user needs, opportunity areas and problem solutions.

6.3.3 Experiment Execution

The participants had enrolled in a two-day Seminar & workshop on New Product Development and participated in the experiment as part of the training activity. The Analogy triggering and idea generation was done individually as seen in Figure 6.3; the pool of ideas was together used in a group activity to generate new product ideas. At the beginning of the process, the participants were asked to intuitively and spontaneously generate as many

attributes and force-fit them to form as many ideas for the development of the new product in hand using the generative framework depicted in Figure 6.2.

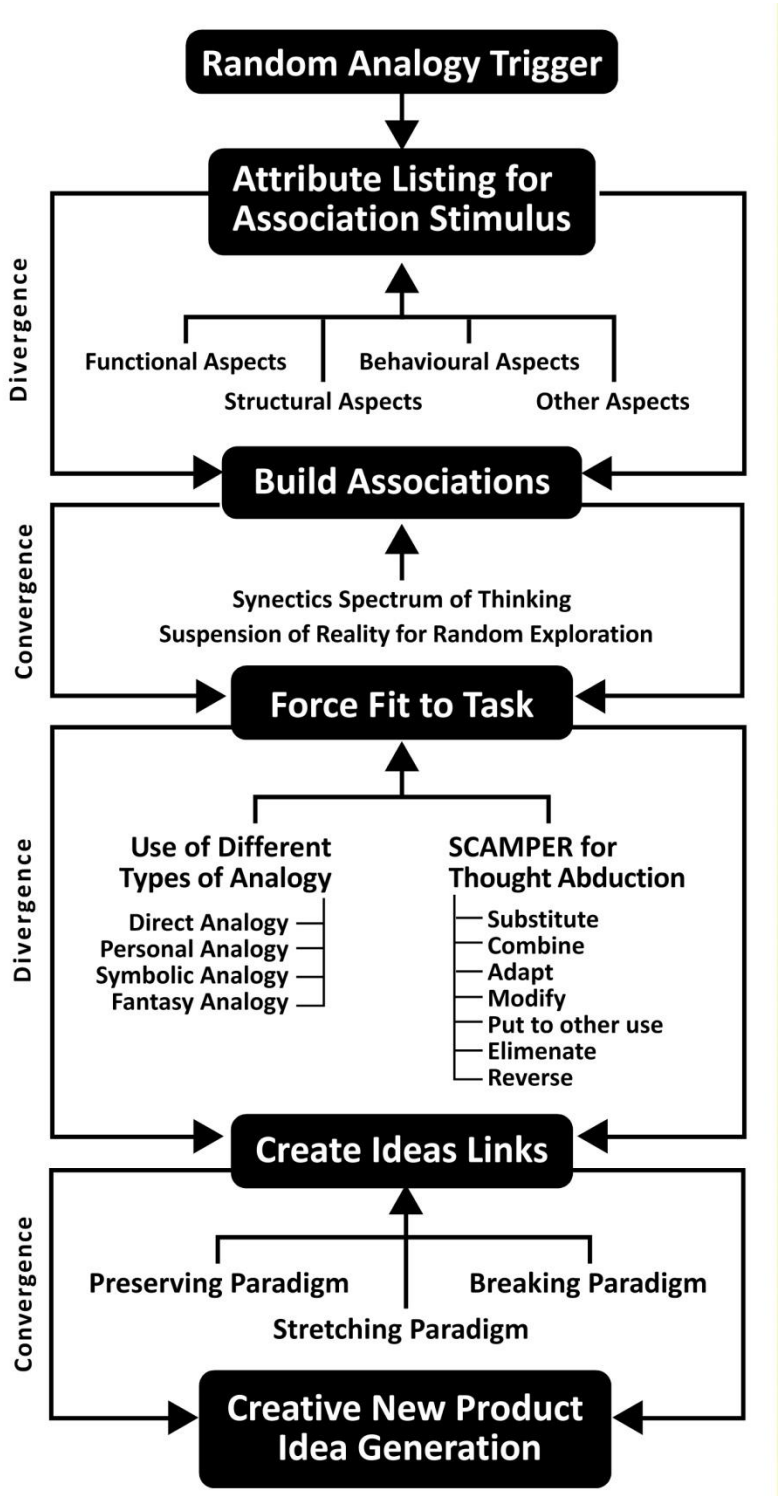


Figure 6.2: Random Analogy Triggered Generative Framework

They were given 20 minutes to do the task. This process was documented in a written format that was given to them earlier.

Figure 6.3: Individual Analogy triggered attribute listing and idea association building

In the second phase, the participants congregated in their respective groups to share all the ideas generated as seen in Figure 6.4. They were allotted 2 hours to complete the final new product concepts. The participants were asked to record the ideas in the form of written words and sketches on sticky sheets. They then grouped ideas together to form new product concepts. The participants were encouraged to explore away from the direct structural analogy representation to more lateral functional and behavioural representation. They were required to extract a wide range of ideas from the analogy drivers.

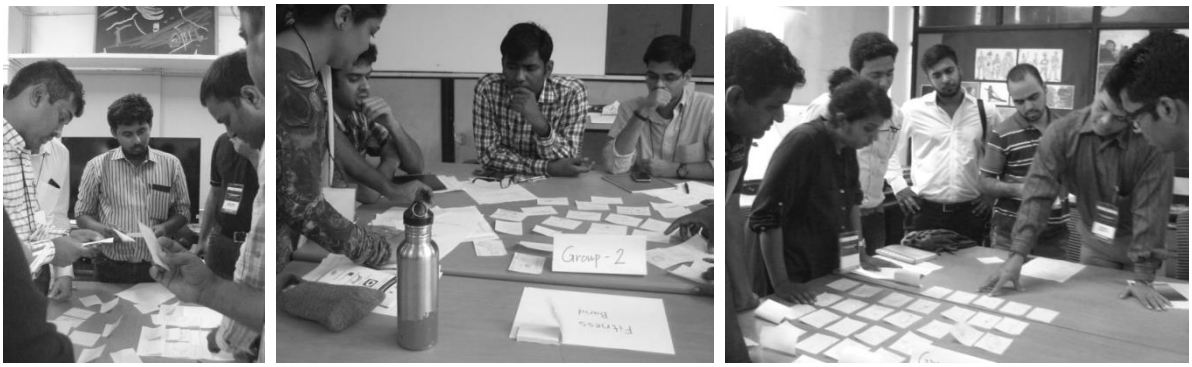


Figure 6.4: Group activity of idea pooling and New Product Concept creation

6.3.4 Sample Participants

Eighty mid-level executives of different disciplines were mixed equally into eight teams to perform the given task.

6.3.5 Evaluating Process

On the completion of the ideation process in the stipulated time frame, all the documented ideas were collected for the purpose of studying the role of random analogy trigger on ideation using the given framework, where two sets of factors were looked into. Since the field of inquiry is the creative idea generation, the Torrance parameters were followed. The requirements set were the number of ideas to quantify the level of exploration carried out. It was important to see the flexibility of thought and radical exploration to articulate the role of a random analogy trigger clearly. Novelty provides a measure of the creativity/originality level of a given solution (Markman & Wood, 2009), i.e., its uniqueness or originality within a context. Finally, we also included a quality evaluation because no matter how novel an idea might be, if it does not meet customer needs, process specifications, technical and economic feasibility - it will be discarded by the customer or solution implementer (Markman & Wood, 2009).

Along with it, the associative thoughts and ideas generated were coded and categorized to summarise the data.

6.3.6 Data Collection

The documented ideas of the participants in the respective worksheets were marked with codes for analysis. The ideas generated were evaluated by three different domain knowledge expert ratters. The extent to which the analogical attributes are represented as ideas is plotted along the creative continuum. This was to correlate the boundary-stretching or breaking assets of the new product ideas and find the relation to the unrelated analogy, the forced association, the multiple analogy triggers and the unusual modes of expressions.

6.3.7 Output and Observation

The ideas generated were assessed for their novelty value using the Creativity continuum (McFadzean 1999) to observe the phenomena. According to VanGundy, ‘Wishful Thinking,’ a paradigm breaking technique is frequently overlooked by pragmatic-minded individuals. Such persons often assume that alternative problem perspectives must be based upon logical or rational modes of analysis (VanGundy1988).

Table 6.1 The characteristics of creative continuum

	Paradigm Preserving	**Paradigm Stretched**	**Paradigm Breaking**
Product /problem Boundaries	Unchanged	Stretched	Broken
Reduction of Cognitive Inertia	Low	Medium	High
Potential Apprehensions	Low	Medium	High
Use of Imagination	No	Necessary	Necessary
Stimuli Types	Related Stimuli	Unrelated Stimuli	Unrelated Stimuli
Types of Association	Free Association	Forced Association	Forced Association
Levels of Creative Stimulation	Low	Medium	High

Table 6.2: Parameters of defining ideas to the creative continuum

	Judging Parameters	**Paradigm Preserving**	**Paradigm Stretched**	**Paradigm Breaking**
1	Product /Problem Boundaries	Unchanged	Changed slightly	Changed fully
2	Imaginative Use	None	Slightly Imaginative	Very Imaginative
3	Stimuli Types	Related to the Stimuli	Unrelated to the Stimuli	Unrelated to the Stimuli
4	Types of Association	Direct and Obvious Association	Forced yet not so Obvious Association	Forced Radical Association
5	Novelty Level	Low	Medium	High

CII GROUP 1

Task: Innovative lock

Table 6.3: A view of one groups idea generation output

Participant	Total Ideas	Fluency of Ideation	Flexibility of Ideation	Novelty of Ideas	Usability of Ideas
1	12	2	2	1	3
2	-	-	-	-	-
3	7	2	2	1	2
4	10	2	3	3	2
5	7	2	3	2	3
6	6	1	2	1	3
7	10	2	2	1	1
8	14	3	3	3	2
9	1	1	-	-	-
10	19	3	3	3	3
Average	**10.65**	**2.12**	**2.5**	**1.87**	**2.37**

Fluency and usability rate : 1= low (1-6) 2= mid (7-12) 3= high (13+)

Flexibility rate: 1= low (1-2) 2= mid (3-4) 3= high (5+)

Novelty rate: 1= low (1-2) 2= mid (3-4) 3= high (5+)

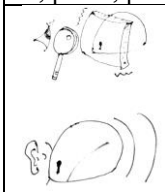
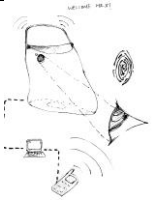
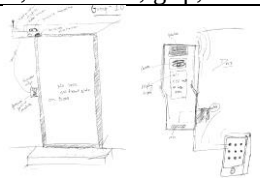
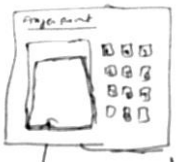
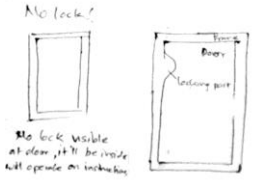
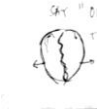
The analysis of ideation performance of individual members of Group A shows that high fluency and flexibility gained through random analogy triggering has positive influence on the novelty level. Though the use of surface associations often lowered the novelty levels amongst participants as seen in Table 6.3. But when similar ideas are combined to bring out

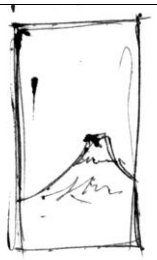
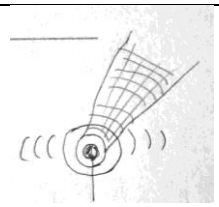
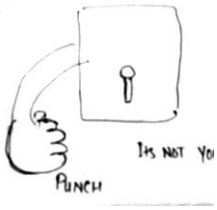
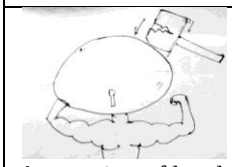
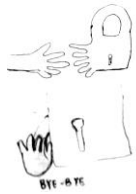
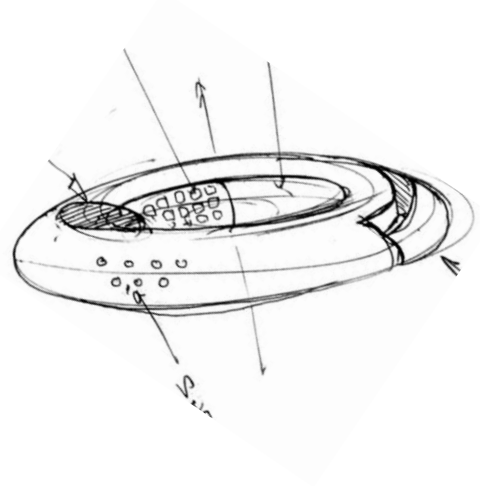
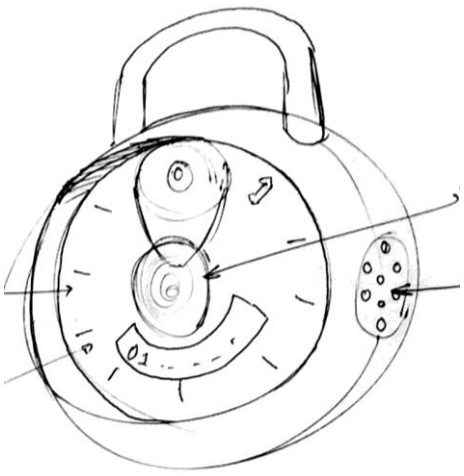
The rater parameters have been set in relation to the experiment structure and constraints.

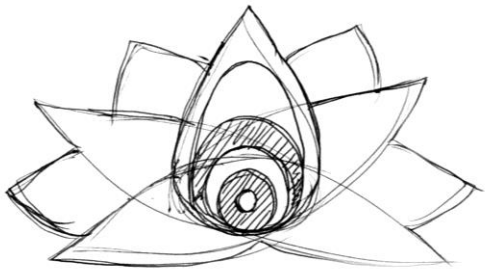
Table 6.4: Idea output performance of all groups

Group	Product	No: of Analogy	Total No: of Association Triggers Generated	Total No: of Idea Links Generated	No: of Ideas Formulated
A	Lock	10	152	86	22
B	Comb	10	128	80	20
C	Bottle	10	124	90	30
D	Watch	10	138	84	24
E	Shoe	10	112	87	24
F	Bin	10	105	73	17
G	Mouse	10	115	90	25
H	Bag	8	110	75	20

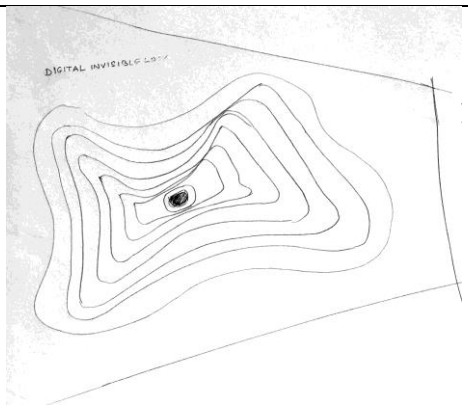
Table 6.5: The idea generation and concept development of Group A

<table>
<tr><td colspan="4">Group A: LOCK
Analogy: Ball, Cup, Car, Pen, Shaver, Bucket, Shirt, Furnace, Shoe, Helmet</td></tr>
<tr><td colspan="4">Associations: Rotate, roll, dog, mud, flower bed, cut disappear, melt, cover, design, personal fit, fill, draw, write, story, ink, liquid, ripple, speed, headlight, brakes, style, temperature, metal, alloy, break, hit, button, personal, Police, License, digital electronics, records, sensor, laces, painting, bath, fabric, handle, move, get in, prank, plastic, protect, net, horn, mirror, button, visor, command, grip, meter, small</td></tr>
<tr><td> 
Lock that can see and hear with rotating vision</td><td>  </td><td> 
No lock in front. Finger print and camera</td><td> 
Personal bio stats security code detector to apply key</td></tr>
<tr><td> 
No lock Visible. Invisible will operate on instruction</td><td> 
Camera and Finger print</td><td> 
Rotating eye to give warning</td><td> 
Finger print scaner</td></tr>
<tr><td> 
Speaking lock</td><td> 
Open seseme command</td><td> 
Lock will leave chemical to detect handling</td><td>Very small lock like rings</td></tr>
</table>

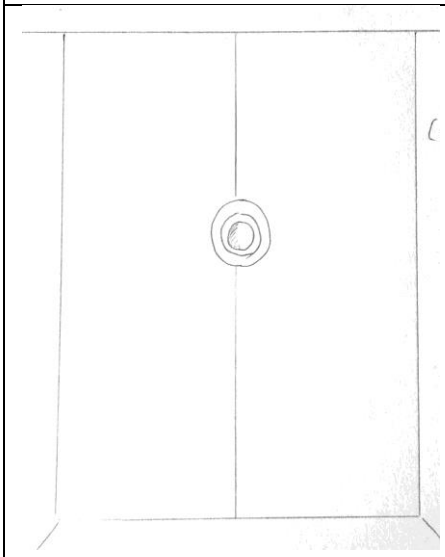
 A painting camaflouged lock with code	 Lock with multiple latches integrated in it The pattern acts as code	 Painting with magic eye	 Key links to match human face
 Shaver lock will chew false key Uses electronic key	 Palm detector Through net to capture	 Punch bag to disarm and capture	 Self defence lock gives a punch to intruder
 A covering of head and disorrient	 Hand shake lock		
CONCEPT			
 AC_1 Multi- security, Oval lock of special alloy, with a keypad code and finger print sensor and speaker for personal comand		 AC_2 Dialed Key.Touchscreen and finger print sensor. Speaker for information documentation.	



AC_3
Camaflaged lock. Looks like a flower, wth magic eye center to record activity outside door.
Built in camera and finger print sensor
Will alert on tampering and scare by barking sound. Squrt liquid to disarm



AC_4
Digital security, invisible lock
A wall painting like ripple
Transforms on finger print recognition.
Layered information detector before opening



AC_5
Palm detctor bio stats through handshake. No Key tension
Will trigger attack on intruder. Givies sonic waves.
Captures and reports
Takes voice command.

Table 6.6: Overview of all groups Ideation performance

Group	Product	Idea Fluency	Idea Flexibility	Concepts	Concept Novelty	Concept paradigm
A	Lock	High	High	AC_1	High	PS
				AC_2	Medium	PP
				AC_3	High	PB
				AC_4	High	PB
				AC_5	High	PB
B	Comb	High	High	BC_1	High	PB
				BC_2	Medium	PS
				BC_3	High	PB
				BC_4	Medium	PP
				BC_5	High	PB
C	Bottle	High	High	CC_1	High	PB
				CC_2	Medium	PS
				CC_3	High	PS
				CC_4	High	PB
				CC_5	High	PB
D	Watch	High	High	DC_1	High	PB
				DC_2	Medium	PS
				DC_3	High	PB
				DC_4	High	PB
				DC_5	High	PB
E	Shoe	High	High	EC_1	High	PB
				EC_2	High	PB
				EC_3	Medium	PS
				EC_4	High	PB
				EC_5	High	PB
F	Bin	High	High	FC_1	High	PB
				FC_2	High	PB
				FC_3	Medium	PS
				FC_4	High	PB
				FC_5	High	PB
G	Mouse	High	High	GC_1	High	PS
				GC_2	High	PB
				GC_3	High	PB
				GC_4	Medium	PS
				GC_5	High	PB
				GC_6	High	PB
H	Bag	High	High	HC_1	Medium	PS
				HC_2	High	PB
				HC_3	High	PB
				HC_4	High	PB
				HC_5	High	PB

Paradigm preserving ideas exist within the product boundary and Paradigm Modifying Ideas are the ones that stretch or break the product boundary.

It is seen from Tables 6.4, 6.5 and 6.6 that unrelated stimuli to build forced association, gives high level of creative stimulation to breaks cognitive inertia and potential apprehension of radical thinking. The forced random analogy triggering allowed the generation of large pool of idea links and high level of idea fluency and flexibility. This in turn has reflected on the high level of novelty and paradigm modification of the concepts developed. Detailed depiction of ideas are compiled in Appendix C.

6.4 Concluding Remarks

From the perspective of random analogy triggers for idea generation to achieve radical novelty, the methods used should allow from paradigm stretching to paradigm-breaking new product ideas. An analogy is a device for conveying that two situations or domains share relational structure despite arbitrary degrees of difference in the objects that make up the domains (Gentner, 1983). It is the relation mapping that is important, not mere object similarity. The analogy process of comparison operates so as to favour interconnected systems of relations and their arguments. Research suggests that alignable differences are given more weight in choice situations than non-alignable differences. But in the case of new product ideation, the forced unrelated thought with the least similarity factors when aligned to the target has a greater potential of far-reaching exploration and novel outputs. To add validity to the novelty of an idea, Kaufman suggested the subsuming of usefulness, appropriateness, or value (Kaufman1993). Boden clearly described radical novelty as ‘thinking the impossible,’ by making a radical departure from a standard outlook on a problem, and challenging the basic rules of a particular conceptual space (Boden1991), containing basic features of novelty, unconventionality, and validity.

The forced random analogy triggered new product idea generation abducts logical reasoning in the early stage of association building and supports novice designers’ divergent thinking to explore radical associations. Application of this triggering process to mid-level designers’idea generation task resulted in radical (solutions) design ideas. The participants experienced the value of random analogy trigger in raising their creative output. Also,

pooling the multiple analogies triggered associations and force-fitting them to form ideas for the target task proved to be prolific in nature as well as radical.

The study brought to light the potential of random analogy trigger in paradigm modifying idea generation for new product design by forcing the mind to generate multiple cues that can be force-fitted to form a cross-domain association to form product ideas, as demonstrated in Table 6.5. This helped ground our query of the possibility of radical paradigm modifying ideation with a random analogy trigger process. It is seen to be helpful for both the individual level as well as a group level in the delivery of the high level of radical ideas. As group members add ideas, the overall concept becomes more complete and improves - leading to richer concepts. It also brought to light the ease and speed of the generation process that can help overcome the difficulties faced by novices in idea productivity. Quick and innovative ideas are the driving factor of business today.

The experiment showed some positive relation between the number of radical product ideas produced and the number of triggers and associations drawn from the analogy, thus supporting the principle of seeking a large quantity as well as varied types of ideas.

Chapter7

Findings and Recommendation

7.1 Introduction

This research carried out three empirical studies, each exploring different facets of the use of analogy triggers on new product design ideation. The three stage study and analysis helped in gaining clearer insights into the phenomenon of analogy triggered idea generation. The studies helped in creating a framework for analogy driven idea generation. The study brought out the implications, possibilities and constraints on the creative idea output.

7.2 Findings

This research study chooses to explore the workings of analogy triggered idea generation for new product ideas on novice and mid-level designers in a three stage data collection process. The key focus of this research was to understand, random analogy triggers, effects of choice on analogy triggers, associative activation, types of transfer and implications on generated ideas. Since our mind is governed strongly by the logical gatekeepers, they dissuade the mind from illogical thinking. During analogical thinking, the tendency of taking the 'path of least resistance' is often found. This causes a cognitive dissonance that makes us take familiar decisions, in this case choosing analogies that we are sure about giving solutions. It is often difficult to make connection to different fields. It is through the process of associative activation that, far analogies can be linked to target task to produce more creative output (Ward 1998). This reliance on surface attributes for transferring the originality of ideas is clearly hindered.

7.2.1 Introductory Study

The first experience of observing the application of analogy triggers for idea generation for a given design task by 20 engineering students from different disciplines was of a positive note. In observing the idea generation phenomenon in two treatment situations in Table 7.1,

the directed use of analogy triggers allowed novice designers to explore more and varied ideas by building new associations instead of zeroing in on direct solution ideas that can lead to fairly obvious outcomes. Thus, it seems to have a clear indication on the creative idea production.

Being a preliminary study, it set the base of the research and answered the first research question "How do novice designers choose analogy triggers to generate creative ideas for new products and what effect does it have on creative idea production?" From the analysis of the data from the introductory study (chapter 4), it was observed that engaging in analogical triggered idea generation showed a visible variance in the level of creative output. Ideating without forced analogy triggers showed moderate fluency and low to moderate flexibility in idea production. Even though subsequent elaboration was noticed, novelty output was partial. On the other hand, the deliberate use of analogy triggers for idea generation showed positive results in idea output fluency and flexibility. Though elaboration decreased, the novelty of the ideas produced seemed encouraging, as seen in Table 7.1

Table.7.1: A comparative visual representation of the parameter distribution

	Fluency		Flexibility		Usefulness		Novelty		Remarks
CG									Without analogy triggers for idea generation, there was moderate fluency and low flexibility, and partial novelty. Most of the participants tried similar ideas, through logical association.
TG									With random analogy triggers for idea generation, there was increase in levels of fluency and flexibility. There was an increase in the novelty level. More radical exploration was observed.

Colour code for the levels : Low Moderate High

These results indicate that training in analogical idea generation and problem solving with forced use of analogy triggers helped the participants towards more creative ideation. In Figure 7.1 we can see that the Idea Generation phenomena undergoes variance based on differing treatments. However, it does so with a clear indication towards a positive influence of analogy-based thinking for generating new product ideas for novice designers conducting a design task. It also brought to light that the use of analogy in idea generation opened different paths of exploration, as it was observed that the participants approached different idea routes in innovative manners. To summarize, most of the participants' production of novel ideas was observed to have gained positively with the use of analogy triggers.

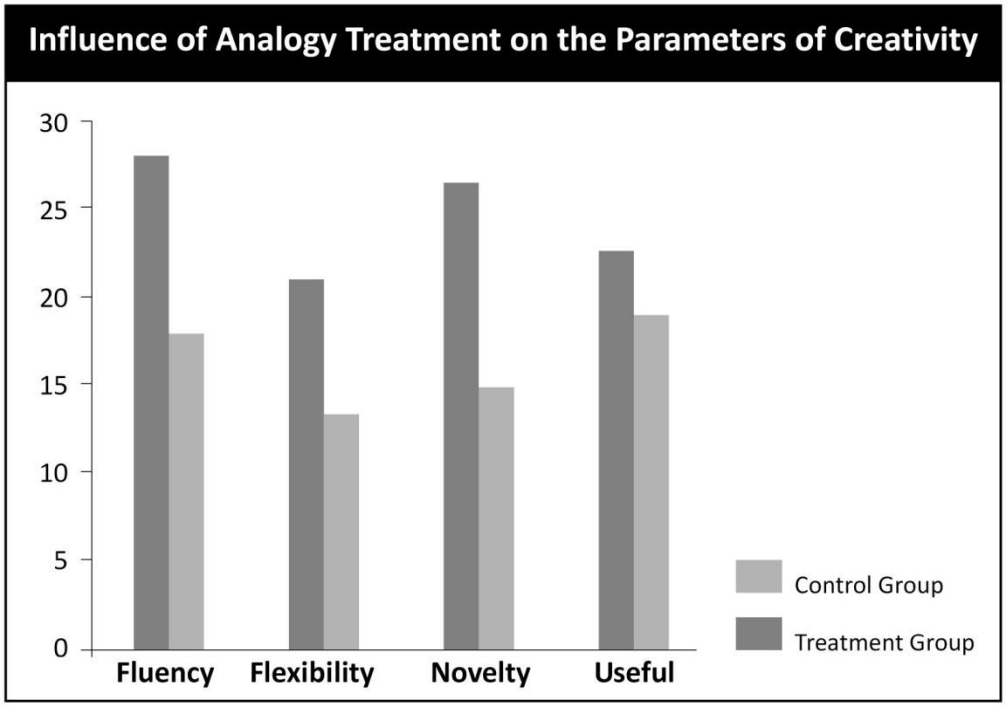


Figure 7.1: Influence of analogy treatment on the parameters of creativity

The role of analogy triggers has shown encouraging implications on the generative and explorative aspects during idea generation. Most of the participants' production of novel ideas was observed to have grown positively.

Furthermore the participants revealed that the analogy triggered approach helped in arriving sooner at novel solutions, compared to their 'conventional' problem solving approach. They were able to not only generate a lot of ideas from varied angles that helped in the originality

of the outcomes. But it was not easy to maximize the full potential of the analogy and in some cases led to premature finalization of ideas. The participants had some difficulty in building far associations that inhibited the production of novel ideas. In view of these limitations the parameters of study was set for the first exploratory study.

7.2.2 Exploratory Study 1

This study further explored the analogy triggered idea generation phenomenon with random analogy; its objective being to study how and why the choice of the type of analogy trigger affects idea exploration and novelty generation. This study was crucial to understand the inherent potential as well as the challenges in using analogy for the design idea generation process. To address this, the second research question was designed: "How does the use of random analogy triggers get affected and what are its effects on associative activation and creative idea exploration?"

The sample targets chosen were mid-level engineering designers and product designers with 2-6 years' experience. The study explored two conditions to draw its understanding of this random triggering process on mid-level designers' idea generation. The ideas generated were assessed for their novelty value by mapping them on the 'spectrum of innovative thinking' to elucidate insightful differences in the phenomenon of idea generation.

The analysis from this study in chapter 5, revealed the potential of forced random analogy triggers in abducting logical reasoning in the early stage of new product idea generation, and supports the mid-level designers' divergent thoughts to explore radical associations. The results brought out clear contrasting views between the two conditions. The participants in the experimental conditions could generate multiple analogy triggered associations and by force-fitting them to form ideas for the target task, were able to deliver both radical as well as prolific creative outputs.

Figure 7.2 shows that starting with forced unrelated random analogy triggers, the Treatment Teams were able to explore idea alternatives in various fields of the product - from material, technology, structure, interaction etc. - and generate novel solutions. In contrast, the Control Teams demonstrated resistance to breaking out of logical culminations of problem solving and inhibition towards radical idea exploration.

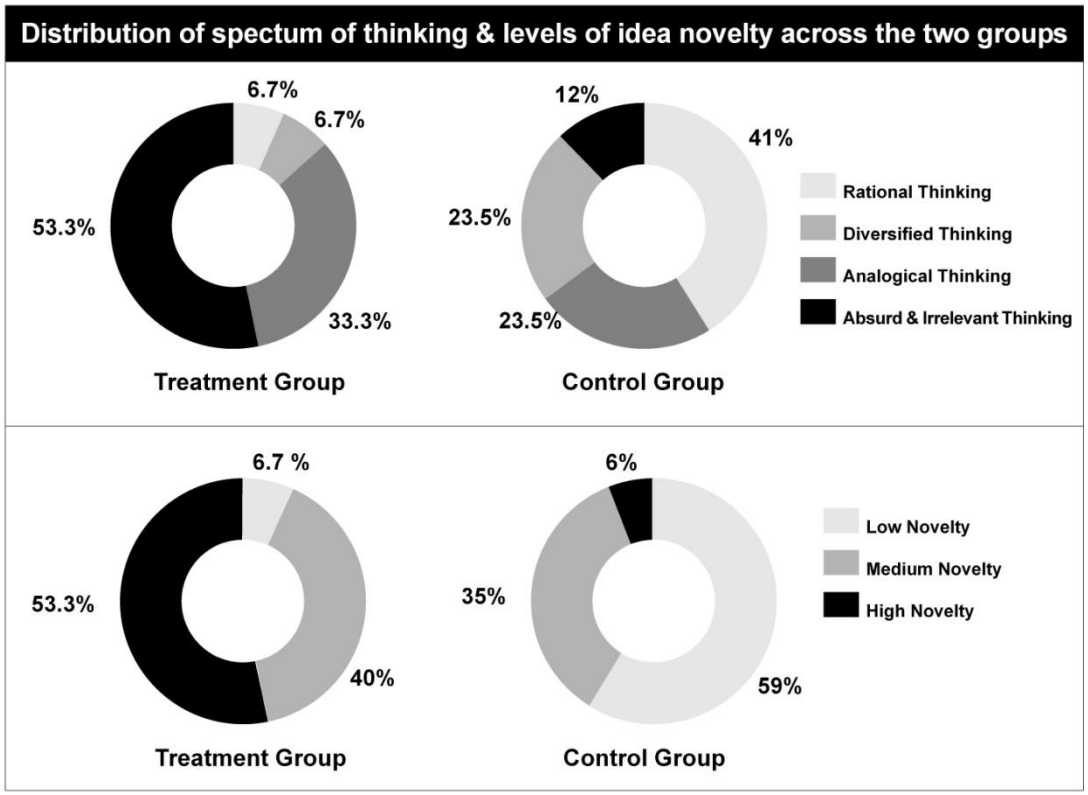


Figure 7.2: Distribution of spectrum of thinking and level of idea novelty

Based on the differences demonstrated in the phenomenon of idea generation with forced analogy triggers through the comparative study, there was positive inclination towards radical exploration. Another interesting insight in the case of new product ideas that emerged was the fact that random analogical thinking when used in a non-logical way can result in bringing novelty in the creative output. This was evident from the Treatment Teams responsiveness to radical analogy triggers which helped them to 'suspend reality' in new association building while ideating. This not only liberated exploration, but pushed the outcomes to more creative levels. However, the Control Teams fixations on logical choices of solution driving analogy triggers limited radical exploration and creative output.

The approach of using analogy triggers for idea generation tasks by the teams in the two conditions clearly indicates the necessity of forcing the mind to abduct itself from logical thinking to come up with new ideas. That in the process of using analogy triggers, a conscious effort for the 'suspension of reality' is needed when building radical ideas. What

apparently seems to pose a constraint in the ideation process (of the Control Teams), could be used as an enhancer for novelty.

The above findings also brings to light the difficulties faced in using random analogy, thus predicting further scope for a guiding framework for productive and creative idea generation. To further observe this and bring about a conclusive understanding of the random analogy triggered idea generation phenomenon, the study was designed and carried out as mentioned below.

7.2.3 Exploratory study 2

Based on the insights gained from the previous studies, this research study explores the possibilities of radical ideation in the early stage of the design process and the creation of radical ideas through forced analogical association towards solution fitment. This facilitates in providing a head start to novice designers. This is critical to surmount linear patterned thinking and led to open radical generative idea iterations, right in the beginning.

While studies reveal that analogy usage is pervasive in a variety of design disciplines, there is still scope to study the aspects of the phenomenon of idea generation with random analogy by novice and mid-level designers.

The foremost goal in this regard is to mitigate the challenges they face at taking the leap into radical exploration. To this end, the evolution and implementation of the guiding framework of random analogy use for idea generation was carried out on a mixed group of novice and mid-level designers from design and engineering backgrounds. The following analyses were conducted:

- The relation of the random stimuli to trigger forced association of unrelated stimuli.
- The use of multiple stimuli and the unusual mode of expression generated.
- Random analogy triggered idea generation and paradigm changing aspects of idea outputs.

The study brought to light the potential of random analogy triggers in paradigm breaking idea generation for new product design by forcing the mind to generate multiple cues that can be force fitted to form cross domain associations to form product ideas. The coding and categorization of ideas of associative thoughts generated a summarization of the data and a

better understanding of the phenomenon. The assessment of the ideas based on the characteristics of the creative continuum proposed by McFadzean and their relation to Torrance Creativity Test parameters. (McFadzean 1999, Torrance 1974)

From the perspective of random analogy triggered idea generation within the guiding framework, the paradigm changing idea output showed positive trends. The research suggests that alignable differences are given more weightage in choice situations than non-alignable differences. But in the case of new product ideation, the forced unrelated thoughts with the least similar factors when aligned to the target showed greater potential of far reaching exploration and novel outputs. Unconventionality was achieved through radical departures from a standard outlook on a problem, and challenging the basic rules of a particular conceptual space.

Application of this triggering process to mid-level designers' idea generation tasks resulted in radical (solutions) design ideas. It was observed to be helpful at both the individual as well as a group level in delivering a high level of radical ideas. As multiple triggers facilitate idea fluency and flexibility in the group ideation scenario within a short period of time, a rich resource of ideas could be generated, leading to richer product concepts. An overview of the insights depicting some positive relations between the number of radical product ideas produced and the number of triggers and associations drawn from the analogy are described in chapter 6. This in turn supports the principle of seeking a large quantity as well as varied types of ideas for creative idea production. A training program supported with a guiding framework brought ease and speed in the generation of associations and helped build radical ideas. This helped ground our query of the possibility of generating radical paradigm modifying ideas with random analogy triggers.

7.3 Concluding Remarks

The study highlights the significance of using random analogy triggers in the idea generation phase of the design process. As suggested from the analysis, a simple step by step training framework along with descriptive process sheets will help in maximizing the scope of this phenomenon. Results and inferences from this study can further help in the development of

an analogy simulated association generating facilitation to help develop paradigm moving ideas. This will support the design process in both industry as well as academia.

Moreover findings from this study can be successfully applied in developing a pedagogical intervention for training in radical thinking through random analogy triggers, so that designers can create a multitude of inferences from a single analogy. The findings from this research can also be applied to teaching methods. These can help novice designers with systematic approaches to highlight more domain general, as well as intrinsic ways of thinking and exploring radical thought processes.

Chapter 8
Conclusions and Recommendations

8.1 Discussion of the Findings

The following research intended to bring to light the role of random analogy triggers on creative idea generation for new products from novice designers to mid-level design executives. The three stage study was conducted sequentially with the sample population consisting of undergraduate engineering students taking design elective courses at IIT Bombay and mid-level designers and design engineers partaking in an Innovation workshop. The aim was to clearly understand and state the phenomena of the creative generation of new product ideas within a ‘Random Analogy Trigger Generation Framework’. Each study's findings revealed deep insights that were dovetailed into the subsequent study to finally establish the abductive mechanism and generative potential of the use of random analogy triggered ideation.

The results from the research revealed that random analogy generative framework helped facilitate creative idea generation for novice and mid-level product designers and design engineers, with the generative process being employed through forced random analogy triggered ideation for new product designs. The design ideas generated during the various stages of the research study revealed key factors of inhibition and enhancement of creative thinking and the ideation output.

The random analogy triggered new product design idea generation process was employed to study the application and implication of analogy use and its effect on the ideation output. Furthermore, it helped to develop an understanding of the factors inhibiting and enhancing it. This brought to the forefront the requirement of a guiding framework, its development and its implementation.

8.2 Summary of the findings

Based on the findings, the role of random analogy in new product design ideation has been depicted in tables 8.1, 8.2 and 8.4, bringing out the influencing and challenging factors within the context of use.

Table 8.1 Overview of Base Exploratory Study

	Experiment	**Research Query**	**Findings from research study**
1	Base exploratory study with novice designers. Individual level ideation.	How novice designers generate ideas with or without random analogy.	Increase in idea generation level in the area of fluency, flexibility and novelty when administering random analogy.
		What are the challenges displayed in the use of analogy to trigger idea generation?	Mind seeks solution ideas when generating ideas. Choosing an analogy trigger to generate ideas is not prevalent.
			There is a natural restrain in allowing the mind to be abducted from logical thinking.
			There is an inhibition towards alternative generation.
			Have difficulty in exhaustive attribute breakup of the analogy trigger.
		What are the advantages displayed in the use of analogy to trigger idea generation?	When forced to use random analogy to trigger ideation, they were able to explore radical domains and create new associations and thus more creative ideas.
			There is an inclination towards more surface property association.
			When delving into deeper associations and attribute building more creative ideas are generated.
The base study was primarily to assess the research instrument and procedure. The limitations observed were used in the improvement of the subsequent data collection instrument to build a robust intervention to prove assumption.			

Table 8.2 Overview of Exploratory Study2

	Experiment	**Research Query**	**Findings from research study**
2	Exploratory study 2 with mid-level product designers and design engineers. Group level idea generation.	How was the random analogy chosen and used in a group ideation process?	When choosing an analogy, the mind is stirred logically to a solution driven analogy which fixates on logical attribute triggers curbing exploration.
			External random triggering pushes the mind to come out of the path of least resistance and carry out radical exploration.
		What was the degree of suspension of reality in idea exploration when employing random analogy?	A conscious suspension of logical thinking helped in choosing random analogy triggers and helped to generate varied range of attributes and build novel connections to the task in hand.
			Moving away from the rational association to the more radical and wishful association helped open exploration.
		What was the level of creative output?	Ideas generated with forced random analogy triggers exhibited greater creative quality.
			Within the limited time span there was a noticeable difference in the creative output of the various test conditions.
		What limitations are observed in the use of random analogy was observed?	Need for a facilitating framework to guide attribute breakdown.
The second study re-affirmed the mental process of analogy choosing for solution finding, thus consciously avoiding abduction, the reason being governed by the mind's choice of the path of least resistance. This is done so as to address it through a guiding framework.			

8.2.1 The findings summary and development of Guiding framework

The literature review of the use of analogy for designing products projected the duality of analogy as a divergent thinking stimulator by allowing association building through cross transfer across domains that converge logically by adapting the transferred component to the

target domain. This occurs by identifying and mapping common substructures of the two domains to each other, resulting in an analogical relation.

Ideation with random analogy is an important generative stimulator for creative ideas. As a conscious cognitive process, it is avoided due to the fear of rejection. Very little research work has investigated the generative enhancement of the early ideation phase of new product design, though analogies by themselves have had extensive exploration in engineering and computer science. As a result, we have found two sets of contradictions in the study of analogy driven creativity:

i) The establishment of an analogy is usually governed by certain constraints, like systematic and structural consistency, or a one-to-one restriction on possible mappings, although there is no general accepted set of such principles.

ii) It is important to notice that an analogical inference does not result in factual knowledge, even when the source and target domain consists of definite facts. It is the task of the reasoner to carefully examine the results - may it be for logical consistency or for empirical evidence - before accepting them as part of knowledge about the target domain.

Thus, we can argue there is no right or wrong analogy for new product idea generation. Rather they can be more or less plausible, based on the degree of structural coherence that they exhibit, possibly depending on the context and analogical conclusion they allow one to draw. (Krumnack et. al. 2013).

Reports from the three studies indicated favourable effect of random analogy triggered ideation and helped to draw certain conclusions. A clear articulation of the phenomenon and a positive direction to the ways of mitigation of barriers to radical ideation for novel idea output with forced random analogy triggers is seen. The understanding of the challenges and opportunities underlying the analogy driven idea generation phenomenon helped develop a random analogy based idea generation guiding framework for new product design to facilitate novice designers and provide positive results. Also through weighing the scope and limitations of the findings, future work recommendation is proposed. As revealed from

previous research conscious cognitive process of analogy application in thinking reasons for the right analogy so as to avoid fear of rejection/ failure.

Table 8.3 Overview of Final exploratory study

	Experiment	**Research Query**	**Findings from research study**
3	Final exploratory Study with mixed group using random analogy triggering framework. Two phase idea generation from individual level to group level.	How can the full generative potential of random analogy trigger be utilized?	The conscious abduction of the mind by breaking down attributes of the random analogy without knowing the task in hand helped stir the mind to generate multiple and varied lists, which helped catalyse a multitude of idea associations.
			It favourably displayed the fluency, flexibility as well as novelty value of the generated creative outputs.
		How did the framework and administering process align with the research objective?	The guiding framework forced the participants to generate a multitude of divergent attribute triggers and ideas at an individual level and a large pool of ideas for the team, which facilitated robust and creative new product ideas. Though there were some similar ideas, it did not make any negative difference in the creative output.
			It eliminated the scope of criticism of absurdity, thus allowing the mind to use the analogy for abductive thinking and suspension of reality in the exploration phase.
			It also reduced the process of free riding on others' ideas and maximized the generative operation.
		What limitations were observed in the use of random analogy?	Even though the guiding framework was explicitly explained and helped overcome the challenges of maximizing the diverse generative potential of random analogy and use it favourably to stir the mind towards creative and paradigm transforming ideas, breaking out of our cognitive tuning of reasoning with analogy requires training at a fundamental level of academic and industry knowledge.

The administration of the guiding framework confirmed our predictive assumption of great potential of random analogy in abducting the mind to a generative exploration of creative design output.

8.2.2 The findings summary and guiding framework methodology and efficacy

Thus, a systematic testing of the assumption that random analogy triggered idea generation can manifest great creative potential to enhance the creative output of novice and mid-level designers. Drawing inference from studying the phenomena of random analogy triggered ideation amongst engineering students, mid-level professional engineers and product designers, key factors affecting the generative potential across participant groups were understood and the guiding framework of random analogy attribute generation and idea links generation was created.

The results of the primary experiments were used to develop the research instrument and procedure. It was observed that creativity tasks are highly taxing in nature to the brain (Ward et. al 2002), and creates mental pressure when asked to build associations with the random analogy. This hampers divergent exploration and stunts creativity. This led to more explicit instructions and a guiding framework for generation of maximum attribute of the analogy trigger through a systematic categorization of areas to address and force fit the multiple attribute triggers to catalyse ideas. Forcing the mind out of the logical to the radical helped prolific ideation by unclogging the mental processing. Furthermore, this enabled recall of past experience in association to the analogy in hand, and find useful commonalties between the objects, their attributes and the task ideas. This actively constructive and emergent approach facilitated the ability to construct new associations perceptually, cognitively, kinaesthetically, emotionally, etc.

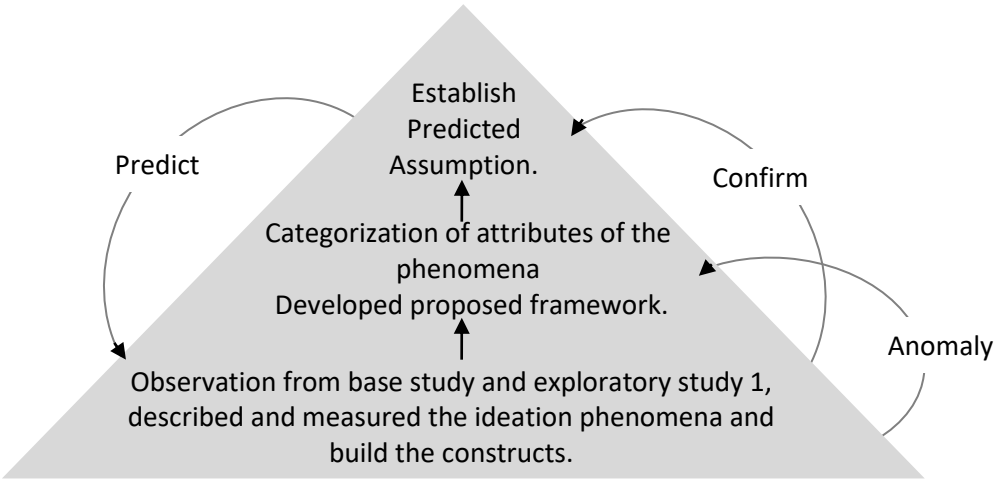


Figure 8.1 Process diagram of building theory on the random analogy triggered creative ideation

We explore the handiness and the effectiveness of training students and mid-level product and engineering designers in analogy triggered creative generative process, an essential ability in the production of new creative ideas and concepts in the field of product design. It raises the question of designing a training module within a specific course that can help in understanding the essence of creativity and hence enhance the confidence in acquiring its skills.

8.2.3 Limitations and Future Scope

The generative aspect of analogy to trigger multiple thoughts significantly affected the quantity and quality of ideas, in both individual as well as group settings. There was a tendency of fixating on the surface attributes and using them directly in the target domain that limits idea novelty. Thus, to reap the opportunity and override the challenges, the random analogy is seen to suspend logical thinking to explore multiple radical thoughts. There was a positive relationship between the radical associations and creative components of the ideas produced. The team exercise operated initially at the individual level in building the attribute triggers and building idea connections for the given task. Subsequently, using the pool of ideas helped build richer connections towards robust and creative ideas. The guiding framework showed positive implications on creative production of ideas in a short

time span for novice and mid-level designers, since an analogy has varied inferences and can trigger unique connections based on individuals' own perceptions and experience leading to unexpected creative solutions.

This research was able to answer several questions related to the role of random analogy on idea generation, and also brings out some procedural actions to address the challenges of abducting the mind to radical exploration. Though a conclusive guiding framework was helpful and confirmed our assumption of the creativity generation potential of random analogy in the early phase of idea generation. The simple step by step instruction along with the descriptive process sheets facilitate in maximizing the scope of using random analogy for effective ideation in the design process. Design being an activity to do with thinking process, there is bound to be barriers of perception and attitude to inhibit the process. An inculcation of abductive thinking for generative exploration requires a training program that needs to be developed and initiated so as to act as a self-facilitator. This requires further study, a deeper understanding of the interaction of the mind and the random stimuli to support the development of design methodology for pedagogic application.

Though the research was scoped for product design, its flexible framework can be tailored to apply in various allied domains. Teaching methods need to be developed to provide systematic approaches to build ways of thinking and learning about the products and problems encountered in different disciplines.

8.3 Research contribution & Scope

No work has substantiated the great potential of random analogy to draw a varied multitude of inferences and appropriate the analogy at hand. In the early stage of idea generation, judgement and rejection of any thought can carry the risk of negating potential ideas, whereas the random analogy triggered ideation by daring the mind to draw deeper inferences from simple mundane things can hold logical reasoning at bay. Unlike linguistics, the role of analogy in new product design goes beyond problem solving, comprehending or decision making; its triggering and opening new areas of exploration that transpose the new knowledge gained to creatively fit the task at hand, thus developing a specific way of analogy application for the product design field. The simple but rigorous process of random analogy

usage for new product idea generation has been able to maximize analogies' potential to solve problems by applying understanding from the source domain to the target domain, as well as fully capitalize on the random trigger to abduct from logical reasoning. This takes away the step of evaluation the analogy requires for its appropriateness.

Design being a creative field, thrives on multiple variations of exploration. The use of analogy in the cognitive process is for logical reasoning, where an analogy is an analogy that helps to understand difficult or different things from a similar/familiar perspective. That is why, while being in the process of communication and comprehension, there has to be a right perception trigger or else it will go wrong. But in the case of design, which is an ambiguous activity in the early stages, the randomness creates that possibility of abduction of logical reasoning. It is that abduction that is necessary for the creative leap. Therefore, we can see that the use of analogy driven ideation for product design has two properties:

i) The divergence property of opening up the whole area of exploration (through a catalytic way).

ii) The convergence property of force fitting the divergent thoughts to the target in a creative way.

Subsequently when people are looking for analogy for solution finding it starts with a converging towards the right sources to produce the right solution, thus limiting the divergent exploration.

This is why the random application of analogy displays the special property of abducting the mind and forcing it to think illogically and build radical connections/associations, by opening the exploration space first and then converge to develop creative/radical concepts to fit into the product task at hand.

We in our research are not following the path of 'Design by analogy' but we are following the analogy driven Ideation & exploration pushing the realm of ideas towards paradigm transforming levels. This allows productive leapfrogging of ideas, as seen from the last experiment, because in engineering design or engineering education the focus is to look for problem solution ideas. So analogous solution sourcing facilitation becomes the main

operating area for analogies. Where attributes of function, form, structure are transferred from the source to enhance products. But for application in product design it should creatively explore alternative ideas, using analogy as a journey for discovering the unknown and using those new findings for building new ideas. Eg. Velcro, where a random analogy came about and was force fitted to a unique need fulfilment and a paradigm transformative idea.

When there is a structured way of doing idea generation with random analogy then all analogy has the potential for the right. Thus, random analogy can push towards accidental discovery of radical properties that can help form creative products by force fitting them to logical materials and applications for the innovation to evolve to bring about richer discoveries. Since it's a generative process, there cannot be convergence right in the beginning. The framework gives a scoping of random exploration of diverse attributes in a completely different scenario and the use of the exploration to force fit towards tangible ideas to build the new product concept, a great leap can be observed. Since the convergence process is very logical and reasoned out, the value of usability along with novelty are truly maintained. The idea even in this early stage is not vague - as visible from the third design workshop.

Since the idea generation process and the analogical thinking process are both complex, so are their various influencing factors and outcomes. The guiding framework can facilitate in maximizing the potential of the process as well as the development of the creative outcome. The outcomes have been able to deliberate on the ease and speed of the idea generation process leading to productivity of novice designers. Consequently, the findings from this study are highly relevant to the modern industry because generating a number of unique ideas in a timely fashion is the key to innovation. Thus, posing an inquiry into the larger context of design/engineering pedagogy aids and enriches creative thinking, and should be started at the school level within the curriculum.

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APPENDICES

The study directions, parameters of observation, the idea outputs and observation notes of the three studies are compiled as follows:

Appendix A: Study 1- Exploratory study with novice designers. Individual level ideation

Appendix B: Study 2- Exploratory study with mid level product designers and design engineers. Group level idea generation

Appendix C: Study 3- Exploratory study with mixed group. Two phase idea generation from individual level to group level.

Appendix A: Study 1- Exploratory study with novice designers. Individual level ideation

Instruction to Participants:

You are requested to keep your phones away.

TASK

1. **Control Group (CG)**
   Generate radical and innovative product ideas to facilitate reading while lying down.

2. **Treatment Group (TG)**
   Generate ideas for an innovative rain guard for Mumbai commuters during the rains with the use of analogy method and association by choosing your own analogy (minimum 2 analogies, one object and one animal)

DELIVERABLES

You will perform your task individually without discussing your ideas with others.

You will record your ideas in the idea-sheets provided, in the form of sketches and annotations. You can use as many sheets as per your requirement.

You will get one and a half hours to complete the given task and submit the idea-sheets

EVALUATION

You will be scored on the four parameters of Fluency (Quantity of ideas), Flexibility (Varity of alternative routes), Originality (Uncommon and unique to the group), and Usefulness (Feasibility) of idea generation.

PS. Similar ideas will reduce your originality scores.

Instruction to Rater:

You are requested to rate each individual's idea generation on the given parameters

Fluency of idea generation: Number of ideas generated to the given problem (can be in the same area or outside).

1 idea = Low Fluency (1)

2-3 ideas =Moderate Fluency (2)

4+ ideas = High Fluency (3)

Flexibility in idea generation: Variety of possibilities and different realms of thoughts explored to find (unique) solutions.

No variation= No Flexibility (1)

2 Variation= Moderate Flexibility (2)

3+ variation= high Flexibility

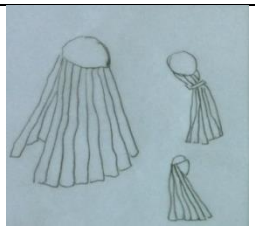
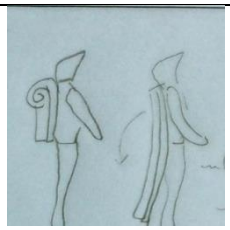
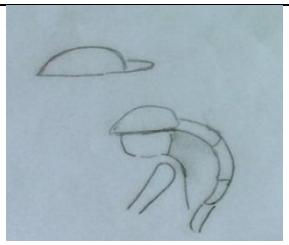
Novelty/Originality of ideas: Number of unique and unusual ideas (within the group) produced.

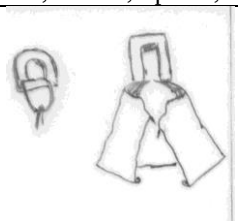
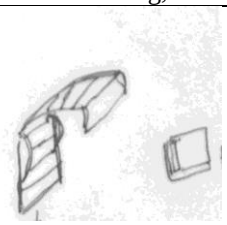
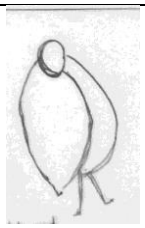
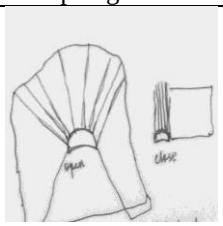
Obvious Idea or common to many in the group= Low Novelty (1)

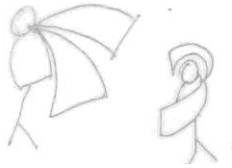
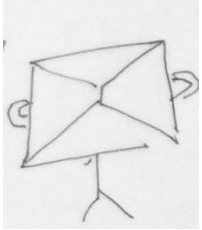
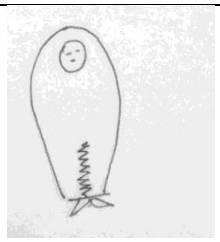
Not so Obvious Idea, could have slight similarity with 1 or 2 others= Moderate Novelty (2)

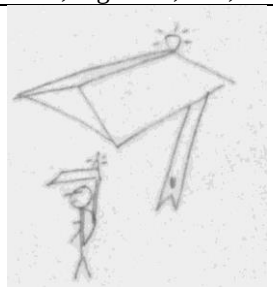
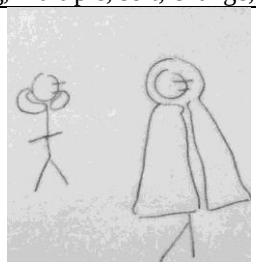
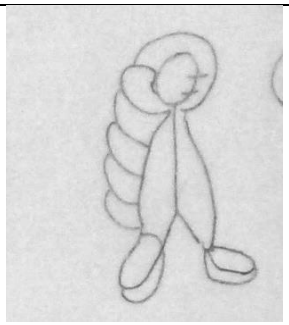
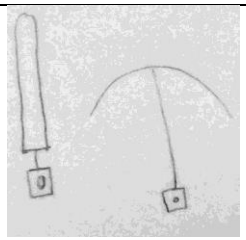
Unusual Ideas not common to any one = Novel idea (3)

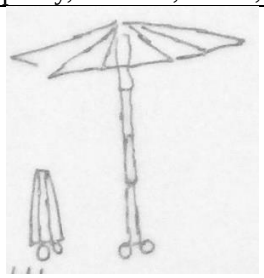
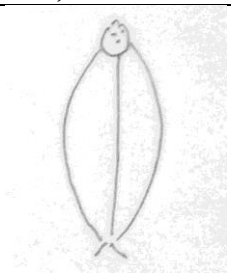
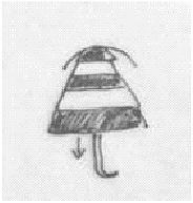
Treatment Group (TG)

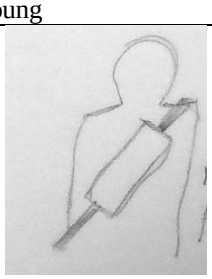
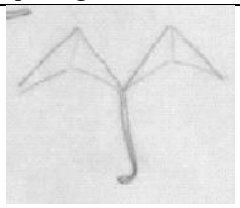
TG 1: Ideas	**Analogy: Hair, Duck. cap**	
Attributes: long strands, braids, crown, feather, wings, swim, light, float, beak, sound, rotate neck		
 Wear like head gear. Braid like strands form flexible cover	  Can be curled up and open like hair and cover back. Help float and give sound alarm	
 Flexible and expandable cap peek. Rotate to direction of rain and drain out water		

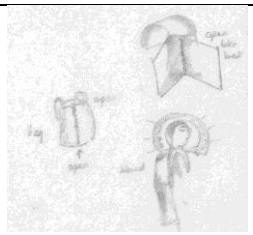
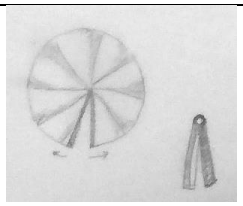
TG 2: Ideas	**Analogy: Snake, Porcupine, Rumali roti,**	
Attributes: Rope, opens, cold, Sense, Swallow whole, Scales, hood, egg, spikes, defense, soft, stretch, Spread, maida doh, round cooking, folds, warm		
 Rain gear folds like rope, opens to form cloak. Keeps temperature cold and hot for body comfort with scale like sections	 Hood for head stands up. Fits to back, holds upright on spine Scale like sections expand and covers face and body. Sensor tip detect rain and open guard	  Egg shaped pod cover. Smart material can expand and contract. Can form canopy cover
 Smart material can be carried like ball, stretch toform sheetcover	 Spike like frame fit to back, sensor tip detectrain and open	

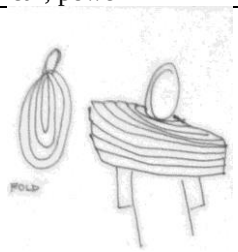
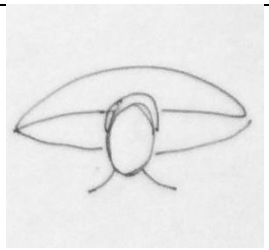
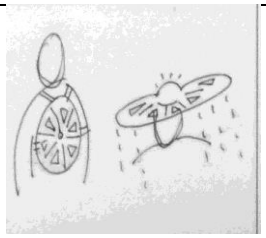
TG 3: Ideas	**Analogy: Bag, Peacock**	
Attributes: Contract and expand, fold, fan out, feather, colour, rain, synthetic material, cover, zip. Secure, handle, compartments, fill		
 Wrap like wings and fold in. Light material	 Bag opens to form roof.	 Fan out compartments. Can be filled with air to float
 Folding zip up body cover, selicon material		

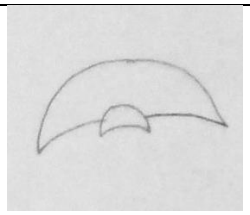
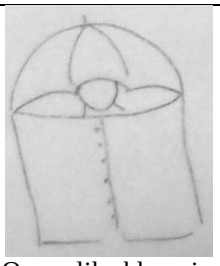
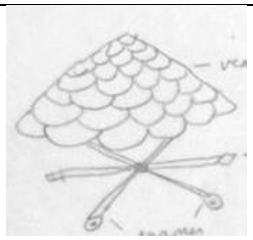
TG 4: Ideas	**Analogy: Analogy: Lamp, Bow & Arrow Caterpillar**	
Attributes: light, shade, bowl shape, lifestyle, fashion, direct light, stretch, cover, rim, reach, segments, curl, long, multiple, soft, change, protect		
 Shade like attachment, with bulb to signal and illuminate	 Fashionable collar rim switch on to open as coat	 Segmented cocoon like bodysuit that curls up and contracts.
 Stretch like bow and arrow on rain intensity	 Lamp shade shaped umrella lit handel	

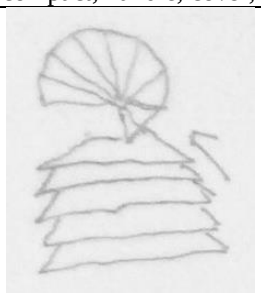
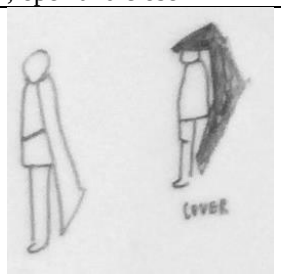
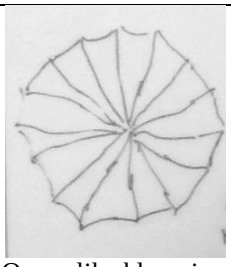
TG 5: Ideas	**Analogy: Fan, Leaf, dog**	
Attributes: Rotate, blades, Air, Fold, close, separate, natural, oxygen, absorb, repel, purify, obedient, follow, protect, sense		
 Folding self standing, walking rain cover, follow around. Can sense rain and activates	 Leaf like covering, natural and breathable	 Rotating water sucking filter and collector. covers and sustains
 Open and extend blades Cover and fresh air		

TG 6: Ideas	**Analogy: Funnel, Bird**	
Attributes: Filter, narrow, wings, upside down, protect young		
 Funnel type expanding reverse mechanism opening	 Water funnel sprout out, directs out water, no splash	 Folds up opens like shawl and cover
 Fold extention to accommodate family		

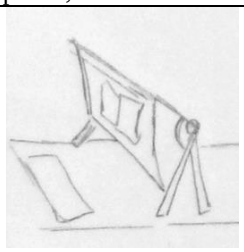
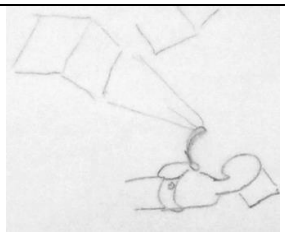
TG 7: Ideas	**Analogy: Bridge, Bat, Squid**	
Attributes: Wings, folding, blind, sonar, cave, flat, support, ink, hide, pouch, tentacles, suction, change		
 Bag with wing like cover, danger detection vibration and sound alert	 Arm support, head holder to cover.	 Folds and in and spread
 Pocket spray, not visible water-proofing.		

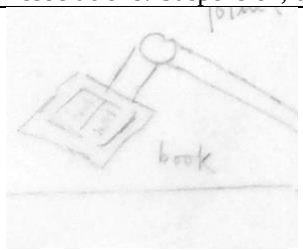
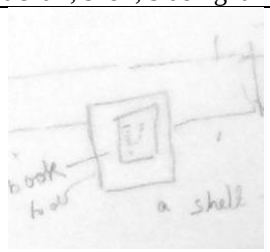
TG 8: Ideas	**Analogy: Flying saucer, Lion**	
Attributes: Sifi, star wars, force-field, levitate, aliens, appendages, Africa, fur, hunt, no fear, power		
 African tribal neck gear, wire like shell cover	 Deflective dome cover head gear	 Hover cover, GPS tracker, with force-field to keep water out.
 Rotation power wand to deflect rain. Jet mechanism to levitate		

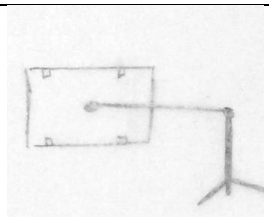
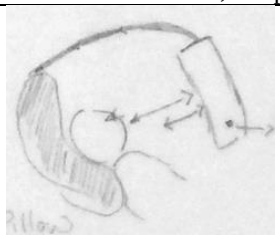
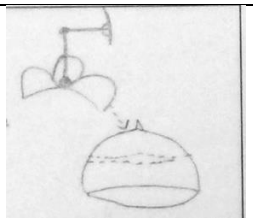
TG 9: Ideas	**Analogy: Fish, mushroom, bag**	
Attributes: layers, oyster shell, breathable, organic, toad stool, gills, scales, grows out, water repellent, clasp, lining		
 Collapsible helmet that transforms to body and head	 Wing like Collapsible tent cover	 Opens like blooming petals and can close like hand fan
 Back attachment like wings, wth light reflectors and sensors for safety		

TG 10: Ideas	**Analogy: Butterfly, fan, tent, helmet**	
Attributes: Fold, wings, colour pigments, fly, transform, flower, bloom, collapsible, compact, handle, cover, wizer, open and close		
 Collapsible helmet that transforms to body and head	 Wing like Collapsible tent cover	 Opens like blooming petals and can close like hand fan
 Back attachment like wings, wth light reflectors and sensors for safety		

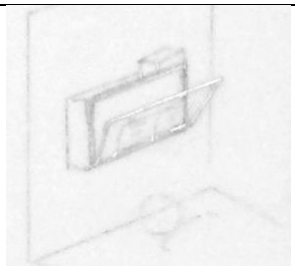
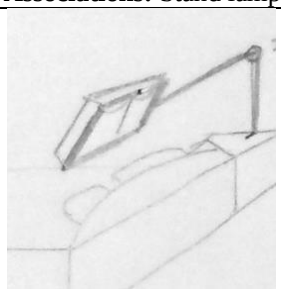
Control Group (CG)

CG 1: Ideas	**Associations:** Spider hanging, cloths rack pulley, harry potter, bed stand	
 Pulley rack to suspend book like spider	 Adjustable bed stand	 Books in space- projection device

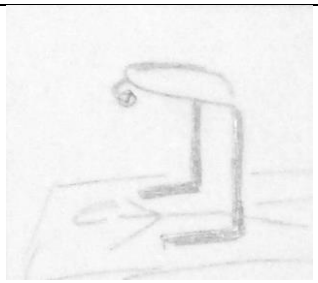
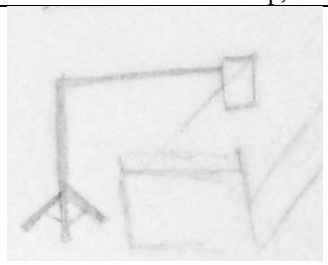
CG 2: Ideas	**Associations:** Suspension, dentist chair, shelf, side light	
Wire to suspend book from ceiling	 Rotating armature with book and magnifier attach to bed	 Shelf type side bed light reader

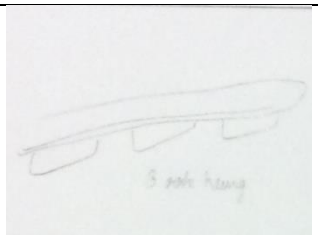
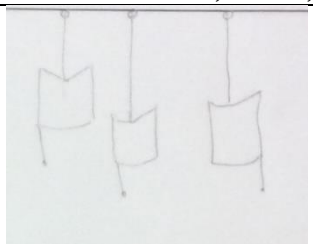
CG 3: Ideas	**Associations:** Stand, lamp, fan, vacuum	
 Book holder and stand, adjustable tilt	 Detachable and potable, rotating, pillow attachment	 Rotating vacuum ceiling attachment

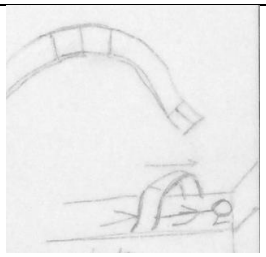
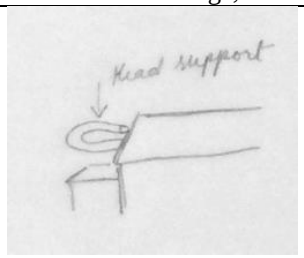
CG 4: Ideas	**Associations:** Stand, kids mobile suspenders	
 Adjustable stand with page holder	 Rod attachment with tilting book holder	

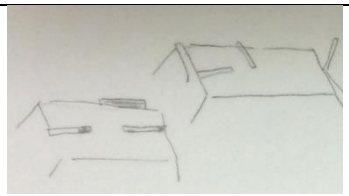
CG 5: Ideas	**Associations:** Stand lamp, shelf	
 Shelf opening to place book	 Stand lamp like book holder	

CG 6: Ideas Hanging pulley rope with books clipped to bring down and send up

CG 7: Ideas	**Associations:** Stand lamp, bed stand	
 Adjustable bed resting book holder	 Stand lamp like book holder	

CG 8: Ideas	**Associations:** racks, louvers, hanging lights
 Book hangers	 Hanging book, pull down to read

CG 9: Ideas	**Associations:** Bridge, Rabbit burrow	
 Sliding book bridge	 Head holder to read book below	

CG 10: Ideas	**Associations:** Stand, lamp, slope	
 Clamped slope adjustable bed table	 Hanging book support	

Appendix B: Study 2- Exploratory study with mid level product designers and design engineers. Group level idea generation

Instruction to Participants:

You are requested to keep your phones away.

TASK

To generate ideas for an innovative security device for a residential complex

1. **Control Group (CG)**
   Generate radical and innovative product ideas using random analogy trigger of your choice.

2. **Treatment Group (TG)**
3. Generate radical and innovative product ideas using given random analogy trigger.

DELIVERABLES

You will perform the task within the team. You will follow the attribute breaking and idea linking process.

You will record your ideas in post-its in the form of sketches or written words. Then cluster ideas to form product concepts.

Each team will present their ideas.

EVALUATION

The teams will be scored on the novelty level of radical association

Instruction to Rater:

You are requested to rate each individual's idea generation on the given parameters

Novelty/Originality of ideas: Number of unique and unusual ideas (within the group) produced.

Obvious Idea or common to many in the group= Low Novelty (1)

Not so Obvious Idea, could have slight similarity with 1 or 2 others= Moderate Novelty (2)

Unusual Ideas not common to any one = Novel idea (3)

Study 2 Control Group Idea table

Group 1 (Control Group), Chosen Analogy: Student				
Attribute Trigger	**Solution ideas**	**Thinking Spectrum**	**Idea Novelty**	**Idea type**
Books , Knowledge, Obedient, Discipline, Data, Hard working, Efficient, Uniform, Note book, Report, Grade, Vigilant, Command	TC1S1 Store exhaustive data base to verify entrants	RT	low	PP
	TC1S2 System will follow order	RT	low	PP
	TC1S3 Efficient round the clock vigilance	RT	low	PP
	TC1S4 Immediate Disruption report	RT	low	PP
	TC1S5 Efficient computer network for data analysis of activities	RT	low	PP
	TC1S6 Sensor based red spot lighting with AI program, to focus on miscreants	DT	low	PP
	TC1S7 Self generative work without electricity	DT	low	PP
	TC1S8 Sensor based straps to detect un-uniform behavior and detain	AT	medium	PS
Group 2 (Control Group), Chosen Analogy: Pen				
Attribute Trigger	**Solution ideas**	**Thinking Spectrum**	**Idea Novelty**	**Idea type**
Write, memory, Grip, Non slip, create, sketch, ink, stain, colour, paper, Plastic, Metal, Sword, fountain, exam, point, Signature, Novel, Mystery, fight	TC2S1 File a report	RT	low	PP
	TC2S2 Making a sketch	RT	low	PP
	TC2S3 Leave an invisible mark (signature) on hand when making entry to trace incase of robbery.	DT	medium	PS
	TC2S4 Report Disruption to control room	DT	low	PP
	TC2S5 Answer all questions on virtual panel for analysis and record	AT	medium	PP

	TC2S6 Mystery trap doors and shafts to abduct thieves and disarm	AT	medium	PS
	TC2S7 In case of theft the boundary will activate gripping device to capture runaway	AT	medium	PS
	TC2S8 Virtual waterfall like scanner screen	AIT	medium	PS
	TC2S9 In break-in or robbery situation, sword like barricades will form to capture miscreants	AIT	high	PB

Study 2 Treatment Group Idea table

Group 3 (TG), Forced Analogy: Samosa				
Attribute Trigger	**Solution ideas**	**Thinking Spectrum**	**Idea Novelty**	**Idea type**
Inviting, Flavour, Greed Snack, Layers, Crisp, Spicy, Eat. Masala, Spike, Hit, Cook & fry, Anytime, Recipe, Triangle shape, grids, Bermuda Triangle	TT1S1 Decoy Trap to tempt and catch	AT	medium	PS
	TT1S2 Body smell detector	AIT	high	PB
	TT1S3 Repellent to ward away	AT	medium	PS
	TT1S4 Orally induced lie detector	AIT	high	PB
	TT1S5 Repellant to make sneeze and collect DNA, detect miscreant	AIT	high	PB
	TT1S6 Special rays to fry and deactivate any arms	AIT	high	PS
	TT1S7 Specific data system connection Slaps on chip on attempting robbing report data for verification and track	AIT	high	PB
	TT1S8 Invisible security grid- Entrap and transpose to police	AIT	high	PB

Group 4 (TG), Forced Analogy: Student				
Attribute Trigger	**Solution ideas**	**Thinking Spectrum**	**Idea Novelty**	**Idea type**
Obedient & Command, Discipline, Books, Vigilant, Data, Hard working, Efficient, Uniform, Bunk, Proxy, Cheat, Detention, School ground, Teacher, Punish, Pranks, Tree, Tiffin, backpack, Smoke, Drugs, injection, Hoody	TT2S1 Vigilant system, Follow command remotely	RT	Low	PP
	TT2S2 Database mapping to verify personal data	DT	medium	PP
	TT2S3 Enter through play equipment to capture biometric data	AT	medium	PS
	TT2S4 Wearable device to Detect in discipline, sensors to spray invisible chemical, colour later	AT	high	PB
	TT2S5 Capture micro data By taking picture report to police, on suspicion get covered by hoody	AIT	high	
	TT2S6 Hidden decoy to give coded alarm to bring out paralyzing injection	AIT	high	PS
	TT2S7 Self generative system, that project holographic guards	AIT	medium	PS

RT: Rational thinking, DT: Diversified thinking, AT: Analogical thinking, AIT: Absurd and irrelevant thinking

PP: Paradigm preserving (Ideas within the problem boundry)

PS: Paradigm Stretching (Ideas moving slightly from problem boundry)

PB: Paradigm Breaking (Radical ideas outside the problem boundry)

Appendix C: Study 3- Exploratory study with mixed group. Two phase idea generation from individual level to group level.

The Task Process

Sl	Process	Time
1	Briefing about the workshop, its process, and deliverables	10 minutes
2	**Step 1 (Individual activity) :** Each person choose any man-made object, and write it in the space after 'Object as Analogy'. See that there are no duplicates in the group Each person takes the object/thing and breaks it down to its associations. Write them down under the categories given in the table below	10 minutes
3	**Step 2 (Group activity):** Identified opportunities, problems and user needs for your product and the product position to be taken.	10 minutes
4	**Step 3 (Individual activity):** 'Force fit' the object associations to address the problems, opportunities and needs to generate ideas for the product chosen.(An idea is not a full solution, its components to build an innovative solution) Do not judge or discard any idea think absolutely radically- play around with mad/absurd ideas	30 minutes
5	**Step 4 (Group activity):** Taking all the ideas generated in the group build product concept clusters (use one post it per Idea- use both words and sketches to express the ideas. Please do not overlap the post it). Combine and group the ideas to form New product concepts keeping in mind the problems, opportunities and needs of the product category. Place ideas in order of hierarchy lead by a champion idea that best states your problem and build a new product concept.	60 minutes
6	**Step 5(Group activity):** From the concept clusters formulate an innovative product concept for the particular product segment chosen. Present with visual and written description your final product concept.	60 minutes

Analogy attribute listing and idea association building chart

Object as Analogy:			Product to be designed:
Object Categories	**No:**	**Object Association**	**Idea representation**
Structure Physical Form, shape, components, Material, surface /texture			
Function Direct or indirect Usage			
Behavior Feeling: direct, metaphoric			
Others			

Example

Object as Analogy: Gloves (woollen) **Product: helmet**

Object Categories	**No**	**Object Association**	**Idea representation**
Physical: Form, shape, components, Material, surface/texture	1a	Fibre/yarn	Special fibre (shock absorption) wrap like bandage- wrap protection
	1b	soft	Soft fitting that can be compressed- structure/ mechanism
	1c	flexible	Smart material to fit all size -organic shape shifting
	1d	compartments	Multi info- Licence, insurance, etc details accommodated (physical of virtual)
	1e	stretches	Stretched out to flatten so easy to carry and store
	1f	woven	Weave like structure to inter connect environment sensing to bike speed etc-

			alert/ auto precaution etc
	1g	Cover	A switch on protective shield- the light sabers in star wars
Feeling: direct, metaphoric	1h	Warmth	Device to keep you in good mood
	1i	Cozy	Have a air conditioning facility
	1j	Protection	Sonic device to warn incoming traffic to maintain safe distance
	1k	Attack	Pepper sprayer for attacker
	1l	Soft	
Usage	1m	Weather proof	Can have a rolled out jacket
	1n	protects	Special material for emergency impact
	1o	Fits to shape	
	1p	Wear it	A helmet that can be pulled over head
Others:	1q	Winter	Weather guard- cool in summer, warm in winter
	1r	Mountains	Navigator to give directions
	1s	Tea	Have a tea maker
	1t	Warm	
	1u	Snow	Peak structured surface to absorb impact

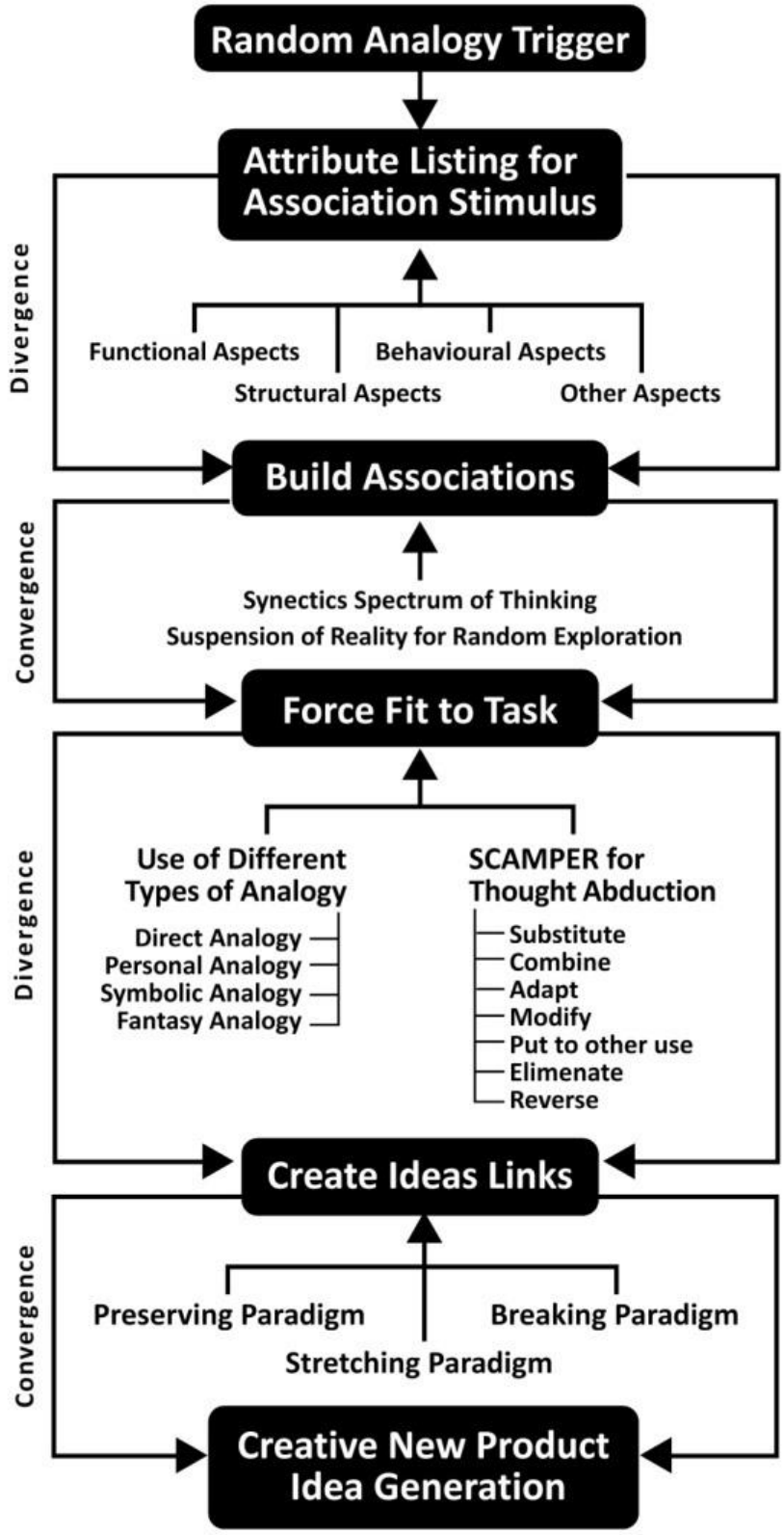
CONCEPT CLUSTER

Smart material to fit all size- A helmet that can be pulled over head
Soft fitting that can be compressed, Stretched out to flatten or rolled. Multi info- Licence, insurance, etc details. Device to keep you in good mood. Can have a air conditioning
Sonic device to warn incoming traffic to maintain safe distance. Pepper sprayer for attacker
Navigator to give directions. Have a tea maker

New Product Concept:

A Helmet that can have a flexi fit and collapsible carrying like a virtual pagri, with Hi- tech wired Multi facility (all the added functions) and sensor based protection device for alert and avoid accidents. Captures and stores data like black box

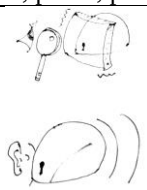
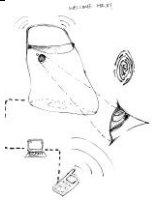
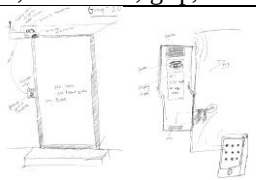
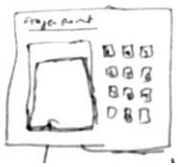
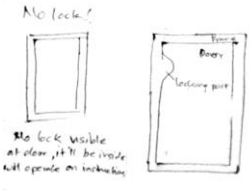
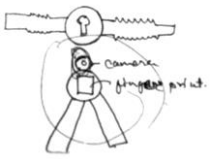
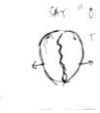
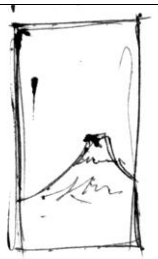
Assisting Framework for Idea Generation

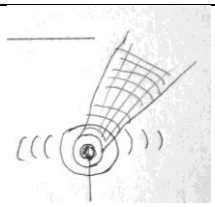
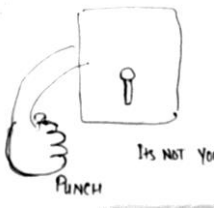
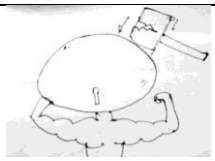
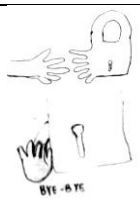
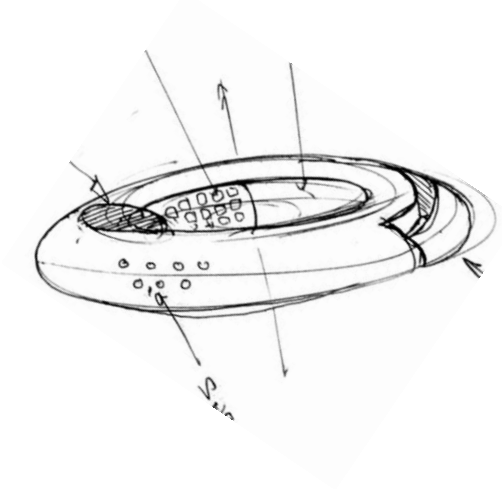
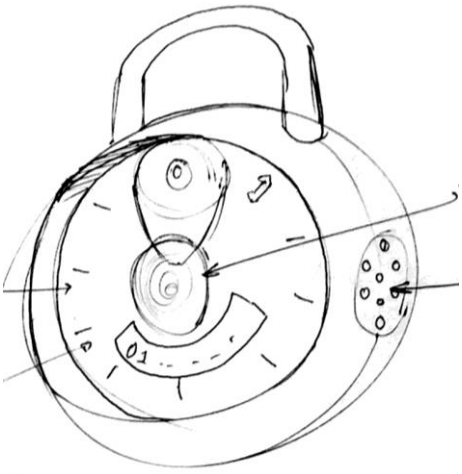
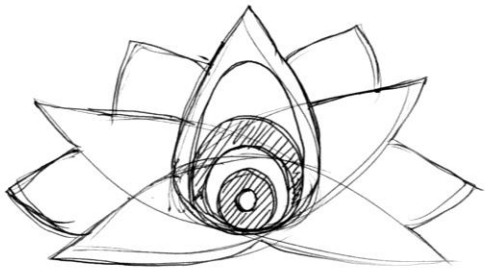
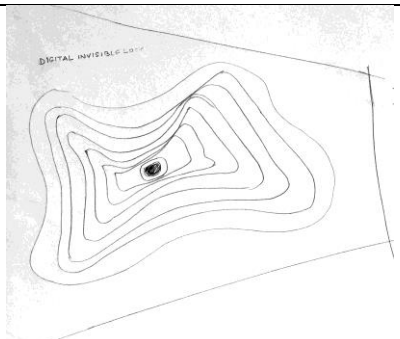


Idea Scoring parameters

	Idea Scoring Parameters	Level Descriptions			
		3 (High)	**2 (Medium)**	**1 (Low)**	
1	**Novelty:** the degree to which the idea is rare, ingenious, imaginative or surprising and Paradigm Modifying	Rare, unusual, ingenious, imaginative, interesting, surprising	Interesting, not very common	Common mundane ideas	
		Paradigm Breaking: change problem boundaries, use of unrelated stimuli, Forced radical associations, absurd and Imaginative thinking	**Paradigm Stretched:** slightly change problem boundaries, use of unrelated stimuli, Forced not so obvious associations, slightly imaginative	**Paradigm Preserving:** unchanged problem boundaries, use of related stimuli, Direct and obvious associations, non imaginative rational thinking	
2	**Usefulness:** the degree to which the idea is applicable to the task and give solution ideas.	Solves identified needs and implied problems	May depict some benefits in solving the problem	Does not produce useful outcome	
3	**Fluency:**	Large quantity of ideas	Moderate quantity of ideas	Inadequate quantity of ideas	
4	**Flexibility:**	Multiple new routes of exploration	Few new routes of exploration	Singular route of exploration	

All Group Idea production documentation

Group A: LOCK **Analogy: Ball, Cup, Car, Pen, Shaver, Bucket, Shirt, Furnace, Shoe, Helmet**			
Associations: Rotate, roll, dog, mud, flower bed, cut disappear, melt, cover, design, personal fit, fill, draw, write, story, ink, liquid, ripple, speed, headlight, brakes, style, temperature, metal, alloy, break, hit, button, personal, Police, License, digital electronics, records, sensor, laces, painting, bath, fabric, handle, move, get in, prank, plastic, protect, net, horn, mirror, button, visor, command, grip, meter, small			
 Lock that can see and hear with rotating vision		 No lock in front. Finger print and camera	 Personal bio stats security code detector to apply key
 No lock Visible. Invisible will operate on instruction	 Camera and Finger print	 Rotating eye to give warning	 Finger print scaner
 Speaking lock	 Open seseme command	 Lock will leave chemical to detect handling	Very small lock like rings
 A painting camaflouged lock with code	 Lock with multiple latches integrated in it The pattern acts as code	 Painting with magic eye	 Key links to match human face

 Shaver lock will chew false key Uses electronic key	 Palm detector Through net to capture	 Punch bag to disarm and capture	 Self defence lock gives a punch to intruder
 A covering of head and disorrient	 Hand shake lock		
CONCEPT			
 AC_1 Multi- security, Oval lock of special alloy, with a keypad code and finger print sensor and speaker for personal comand		 AC_2 Dialed Key.Touchscreen and finger print sensor. Speaker for information documentation.	
 AC_3 Camaflaged lock. Looks like a flower, wth magic eye center to record activity outside door. Built in camera and finger print sensor Will alert on tampering and scare by barking sound. Squrt liquid to disarm		 AC_4 Digital security, invisible lock A wall painting like ripple Transforms on finger print recognition. Layered information detector before opening	

List of publications

Sinha, S. and Chakravarthy B.K. (2011). *Creativity the cornerstone for Innovation: learning's from experiments using analogy for idea generation*, Mumbai: 2nd Annual Global Conference on Entrepreneurship and Technology Innovation, IITBombay

Sinha, S. and Chakravarthy B.K. (2013). *A design inquiry into the role of analogy in form exploration: an exploratory study*, Chennai: International Conference on Research in Design, ICoRD13, IIT Madras

Joshi P. and Sinha, S. (2017). *The effect of idea representation techniques on design decisions during idea exploration phase: an exploratory study of new product design*, Guwahati: International Conference on Research in Design, ICoRD17, IIT Guwahati

Sinha, S. And Joshi P. Chakravarthy B.K. (2019). : *Fostering Creative Ideation : A Case of Idea Stimulation with Analogy*, Ahmedabad: Special issue of International Journal of Research and Analytical Reviews – IJRAR

Joshi P. and Sinha, S. (2019). *A design inquiry into the role of design process in fostering creative exploration of ideas and concepts: an exploratory study of design projects of non-design students,*Glasgow: The 21st International Conference on Engineering and Product Design Education, UK

Other recognition and work done

Conducting Creative thinking with analogy workshops at IIM Udaypur, NIFT Mumbai, IDC, IITB, since 2011

Conducted Idea generation workshop for productive ideation for Honeywell, for SMEs at CII conclave, Kolkata police correctional services and at Kolkata School teachers meet.

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