Engineering Design ability assessment process – Three axes system

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Abstract— Engineering Design is the applications of scientific and mathematical principles to a product. When we call someone an efficient designer? When they do it faster, cost effective, the product performs better than others, the user ask for the same product again and again, etc. All these are indicators of engineer's design efficiency. To expect such efficiency from any engineer what qualities should they have and how do we understand their level? This research addresses this aspect by defining the process of designers ability assessment, breaking the basic traits and sub divisions, grading their achievement to different levels and connecting them to overall design ability allows us to quantify. This helps to understand where the engineer is standing and the design expectations we can put on them. This process sets objectives to prepare testing methods for the engineer's assessment. The process aims to bring the quantified levels of design ability over three basic root elements of engineering design, Science, Sociology and Tactics. Placing them on grid one will be able to specify the level of the engineers and their design capability in a simple coordinate system. A beginner may fall at (1,1,1) and an efficient engineer gets measured as (3,3,3)

Index Terms— Design ability assessment,Design education,Design recruitment,Design thinking,Design training, Designer responsibility,Designer selection,Designer testing,Product design,Role of designer,Social sense,Tactical ability,Three axis system.

1 Introduction

Engineering design ability is a key human factor in product innovation and the progress of human society. Having many directions in it, learning and practicing Engineering sign appears to be complex. A detailed assessment process which can bring out strengths and opportunities for any engineer to perform successful product design is still evolving. This research has taken a step forward in the same direction. The engineer's *designe ability* assessment process has to be derived from the roots of thinking ability. Engineering of any product is a combination of science (Physics, Chemistry, etc) and sociology. An engineer can become a good designer, when they are able to apply the theoretical knowledge of sciences with understanding of social/user sense. Design ability depends on logical thinking and analytical approach while applying knowledge and sense. Design ability can be quantified or indexed by asking well prepared questions or giving challenging problems to solve. Knowledge may be categorized by levels like Basic, Complex, and Generative. Basic level confirms the ability of connecting generic scientific knowledge to design requirements and brings theories to the actual product. Complex level confirms the ability to apply non-general / deeper scientific theories / a combination of theories to meet product requirements. Generative level confirms the ability to challenge scientific theories for product design. Similarly, sense of sociology can be measured in levels as common sense, broader sense and futuristic sense. Common sense confirms the ability to judge as being acceptable to all. Broader sense confirms the ability beyond the given product scope boundaries and makes it more versatile. Futuristic sense confirms the ability of anticipating unsaid time connected potentials of the product and makes it suitable for the next generation also.

Tactical ability is required for any engineer for best use of Science and Sociology on a product. This ability allows the engineer to question roots of theories and connect to/ compliment the product requirements. Logical reasoning and analytical thinking are base traits to build tactical ability.

Often mathematics gets used in the assessment process. In reality it is not assessing mathematical ability. It is more application ability of theoretical science to a realistic product. However assessing generic design ability is not enough for a specific engineering industry. There must be some components in the process, related to that specific industry. A Transportation designer performing well may not do the same in software design. The difference lies in product principles and user understanding. Both are subsets of Science and Sociology.

2 Understanding Requirments

Three basic abilities Science , Sociology and Tactical are equally important and influence three different directions on engineer design performance. Somebody with higher Science ability can design a product accurately and never fails in the field. But when they lack Sociology , the product may not get appreciated by the user.

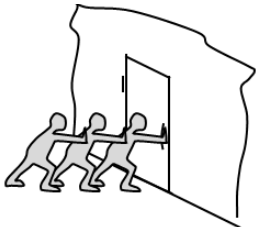

Fig. 1. : A door designed to be air proof, heavy enough to be unbreakable, perfect matching and gives majestic appeal to home. But it needs three people to open and get in. This reflects high science ability and low social sense.

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ISSN 2229-5518

When an engineer is good at Sociology and less at Science they may fail to meet product quality and reliability requirements.

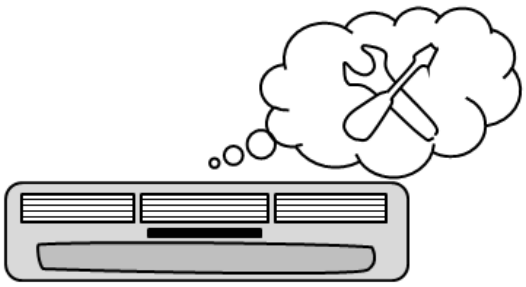

Fig. 2. A room air conditioner with human sensor and ability to remember customer preferences and adjust itself works on latest technology with least energy consumption, easy to operate and highly appreciated by customer while purchasing, but demands to repair compressor at every summer due over load. This reflects high social sense but low science ability.

2.1 Science ability

Science ability can be measured with the help of Mathematics, with two of its components General Mathematics and Industry Mathematics.It is possible that one can be good at General Mathematics , but not Industry Mathematics. But it is not possible that one can be good at Industry Mathematics but not General Mathematics. Questions need to be framed focusing on scientific problems, which can vary with each industry. Both components together gives Science ability , which can be graded into three levels Basic , Conglomerate , Generative.

Basic Level -This test confirms the engineers ability of connecting generic scientific knowledge to design requirements and bringing theories to the actual product. All general theories like, gravity, force, friction, kinematics etc can be applied and prove the product meets the requirements. For example a chair to be designed, fully functional , strong enough , cost effective , if required height adjustable with recliner facility can be expected from a Basic level engineer.

Conglomerate Level – This test confirms an engineer's ability to connect varied /multiple scientific theories and complex mathematics and apply them to product and prove its success. For example a chair for premium application in 1st class air travel with gadgets in it, can be customized to customer themself. This involves integration of different technologies, sub-systems higher accuracy and a robust product design.

Generative Level – This test confirms an engineer's ability to work above the available scientific theories and challenge them. For example a chair can go up and down stairs with gravity balanced , and it can turn into a small sized box when it is not required. A generative level engineer can design and prove such products.

An engineer found at these levels of Basic, Conglomerate and Generative scores as 1, 2, and 3 respectively.

2.2 Sociology Sense

General sense is ability to understand people / situations around and make the best of it. An engineer can think of creating complimenting products to customers to suit their condition , when they have the best sense of surroundings. People who make wonders with waste materials are this type. In Robert Stenberg´s words it is Practical intelligence. Practical intelligence is the ability that individuals use to find the best fit between themselves and the demands of the environment. This sense also allows the engineer to perceive the product as a customer in all respects. They can be a first time user, or an expert user to understand the product. The second component is Industry related sense. Every industry is required to have its own customer behaviors. A best car engineering designer may not be best in toy designing. Here child ignorance is to be sensed , where in a car adults have to be considered. Verifying both separately shows where the lag is. Both together give Sociology sense ability. This can be graded into three levels, Associative sense , Broader sense and Futuristic sense.

Associative Level of sense – Ability to engineer a product which will be well accepted by the user community. No specific negativities get raised by the user. Product performance meets all requirements of the user. But *no problems* is not equal to attractiveness. This level engineer will not be able to add attraction and competitiveness to the product.

Broader Sense Level – Ability to connect the customers to more than their product and find opportunities to compliment more. Offers much more than just the defined product aimed for engineering. User will find it as best for them and feel exceptional. Customer appreciation will be high

Futuristic Sense Level - Ability to think beyond the user requirements and anticipate their needs for the future. Understanding product impact on user communities , adding brand consciousness to the customer's social life beyond the product functions and needs. Engineering all new types of products first time into the market needs this level of sociol ability to succeed. Certain products change the consumer behaviors and bring new trends, this reflects the designers ability and forethought at the beginning of product concept development.

An engineer found in these levels of Associative, Broader and Futuristic is scored as 1, 2, and 3 respectively.

2.3 Tactical – Logical and analytical abilities

Logical reasoning intelligence is the process of using rational and methodical steps to reach conclusions. This ability challenges general rules taken for granted by others and foresee implications beyond the given statements. This ability allows the engineer to take the products to the next level.

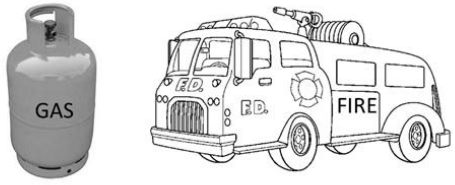

Fig. 3. When we label always the content, why do we write FIRE , when water is filled. Being childish is quality to apply logic and bring basics correct.

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ISSN 2229-5518

Analytical thinking ability allows the engineer to break bigger challenges into smaller ones and address them independently to solve.

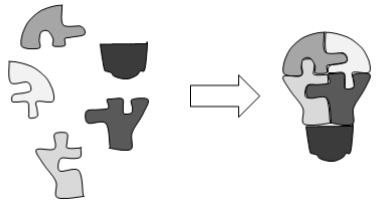

Fig. 4. Engineer can complement each eliment of the product to best of all.

Both Logical and Analytical abilities are heav been researched in the past and well defined test methods are available. Grading both into three levels and combined score can be taken for final assessment. A higher scoring engineer is expected to provide simple solutions even to complex problems. Higher scoring engineers can make better decisions also quicker. Several established methods are available to account one's Logical and Analytical abilities. The Theory of Quantified Fixation , proposed by Thomas J Howard tells the identification of different design thinking blockages to address and improve reasoning, can be applied here. Test methods on Qualitative Reasoning proposed by Maryam Khorshidi , Jay Woodward and Jami Shah can be used while preparing the test. Scores are graded into three levels called Novice, Competent and Expert. A higher tactical ability gives a quicker, and more Robust product designed.

Novice Level- Ability to handle simple and general logics and analyze the problems with fewer parameters in Science and Social

Competent Level– Ability to address complex problems with multiple scientific theories involved and apply them complimenting each other in both Science and Social.

Expert Level- Ability to apply even scientifically challenged theories and socially rejected aspects to make a successful product.

An engineer found in these levels of Novice, Competent and Expert scores 1, 2, and 3 respectively.

3 PROCESS

A set of 6 different tests each scored from 0 to 3 demonstrate all three abilities. Averaging both tests in each trait gives the level of designer. Two of the tests one in Science and one in Sociology differs for each industry. This allows for customizing the assessment according to the products expeted from designer. Figure 5 shows the three traits and their connected tests and levels.

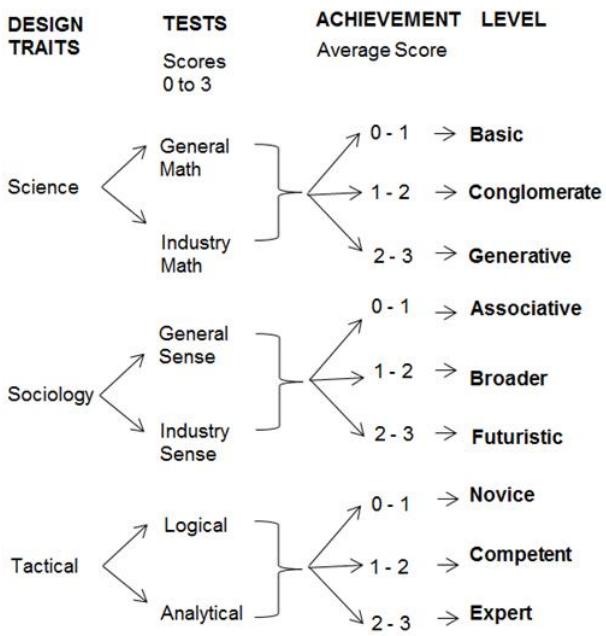

Fig. 5. Three basic traits are measured to their levels through two tests in each.

Placing the levels of three traits in simple cubical coordinate system provides better understanding of engineer's position as in cartesian coordinate system (Science,Social,Tactical)

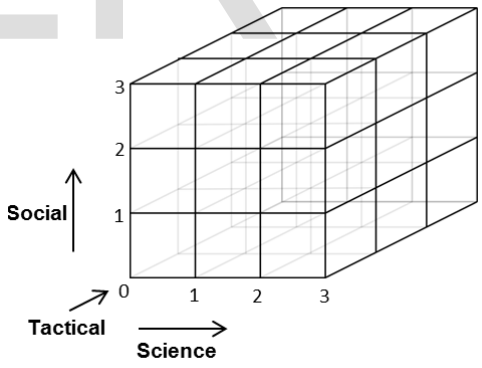

Fig. 6. *A score of (0,0,0) is lowest design capability and (3,3,3) is highest.*

This allows us to know the engineers position exactly and missing elements. The aim is not for everybody to reach (3,3,3) level. It is more of what is expected from that designer. Some designers require a higher level of Science , but not Social and vice versa. But tactical ability is to be considered to keep improving towards 3 for any engineer to be good.in design performance.

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ISSN 2229-5518

4 Grid interpretation

1)An engineer attaining (2,3,2)

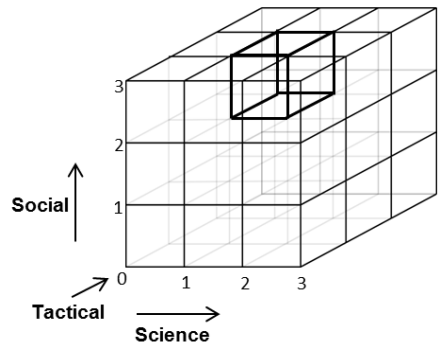

Fig. 6. An engineers ability (2,3,2) positioned in three axis grid

This engineer displayed traits in levels of conglomerate in Science , futuristic in Social and competent in Tactical. They have a high degree of understanding of customer compared to their technical design skills. Products , those are technically less challenged but winning customer physiologically is important will be successful in their hands. Ability to create brands and building emotional bond with the customer is their strength. They will also be successful to designing user interface aspects , as they can perceive themself as end users. However scope exists to improve their Tactical skills, which impacts on timelines.

2)An engineer attaining (3, 1, 3)

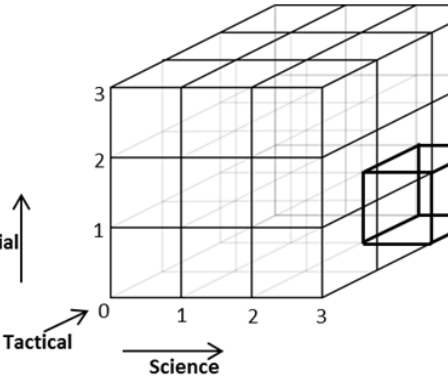

Fig. 7. An engineers ability (3,1,3) positioned in three axis grid

This engineer displayed traits in levels of generative in Science , associative in Social and expert in Tactical. They have high degree Math ability. Along with their Tactical skills they will be able to solve any complex problem quickly. They will be highly efficient and create breakthrough with technologies. But they will fail to understand customer behavior. They fits well to design inside technical systems but not for visible and interactive portion products.

3)An engineer with (2,2,3)

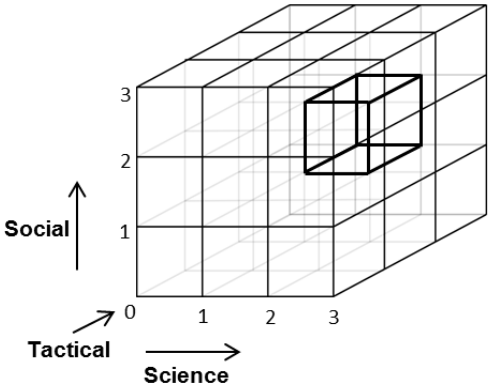

Fig. 8. An engineers ability (2,2,3) positioned in three axis grid.

This engineer displayed traits in levels of conglomerate in Science , broader in Social and expert in Tactical. Products that have less means to customers and are not highly technical go well in their hands. However they can lead and build great design teams with their Tactical trait. Their strength will be questioning others to improve. They might be academically low but gain Tactics with experience.

This process indicates precisely the position of an engineer. Not every product design asks for all three traits. A perfume bottle design will not have many technical calculations, but the shape, colors and over all display need to be emotional to the customer. A Social ability at Futuristic is required here. Similarly an engine design with unconventional fuels is requires a Science level of Generative, but does not require high Social. Tactical is directly related to design success factor and the ability to complete the design faster for both high Science and high Social products.

5 Example for all levels

Looking at one specific design requirement for all levels allows to understand the differences better. For example a coffee cup to be designed. Cup can be simple or scientifically challenged. At the same time, it is a catalog product or high brand couscous product. Figure 9 shows the table of different level traits and their potential expectations.

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ISSN 2229-5518

Trait	Level	Tests	Level wise Potential expectation
Science	Basic	General Maths	Volume calculations , physical strength
		Industry Maths	Preferred cup and handle sizes , heat sensitivity, etc
	Complex	General Maths	Coffee to size ratio with best shape, least qty material used
		Industry Maths	Cup weight sensitivity at full and empty condition.
	Generative	General Maths	Shape leads to uniform hotness to coffee along with uniform consumption
		Industry Maths	Preferred temperatures at handle and at mouth
Sociology	Common	Generic Sense	Complimenting to related products
		Industry Sense	Differentiate coffee and soup
	Broader	Generic Sense	Bonding to user , linking to his life.
		Industry Sense	Modern / New trend and distinguished to competitors
	Futuristic	Generic Sense	Why it is coffee cup, why not cup coffee. Connecting cup brand to social status
		Industry Sense	Upgradable to next generations. Customized Cups.

Fig. 9: Level of design expectations from different traits. This allows differentiation and comparision. Line differentiating from one level to another may change time to time and also the standard of the industry. A highly matured company counts some levels as basic , which may be complex to others.

6. Industry Application and results

This Engineering Design Ability Assessment process has been applied consciously for a long period in a Product Design industry and observations have been captured.

Organization – An Engineering Design services company in which design efficiency is a key business success factor. Business and employee strength is at 60% growth year on year, challenges the selection and training and performance assessment process every time. As this team serves their Global customers, varied expectations, behaviors and interests are involved. Being involved in different products in the service range, design ability requirements and its variations are significant.

Previous Approach – Every engineer in the company has been assessed against a large list of skillset matrix and everybody moves forward at least 20% of their skills year on year. Work management and customer interface have been considered as having bigger job profile , and only engineers with seniority are given those.

New Approach – Assessing all engineers into three axis system of Science, Sociology and Tactical and assigning roles as demand requires. Every engineer is responsible for design productivity, each defins one lead aspect out of the three axes. Some designers are completely technical and responsible for accurate and quick completion of design work, those are empowered to take all design decisions and provided all required resources to perform. Type (3, 2, 2) engineers are in this group with high science ability.

The second set of engineers, those responsible for planning and mobilizing the resources for best utilization, review and synthesis the designs done by the previous set of engineers. Type (2, 2, 3) engineers are in this group with high Tactical ability.

The third set of engineers are customer interfaced to understand and define the design requirements and also convince customer with design outcome. (2, 3, 2) type engineers are in this group with high Sociology ability.

The second and third groups are also involved in defining and improving the workflow processes and systems. Each group is equally important for business and all three are involved in every design success. They are made aware of their strengths and role they are playing in the business. This process of understanding their design ability and giving them the best possible role made them perform to their limits. This improved customer confidence and comfort. Business growth was not only numbers but also resulted in increase in design complexity. An easy and robust recruitment and development process evolved. Engineers time for productivity readiness got reduced. Many internal training and self-development programs could be established with in organization for engineers to know, which block they are in Assessment cube and improve. Regular metric of customer satisfaction reached high.

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Significant improvement seen in employee work satisfaction.

Strength of Design Engineers over 5 years in one of the departments is shown in Figure 10.

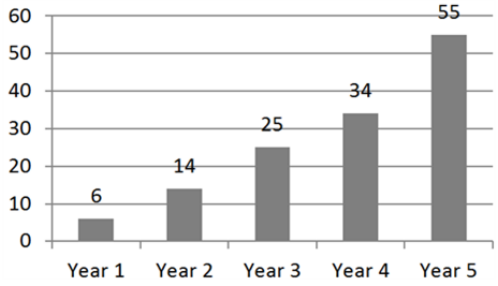

Fig. 10. NA Design support team growth over 5 years with axes system implimetation for designer recruitment, training and work allotment.

Customer satisfaction index changes of the same department over 5 years of application shown in Figure 11. Customer concerns are not seen in later years and percentage of excellent is increased.

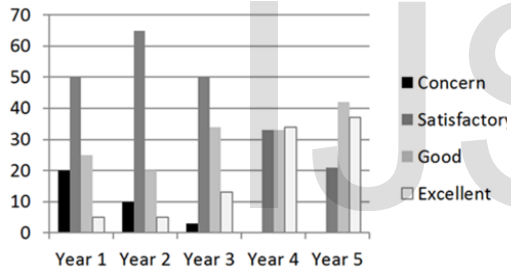

Fig. 11. Focused social sense increase in design engineers displayes better understadnig of customers and eliminates concerns in the first three years.

The value of design engineering is counted with design complexity. Increase in design complexity is visible in Figure 12, over 5 years. Type 1 assignments are relatively less challenged and Type 3 are high.

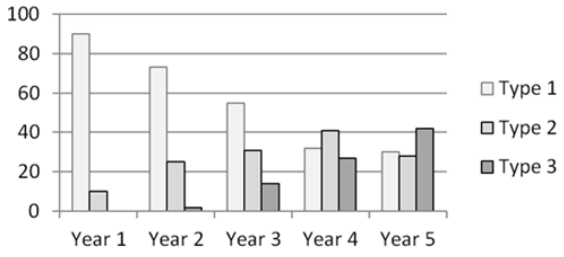

Fig. 12. Increased complexity shows the increase in customer dependency, this also leads to business sustainability.

7 Conclusion

This methodology has been built with experience and research experimentation in industry. A detailed study done over a period, through design engineers recruitment , their performance assesment, connected development plan and re-assessing their performances several times.

Kirton Adaption Innovator (KAI) test measures the Innovation ability taking into account behavior skills. Similarly the Belbin Role test focuses on ability to work together in an Innovation team. The assessment process discussed in this paper is concentrated on one's self-knowledge and its application ability irrespective to others. This process does not show one's teamwork ability, it is all about individual strength of Product Design.

There are few limitations to this process.

1. Level differences may change with time and also maturity of the industry.
2. Tests and scores need to be dynamic and updated periodically.
3. Each industry needs two tests customized to their work environment and technical challenges.

ACKNOWLEDGMENT

I thank all engineers and leadership team supported the experimentation and process refinements. Many previous researches and experts helped in making test papers and solution interpretations has a significant contribution in concluding this study. Further work of making this process more standard, generalized and make available to Educationalists and Industries to apply quicklyand know their engineer's level is progressing. I thank in advance to all participants of this initiative.

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