CREATIVE LEAN DESIGN PROCESS

Alok Kumar Verma[1], **Lalit Kumar Das**[2] **and Ameya Surendra Erande**[3]

[1]*Engineering Technology Department, Lean Institute, Old Dominion University, Norfolk, USA.*
Email: averma@odu.edu
[2]*I.D.D. Centre, Indian Institute of Technology, New Delhi, India.*
Email: lalitdas@gmail.com
[2]*Lean Institute, Old Dominion University, Norfolk, USA.*
Email: aeran001@odu.edu

Use of lean principles in product design process reduces time and cost of designs but it does not look at creativity in design. Creativity in design process is one of the important parameters required to produce good and robust designs to provide improved quality, product performance and reduced lifecycle cost. Intelligent people can be trained to become creative in search for new design solutions. Creativity is a necessary condition for inventiveness and innovations. This paper advocates an approach to induce creativity into engineering design process and then to make process lean in order to obtain desired benefits. Authors recommend use of Learning Style Inventory to select people to develop creativity and then concept maps are used to stimulate the generation of ideas and are believed to aid creativity as they communicate complex ideas and arguments and can transform tacit knowledge into designing team's knowledge. Intelligent designers are recommended to be trained in use of lean tools like Quality Function Deployment (QFD), Integrated Product and Process Design (IPPD), Multi Criteria Decision Making (MCDM) etc. This lean design methodology addresses the need for inquiry based learning to promote the development of creativity, inventiveness and innovations among students/professionals.

Keywords: Creativity, Intelligence, Lean Design, Quality, Project based learning.

1. INTRODUCTION

Product design and manufacturing industry around the world has been facing fierce competition in extremely competitive global environment of the Twenty First Century. Organizations try to launch innovative products with comparatively shorter life cycles than their previous versions/models. This makes it immensely important for companies to create new designs that have value to satisfy customer demands/create new markets. According to a survey on Wikipedia, across a large number of manufacturing and service Organizations found and ranked in decreasing order of popularity that systematic programs of Organizational innovation are most frequently driven by the following goals [1]:

- Improved quality
- Creation of new market
- Extension of the product range
- Reduced labor costs
- Improved production processes
- Reduced materials
- Reduced environmental damage
- Replacement of products/services
- Reduced energy consumption
- Conformance to regulations

Research into Design — Supporting Sustainable Product Development. *Edited by* Amaresh Chakrabarti
 :: *Published by* Research Publishing
ISBN: 978-981-08-7721-7

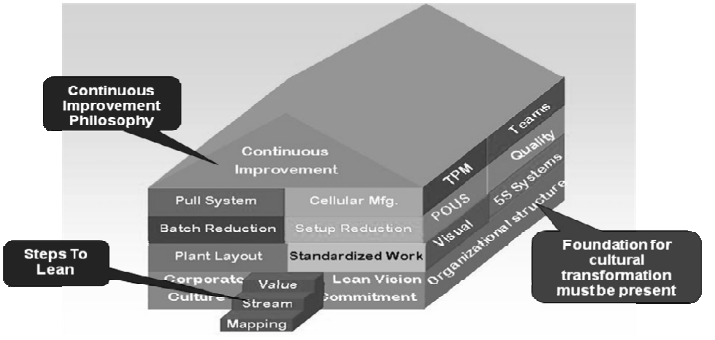

Figure 1. The house of Lean.

Many industry leaders see new product development as an ongoing process (referred to as *continuous development*) in which the entire organization is always looking for opportunities to set and achieve above goals [2]. To reduce the time to market, i.e. time taken to introduce new product in the market, industry uses various Lean tools like Concurrent Engineering, Quality Function Deployment (QFD), Integrated Product and Process Design (IPPD), Value Stream Mapping etc. Lean is a powerful philosophy which advocates minimization of waste by implementing productivity tools and changing work culture. Productivity tools associated with Lean philosophy are shown in Figure 1. Implementation of Lean philosophy within the design process can result in reduction in the lead time and better flow [3]. Leaning the design process can provide following benefits:

- Reduced labor costs
- Improved production processes
- Reduced materials
- Reduced environmental damage
- Replacement of products/services
- Reduced energy consumption
- Improved Quality (to some extent).

but, it does not add creativity to the process which is necessary for top three governing factors i.e.

- Improved quality
- Creation of new market
- Extension of the product range.

2. CREATIVITY

Different authors have defined creativity in many different ways. Theodore Levitt defines the difference between creativity and innovations as "*Creativity* is thinking up new things. *Innovation* is doing new things." George Kneller talks more comprehensively while defining creativity as "creativity, as has been said, consists largely of rearranging what we know in order to find out what we do not know. Hence, to think creatively, we must be able to look afresh at what we normally take for granted." L.K. Das and Kris Kumar define creativity from psychological point of view as "creativity is a result of mental processing that seeks plurality of relationship or configurations from a set of elements. It results in generation of new ideas, association or configurations. Creativity is evidenced by something happening in the mind to generate something original and new" [1]. Some authors consider creativity as a cognitive process or functioning of a genius, or by divine intervention.

Sir Ken Robinson defines creativity as "the process of having original ideas that have value" [4]. This definition is the most comprehensive one and the most relevant one from the product design point of view.

Creativity is an integral and essential part of the engineering design process. Without creativity in design there is no potential for innovation, which is where creative ideas are actually implemented [5] and transformed into commercial value [5, 6]. Innovative products are required to improve quality, creation of new market and extension of the product range.

3. ENGINEERING DESIGN PROCESS

Engineering design process normally consists of following 5 steps [3].

1. Formulation: Transforms design requirements into number of solutions.
2. Synthesis: select the best possible solution based on various requirements
3. Analysis: Analyze the solution for performance and expected results
4. Evaluation: Evaluate results of tests and compare them with the desired results
5. Documentation: Document the process for future purpose.

Creativity is very important in first two steps where some new thinking or rearrangement of the existing data is required.

Engineering design is a team approach and the team should have creative minds to generate new ideas from existing/new data. Edward De Bono has said "There is no doubt that creativity is the most important human resource of all. Without creativity, there would be no progress, and we would be forever repeating the same patterns". It is such an important factor in this competitive world and is evident from the quote from GayMitchell, Executive VP, HR, Royal Bank, "Companies have to nurture [creativity and motivation] — and have to do it by building a compassionate yet performance-driven corporate culture. In the knowledge economy the traditional *soft* people side of our business has become the new *hard* side".

4. CAN CREATIVITY BE TAUGHT/DEVELOPED?

If it takes creative people to innovate new engineering designs, then is creativity a cognitive property as quoted in the previous section by authors of this paper and can it be taught or developed in an individual?

Table 1 shows understanding of cognition, intelligence, creativity, inventiveness and innovation. With this understanding it becomes easier to structure Class room learning so that continual growth in student capability is possible. Students with even lesser intelligence become more productive when put through the above stages of exploration [1].

Table 1. Cascadian connectivity in mental development in design education.

Cognition	Ability to perceive	Improved ability to perceive improves intelligence
Intelligence	Ability to see relationships or configurations	Improved ability to see use intelligence from different viewpoints leads to greater creativity
Creativity	Ability to see many different relationships or configurations	Ability to critically evaluate relationships and configurations leads to inventiveness
Inventiveness	Ability to see new, viable and meaningful relationship	Ability to critically imagine and evaluate inventions in a socio-cultural context leads to innovativeness
Innovation	Ability to see new socially and culturally meaningful relationships	Synergy with society & culture leads to OVATION

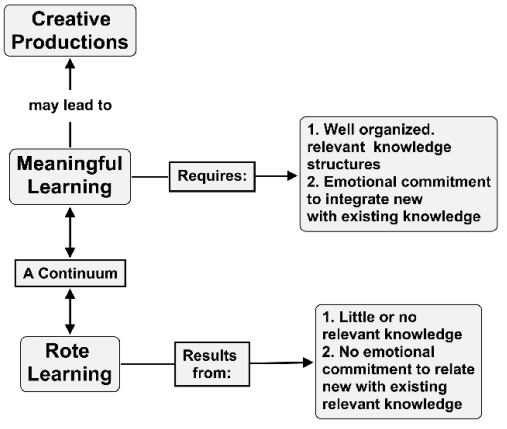

Figure 2. Highly rote to highly meaningful learning Source: *Joseph D. Novak & Alberto J. Cañas*.

Sir Ken Robinson makes the case that creativity can be taught and most people never tap into their full potential [4]. Researchers like Daniel Pink (2005) propose to integrate right-directed thinking representing art, emotion and creativity to left-directed thinking dealing with logic and analysis. Nickerson (1999) however provides a sequential approach of toying with creativity techniques quoting success stories of academia and industry by proposing the following sequence [1]:

- Establish purpose and intention,
- Build basic skills
- Encourage acquisition of domain-specific knowledge
- Stimulate risk-taking
- Focus on Mastery
- Promote beliefs about creativity
- Provide the necessary opportunity
- Develop meta-cognition and self management and
- Employ teaching techniques to promote creative performance.

The authors support the above steps and believe that all of them can be taken during the teaching learning process at the university level. Teaching community should reflect on their current teaching practices and incorporate as many creative activities as possible such as project based learning, open ended problem solving etc. Figure 2 shows difference between meaningful learning and rote learning. Creativity results from very high levels of meaningful learning.

Highly meaningful learning requires well organized, relevant knowledge structures and emotional commitment to integrate new with existing knowledge [7]. This inclination of mind/intellect can be found out by the use of learning style inventory. Authors advocate use of Learning Style Inventory tool developed by David Kolb [8].

Learning Style Inventory is the tool that describes the way you learn and how does one deal with different ideas and day-to-day situation in life.

Abstract Conceptualization is the style which facilitates creativity, where one is able to put forth completely new ideas or rearrange existing data to come up with creative concepts leading to innovation.

Engineering design team should have members who score very high on Abstract Conceptualization axis to generate creative ideas. These creative ideas can then be molded into number of designs satisfying customer needs during the remaining steps of design process.

Authors recommend use of concept map as a tool to generate creative ideas. Concept maps are graphical tool for organizing and representing knowledge. Figure 3 shows a concept map showing key features of concept map. Concept maps are used as a learning tool as well as a tool for

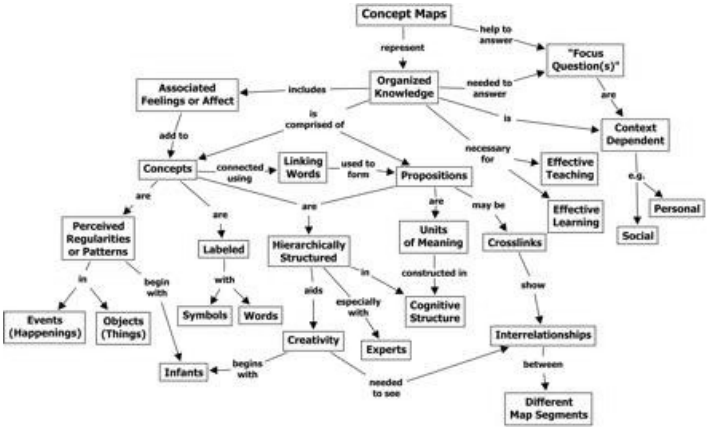

Figure 3. Concept Map Showing Key Features of Concept Map Source: Joseph D. Novak & Alberto J. Cañas.

evaluation. It shows how well can one relate existing data and establish various links between different concepts/ideas. Concept maps can bring out best of the ideas in minds with high abstract thinking capacities and thus engineering design team gets new concepts. Thus authors of this paper propose that creativity can be created/developed among engineering design team members and has tremendous importance in first two stages of the engineering design process. Creativity doesn't have that much importance in the remaining three stages of the process i.e. Analysis, Evaluation and Documentation because these steps are performed as per standards applicable for that particular industry and normally has laid out procedures.

Till now we have discussed creativity in engineering design process; the latter part of this paper shows how to make this process lean, cut down waste and increase efficiency.

5. LEAN ENGINEERING DESIGN PROCESS

Lean philosophy, although evolved in the manufacturing field, finds great applications in any domain of business including design process. Implementing lean in process means cutting down on waste in the process/s and thus increasing efficiency of the process/s. Traditional lean principles reduce cycle time and cost of product design — development. Authors suggest use of the following three Lean tools in the engineering design process which facilitate knowledge management and help produce creative designs.

5.1. Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a method used to identify critical customer attributes and to create a specific link between customer attributes and design parameters. Matrices are used to organize information to help marketers and design engineers answer three primary questions:

- What attributes are critical to our customers?
- What design parameters are important in driving those customer attributes?
- What should the design parameter targets be for the new design?

Organizing framework for the QFD process is done by using a planning tool called the "house of quality" (simplified example above) [8]. Working as a team, design engineers and marketers first establish critical customer attributes for the product. These attributes become the rows of the central matrix of the house of quality. The team may group attributes into broader categories in order to simplify planning and analysis. QFD is used in the first stage of the engineering design process. This

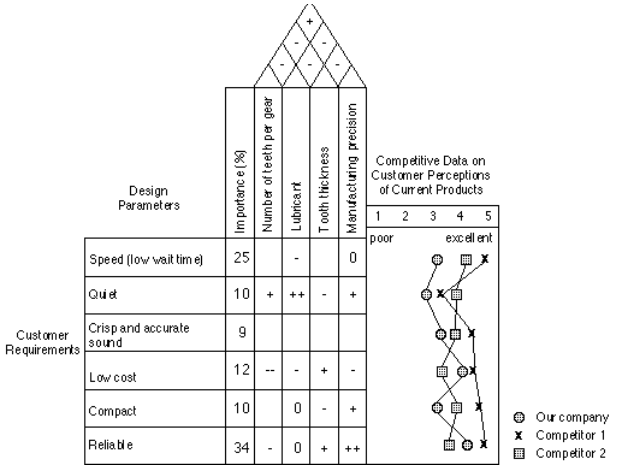

Figure 4. House of Quality in QFD Source: http://www.ifm.eng.cam.ac.uk/dstools/control/qfd.html

takes out waste from the traditional process of putting customer needs into product specification as it channelizes all the information and transforms into matrix.

5.2. Integrated Product and Process Design

Integrated product and process design is the common platform for product and process design people to work concurrently on product design — development. It brings out issues in any process to the surface and hence can be taken care of at the earliest possible stage in engineering design process. It saves a lot of rework, which essentially is a form of waste. IPPD results in [9]:

1. Reduced Cycle Time to deliver a product
2. Reduced System and Product Costs
3. Reduced Risk
4. Improved Quality

Figure 5 shows a generic IPPD process.

5.3. Multi Criteria Decision Making (MCDM)

Design team normally comes up with more than one new concept for the product. Therefore, it becomes very important for the team to select the best design that satisfies customer demands. Multi Criteria

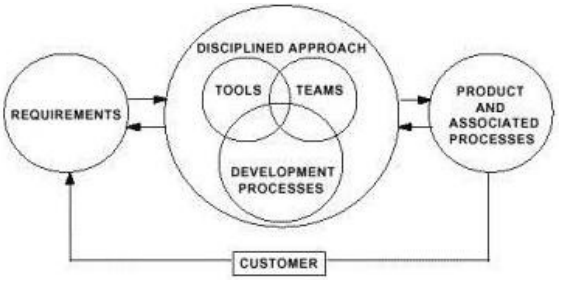

Figure 5. A Generic IPPD Process.

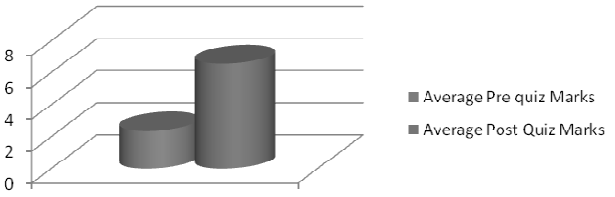

Figure 6. Pre and Post use Survey Results for the Marine Kits 1-4.

Decision Making is used to weigh all the criteria against each other before making the final pick. Some of the methods used in MCDM are

1. Analytic Hierarchy Process (AHP)
2. Weighted Sum Model (WSM)
3. Analytic Network Process (ANP)

Weights and performances are evaluated by subject matter experts in the team.

Use of the above mentioned tools can reduce waste and improve efficiency of the engineering design process.

USE OF PROJECT BASED LEARNING TO SPUR CREATIVITY IN KINDERGARDEN-12 (K-12) - MARINE KITS

Tools mentioned in 5.1, 5.2 and 5.3 are used at undergraduate level and above in the design process, but project based learning tool is extensively used at K-12 level to generate creative designs. The Lean Institute at Old Dominion University has developed four inquiry based learning kits to spur creative thinking among K-12 students. The four Marine Kits are 1. Shipyard Operations, 2. Ship Construction, 3. Ship Stability and 4. Ship Disaster Investigation. The Marine Kits allow teachers to integrate real world applications from a marine engineering perspective for teaching math and science concepts in middle and high schools. The project also provided professional development on marine engineering concepts to the science, mathematics, and technology teachers. The institute has trained hundreds of teachers with the aim to transform the pedagogical practices in K-12 by incorporating project based learning. Research reveals that inquiry-based learning and project-based learning strategies develop communication, problem-solving, and critical thinking skills and improve student achievement. These project based learning kits were developed to increase student awareness about marine industry while improving math and science skills for K-12 students under a project funded by the National Shipbuilding Research Program. Figure 6 shows the results for pre and post use quiz conducted to assess impact of the Marine Kits 1-4.

Figure 6 shows clear increase in marks of the students after Marine Kit activities. This sample result clearly shows that hands-on activities enhance learning in K-12 students. Lean Institute is engaged in creating more projects based and activity based learning modules for K-12 students.

6. CONCLUSIONS

Production of creative design requires two important ingredients, a creative design process and a team of creative designers. Both of these factors compliment each other to produce robust and creative designs with value for the customer. Lean tools can be implemented to make the design process more efficient. However, development of creative designers is a more challenging issue. Research has shown that creativity can be taught/induced/ developed among individuals. This process should start in the K-12 by adopting an educational pedagogy which relies on inquiry and project based learning. For selection of the design team, authors recommend use of learning style inventory to find out abstract conceptualization capabilities among individuals in the design team. Concept maps can be used to

create new ideas apart from being used as an evaluation tool. Use of lean principles like QFD, IPPD, and MCDM are recommended to reduce waste in design process. Selection and training of design team along with implementation of Lean tools in the design process can create following benefits: 1. Creative solutions for new product/s or existing products; 2. Meeting Voice of Customer to the maximum level of customer satisfaction; 3. Improved Quality; 4. Reduction in cycle time; 5. Reduction in other wastes like rework, reinventions and 6. Reduced cost.

REFERENCES & ESSENTIAL BIBLIOGRAPHY

1. Das, L.K. and Kumar, Kris., "Cognition, Intelligence, Creativity to Innovation", International Conference on Research into Design (ICoRD 09), Vol. 1, pp. 18–25, 2009.
2. http://en.wikipedia.org/wiki/New_product_development
3. Verma, A. K. and Dhayagude, S., "Implementing Lean in the design Process — Validation using Physical Simulation", International Conference on Research into Design (ICoRD 09), Vol. 1, 2009.
4. http://sirkenrobinson.com/skr/
5. Howard, T.J., Culley, S.J., Dekoninck, E., "Describing the Creative Design Process by Integration of Engineering Design and Cognitive Psychology literature", Design Studies, Vol. 29, No. 2, pp. 1–21, 2008.
6. Thompson, G., Lordan, M. "A review of creativity principles applied to engineering design", Proceedings of the Institution of Mechanical Engineers, Part E, Journal of Process Mechanical Engineering Vol 213 No E1 pp. 17–31, 1999.
7. Novak, J., Cañas, A., "The Theory Underlying Concept Maps and How to Construct and Use Them", pp. 1–4.
8. Kolb, D., "Learning Style Inventory", McBer and Company, 1985.
9. Wheelwright, S. C. , Clark, K. B., "Revolutionizing Product Development", The Free Press, New York, 1992.
10. http://www.goldpractices.com/practices/ippd/