

3 ■ COGNITION, INTELLIGENCE, CREATIVITY TO INNOVATION

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Understanding the growth of cognition, intelligence, creativity and innovativeness is essential for the development of design education, generally stymied by uneasy tussle between science and arts. The same may be better resolved through an understanding of the progression from cognition to innovation. The paper articulates the basic difference between human cognition, intelligence, creativity, inventiveness and innovations and clarifies concepts to facilitate innovative propensities in design and engineering curricula. Human intelligence is attributed to brain size and complexity of the synaptic structures of brain cells which enable a learner to think fast, analyze problems and consequently perform well in examinations and class tests. Inventiveness and innovations are characterized by co-activation of certain parts of the brain, which enable a person to think creatively. It is recognized that frontal lobes need to be employed critically. Inventiveness and innovation are steps beyond creativity; it cannot be assumed to develop automatically by passing certain types of examinations; it requires a different set of skills, training and encouragement.

Authors present a discourse on the subject with some examples of student work which demonstrates the need for teaching-learning processes in order to promote the development of creativity, inventiveness and innovations.

Keywords: Intelligence, Innovation, Creativity, Critical thinking, Invention.

1. INTRODUCTION

Cognitive domain of knowledge comprises of a hierarchy of learning, i.e., knowing, comprehension, application, analysis, synthesis and evaluation. Extent of learning, i.e., behaviour modification is measured in terms of executable and observable actions such as listing, defining, distinguishing, calculating, comparing and doing something. Does the action of designing fall within such action verbs?

A closer look at the act of designing shows that it is a complex action interwoven with several other actions including conceptualization, innovative thinking, creativity and invention, distinctly different from mere cognition, intelligence and conformity with existing practices. As a matter of fact, engineering design, i.e., designing products and components mechanistically is more of conformance to existing practices of referring to handbooks than designing in the real sense of the word. It usually does not permit designers to look at the real problem and create an entirely new solution. Designing should result in an original product with its own form and function in the true spirit of designing. The paper dwells on distinguishing and redefining some design concepts particularly with reference to the notions of perception, intelligence, creativity and innovation and proposes a way forward to develop student's innovativeness from a given level of intelligence.

2. RELEVANCE TO TERTIARY EDUCATION

Let us look at the relevance of the topic of study to the tertiary education, i.e., at higher level institutions and universities. We teach at all levels with very good intentions, by assuming that our syllabi and methods of teaching and learning will result in 'intelligent, creative, inventive and innovative students' often all at once. However, we admit students based upon their performance in a prior examination or

an entrance examination. We thereby ensure to admit students who can respond to questions fast and correctly. What do we really measure by tests and examinations? Brilliance, intelligence and mastery of the courses they have studied; not their creativity or innovative skills. Then, we hire highly qualified staff members who, in their scholarly pursuit, transmit knowledge and information hour after hour in the classroom situation. Then, the students take examinations and pass by demonstrating that they have learnt whatever was taught to them. How, then, can we expect the students to become creative, innovative and inventive unless we focus on their learning processes and shape them accordingly? It shows that the assumptions of our educational system and the associated expectations in creativity and innovation are too far fetched!

The scenario described above is typical of the developing world, i.e., countries in Africa and Asia but not quite so elsewhere. Many advanced countries admit students based upon interviews and evidence of creative work. The difference is borne out by the fact that a very small percentage of innovative designs and products really come from Africa and Asia. The goal of all engineering and design programmes is to produce students who can design products in their areas of specialisation and we are falling short of this goal.

Let us discover the real problem. Although we start by well selected groups of students on the basis of their intelligence level to pass their previous examinations and we perpetuate the same process of teaching and examination. This is precisely the reason why students may still be intelligent but not creative and innovative. Educationists while selecting suitable students use different cognitive parameters for evaluating potentially good students. In engineering & science, emphasis is on intelligence. In Arts it is on creativity. In Design it is on inventiveness. For any profession to grow to its limits of excellence, we must understand the ways in which development of cognition (perception), intelligence, creativity and innovation can be brought about and ably factor them into the curriculum, into the subject matter and teaching-learning processes. Once a conscious effort is made to inculcate creativity, invention skills and innovativeness then we can begin to expect a movement towards enfoldment of human potential and achievement of professional excellence.

3. WHAT IS INTELLIGENCE?

Intelligence, according to Wikipedia, is an umbrella term used to describe a property of the mind that encompasses many related abilities, such as capacity to reason, to plan, to solve problems, to think abstractly, to comprehend complex ideas, to use language and to learn new things. Intelligence pertains to intellect and to wisdom through one's knowledge and analysis of situations. The word 'intelligence' comes from the Latin verb 'intellegere', which really means to understand. By this token, intelligence is different from being smart or clever which imply an ability to creatively adapt to ones environment. A definition agreed by 52 intelligence researchers signed in 1994 under the auspices of mainstream science of intelligence is 'A very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings.'

Researchers in the field of psychology of learning also define intelligence, e.g., Linda Gottfredson (1998) defines it as 'the ability to deal with cognitive complexity' and Cyril Burt (1931) defines it as 'Innate general cognitive ability'.

4. NEURAL STRUCTURES IN THE BRAIN

Let us look briefly look at the neural structures within the brain, as shown in Figure 1. Researches on neural networks, i.e., structure and functioning have suggested that 'learning must be considered an activity of the brain and, therefore, totally dependant upon one's ability to control and change the structure and function of the brain'. At birth, an infant is endowed with a structure and pre-programmed genes to develop the brain and the infant has the maximum number of neurons, i.e., over a billion cells! Thereafter, neurons are in a state of flux; some dividing to increase the number and others vanishing for

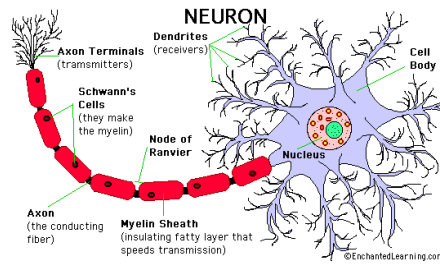


Figure 1. Structure and Interaction of a Neuron Cell (Ref.crystalskullworld.com/Neuron.html.)

some reason or the other! However, the size and mass of the human brain increases with age, without increase in the number of neurons. Increase in size and mass of the brain is due to the ‘functioning’ of the genetic programmes.

‘Functioning’ here refers to numerous branching, i.e., making inter-neuron connections and extensions in the form of protected dendrites and axons. Dendrites and axons are indeed the input and output devices respectively for the neurons. These are like tiny hairy brushes around the cells. The dendrites are assumed to receive signals from other cells whereas axons communicate and send signals to other cells. By virtue of axons, a neuron can send signals to many other neurons located anywhere in the brain, passing the signals over synapses through adjacent cooperating neurons! More the axons interact around them, more powerful they become! Strengthening of connections between cells makes them grow larger; weak linkages may result in loss of cells.

Learning something must be a conscious and focused function of the brain. Learning is a consequence of directed, purposeful thinking, involving the above-said processes in the brain. It is proposed that the brain-body coordination and carefully organized teaching-learning activities involving thinking can enhance learning.

The phenomenon of thinking results in brain activities and restructuring the brain. Brain based learning research (<http://coe.sdsu.edu/eet/articles/brainbased>) suggests that more frequently pathways or patterns of neurons are used, the stronger they become and more likely they will be made again. Simultaneous excitation of multiple pathways and patterns create growth of new neuron connections and enhance potential to learn and to teach how to learn (Kirchhoff, 2006). It supports the widely held concept that multi-sensory learning with say, audio and visual components, is more permanent than single sensory learning (Kumar, 2008).

There are several theories of intelligence; the most widely accepted being the one which constitutes the basis of Intelligence Quotient (IQ) tests. Although several IQ tests have been evolved, all of them appear to correlate well with one another. Intelligence is also significantly correlated with ‘successful training’ and laid down ‘performance outcomes’ and it is the single best predictor of successful job performance (Ree and Earles, 1992).

Howard Gardener’s (1999 and 1983) theory of multiple intelligence developed in 1983 suggests that there are eight different intelligences to account for the broader human potential. These are recognised as linguistic, logical, spatial, body-kinesthetic, musical, interpersonal, intrapersonal and naturalist intelligence. According to him, development of intelligence requires reinforcement of as many as possible from the eight almost simultaneously. This is made possible by using language, numbers, pictures, music, self-reflection, physical experience, social experience and an experience of the natural world!

5. WHICH COMES FIRST: CREATIVITY, INVENTIVENESS AND INNOVATION?

Unlike intelligence, concepts of ‘creativity, innovation and invention’ are generally clubbed together because they are not so simple to define and distinguish. However, a teacher must understand them

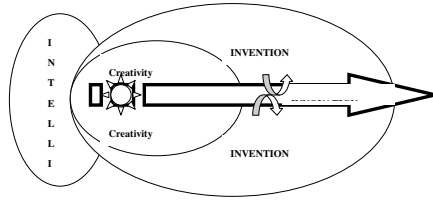


Figure 2. Conceptualization of Creativity Leading to Invention and Innovation.

and their progression well enough to employ such methods of teaching-learning which promote their development

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. Some authors consider creativity as a cognitive process or functioning of a genius, or by divine intervention. Famous examples of creativity are Leonardo Da Vinci's works of art and science fiction which led to several innovations and inventions. The genius of Edison commenced with creativity, i.e., the thought of light through a filament maintained in vacuum but it went much further resulting in both innovation of lighting and invention of the light bulb with far reaching consequences. Creativity has no bounds; once a person is creative, he/she continues to create. This is evidenced by 1093 new patents of creative thoughts filed by Edison. One of them was his installation of a reciprocating water pump which worked, through leverage system, whenever a person came to push the front gate for entry to his house. He managed to fill up his swimming pool by the people coming and going from his house. Recent leaps of creativity, have however, replaced the light bulb with Compact Fluorescent Lamps (CFL), which generate the same illumination with much lower electricity consumption.

Invention is characterized by doing or making something new and useful. It implies that creativity is an important part of invention. As a matter of fact, creativity is the starting point of all invention and innovation. A creative mind may produce a new idea and then proceed to invent, i.e., apply the idea in a specific context, as conceptualized in Figure 2.

The critical question of how to foster creativity, the mother of all inventions and innovations come next. 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:

- 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.

Creative thinking invariably results in the generation of divergent thoughts, e.g., multiplicity of plausible design solutions. For example, the concepts of heating a room may result in a mind map as shown in Figure 3:

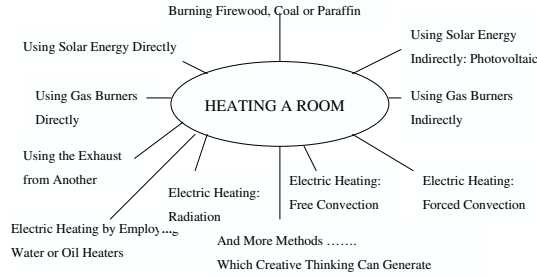


Figure 3. Mind Map for Heating a Room.

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

Invention is said to have occurred if one of the new creative thoughts is put into action. For example, a noiseless free-convection portable and inexpensive solar energy room heater made and demonstrated to be efficient and user-friendly would be an invention.

In Table 1 we describe our understanding of cognition, intelligence, creativity, inventiveness and innovation. With this understanding it becomes easier to structure.

Classroom 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. Let us develop this point a bit further:

In an attempt to teach learners how to design, we must begin by employing their cognitive abilities, i.e., engaging them to perceive things as they are, understand the basic principles and analyse existing objects through identifying paradigms of designing and move to using their intelligence to improve the products and hence develop creative thinking. They should be made to evaluate and engage in critical appreciation of improvements. This process is likely to result in inventive thinking by being able to see new, viable and meaningful relationships. Finally, they should be able to see new socially and culturally meaningful relationships and develop innovative products.

6. SOME DESIGN STUDENT'S INNOVATIVE WORK

Prasant Chandra's "sChOOL Pak" PC caught the eye of Microsoft Chairman and Chief Software Architect Bill Gates who selected it over the nearly 200 other entries. According to Microsoft's Eagan, Gates chose Chandra's sChOOL Pak because he felt it captured a smart trend and pushed thinking about PC design beyond the obvious. Rather than the business-like design of traditional laptops, the sChOOL Pak offers replaceable rubberized shells with hip exterior designs and straps so it could be worn like a backpack. Gates felt Chandra's design helps address multiple important technology issues for Microsoft, including helping people in underserved countries cross the "digital divide". Further it fitted better with cultivating writing and drawing skills. It will also facilitate those with writing impairment. (author's perception).

Vishwas Morgure through his innovation, Plexus, addresses an important issue. How can a wheel chair user commute longer distances and can have a plurality of speeds and maneuverability capabilities. The concept of PLEXUS (wheelchair-transporter) is a solution for those who are in wheelchair and needs some transport and connectivity for the long distances. The concept enables the user to commute longer distances with his wheelchair. The uniqueness of the concept is that the wheelchair itself becomes the driver's seat and one can drive the vehicle while on his wheelchair. The wheel chair like an old man's walking stick is always with him.

7. REFLECTION ON INNOVATION: INVENTION ACCLAIMED

The structure of the word innovation spells out its true meaning

NOVA + OVA + OVATION

Neurobiology research (Heilman, 2005) has demonstrated that 'creative innovation appears to require co-activation and communication between regions of the brain that ordinarily are not strongly connected'. Some evidence of this fact is in the observation of creative people using the frontal lobes of the brain critically. A possible lesson for 'higher order learning' in science and technology is to employ such teaching-learning strategies which result in such a co-activation and communication between those regions of the brain for intelligent people.

A more intelligent person is not necessarily more creative. Intelligence implies seeing the existing relationship. Creativity empowers a person to see further and several possible relationships. Inventiveness implies seeing relationships which are original and have a potential to be advantageous. Innovation implies distinguishing those advantageous relationships that would also be seen as advantageous by a large number of people. This leads to ovation! This is the essential aspect of an invention being recognized as an innovation. Innovation is situated within a cultural context. An intelligent person can become more productive by becoming creative, inventive and innovative and by practicing the same as often as possible.

A fairly large number of observations of 'highly creative people' who excel at creative innovations are that they differ from other intelligent persons in three ways:

- They have firm grasp of subject specific knowledge
- They are naturally used to thinking divergently
- They employ the frontal lobes of the brain visibly

Alice Flaherty (2005) also drew evidence of use of frontal lobes and temporal lobes in creative thinking exercises by brain imaging and drug studies.

A person may remain an intelligent critic and, in time, may reduce to an intelligent observer without ever making headlines in creativity and innovation if the spark of creativity is not introduced in him at an early stage of education.

8. SEARCH FOR THUMB RULES

Now that we have conceived the idea of invention as the generation of something new and useful, let us see how creative skills can be inculcated in human beings. Creativity & inventiveness would have been a common place if some cut-and-dry formulae or thumb rules existed; one would plug in the data to get innovations. Several authors have been proposing that innovation is a step by step process. Jeffrey Govendo (2000) has offered a six-step process for innovation as follows:

- 1 Create a safe haven — physical, virtual or both — for new thinking
- 2 Employ a process for developing new ideas that have been initiated
- 3 Cross pollinate your ideation groups

- 4 Whenever possible, have an accomplished neutral facilitator conduct ideation sessions
- 5 Actively support employees for engaging in the process as well as for the results and benefits
- 6 Conclude every ideation session with a set of action term or recommendations and assurances that they would be followed through.

Another survey (Wikipedia — Innovation)) across a large number of manufacturing and service organizations found and ranked in decreasing order of popularity that systematic programmes of organizational innovation are most frequently driven by the following goals:

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

Skills of inventing have been tried as a part of the curriculum at some universities including the Massachusetts Institute of Technology as propagated by Carmichael and Jansen (Private Communication).

9. CONCLUSION

Intelligence is a nature's endowment to mankind; it enables us to comprehend and analyse complex, concrete and abstract phenomena. Intelligent people do well in studying, remembering, reading and writing. They can be trained to become creative in their search for ideas. Creativity is a necessary a condition for inventiveness and innovations. However, it is not a sufficient condition for innovation to occur. A creative idea put to use and demonstrated to work leads to an invention. An invention that takes the people, system or organization to the next level, perhaps a quantum leap is an innovation. Infusing the spark of creativity in intelligent persons is more likely to result in their becoming more productive. They will become a source of innovations that will transform society. The genius of creativity in scientists may result in better understanding the more comprehensive theories of nature; creativity in engineering and design people will result in paradigm shifts in products, systems services and environment.

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