



Imperatives Cognitive and Affective Skills for Innovative Problem Solving: A Fresh Perspective of

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Some people see things as they are and say why.

I see things that never were and say why not?

- George Bernard Shaw

Abstract

Most educational models that prescribe teaching and training methods to groom school children into innovators fail to take a deeper view of engineering design methodology. Yet others tend to ignore the importance of human values which must be an integral part of any innovative design process. In this paper, We would first disaggregate design capabilities into its constituent capabilities, namely, exploring, creating and converging capabilities, which we need to master to produce better products and services, and then show how the cognitive and affective skills proposed by Benjamin Bloom, and Anderson and Krathwohl in their educational models can directly and significantly contribute to these constituent capabilities. With an improved understanding of the eco-system needed for better design solutions, we suggest that the present education systems, especially in developing countries, be critically reviewed and reoriented from the perspective of producing quality innovative designers, regardless of the problem area.

Key words: innovation; engineering design; education system; problem solving; taxonomy of learning; design capability; cognitive skills; affective skills; exploring capability; creating capability; converging capability.

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1. Introduction

Who is free from irritations that come free with substandard products and services? Perhaps, no one. All that we do is to curse the designer or manufacturer for a moment and soon learn to live a compromised life, if we can't do away with such things. Isn't it common to see a piece of chalk failing to make an impression on black-board, debit card stuck in ATM, an aircraft developing a technical snag, a new cooker-gasket leaking, a computer software hanging, pages coming off a book, paint peeling off walls, unsafe toy, medicine with side-effects, poor education/health service and a million such others. Equally helpless our lives would be, when products or services that solve our problem are yet to be developed. Haven't you yearned for a raincoat or umbrella that remains wet-proof in spite of being drenched in rain so that you can straight fold it into bag? Haven't we cried for a device to rescue a child stuck in a tube well? Is not it good if a spectacle has adjustable focal length? Doesn't a tablet dispenser for aged and illiterates help them to be independent? Can't we design a system which ensures only right persons on right jobs? What about a system that ensures humans are always ethical? Don't we need a mechanism to systematically collect and put to use the bio-wastes generated in marriages and parties? What about cell-phone calls that won't drop or innovative devices that can harvest renewable energy sources? Such products and services when available would make our lives much better. Yes! More often than not, we have craved for newer/better technical solutions to our everyday woes. Thus we see both problems and opportunities

Ask yourselves, why there are yet either no or unsatisfactory solutions to many of our problems? Why aren't we effective in our solution development efforts? Why can't we design better products and services¹? A quick look reveals that there are many links in the process of solution development - identify the users' need, understand it thoroughly, describe its scope, define design requirements, develop and evaluate alternate technical solutions, prepare detailed specifications for the selected one, deploy appropriate resources, use right method to produce and deliver the solution to satisfy the users' needs. The opportunities to produce better solutions slip off our hands not because we are not familiar with this process of developing solutions, but we are not wary of fallacies and weak links that trip us off the right line of attack. Further, we often forget that user should be an indispensable part of this solution development process. With a fair knowledge of the design process, and a concerted effort to acquire the skills to engage in it, one can potentially grow into a successful designer and innovator. It is interesting as well as useful to know if we can create some good ideas to satisfactorily solve problems around us, and convert them into a reality too. If yes, how we need to gear up ourselves? What should be our attitude and approach?

2. Solution Development Process through Engineering Design

Be mindful of the fact that the generation of good solutions requires us to successfully pass through three phases namely, explore, create and converge, in that order. Figure 1 portrays the solution development process and the relationships between these phases. Exploring phase helps to identify the problem, understand its scope and intricacies make initial statement of the need and prepare provisional physical and performance specifications of the product/service being contemplated. Next, in the Creating phase, a large number of alternative ideas are generated. Free-wheeling of mind and working with abstract thoughts are a part of this. Finally, in the Converging phase, these alternative ideas/solutions are systematically evaluated so as to choose the best one which can be further developed to provide a most suitable solution to the problem on hand. We must appreciate the fact that we may need to loop back from a given phase to its previous phases for want of better information/solution. Thus design work is more often iterative in nature.

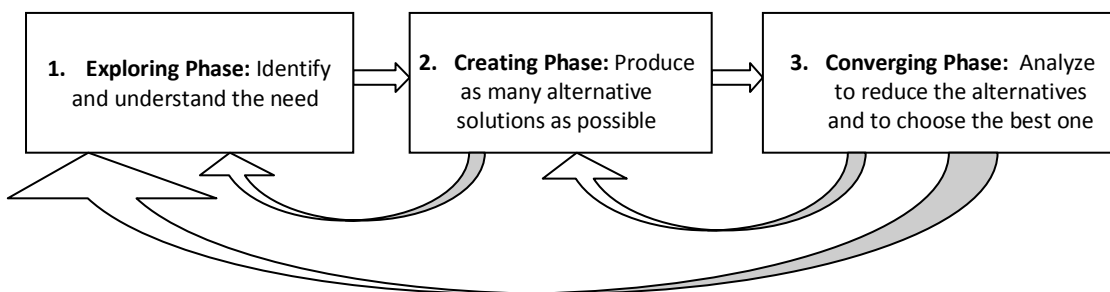


Figure 1. Solution development process

¹ The Accreditation Board for Engineering and Technology (ABET) definition states that engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.



The Engineering design steps involved in each of these phases are shown in figure 2. A brief description of them follows.

- We get to know the need to be addressed either by our own observation or through our client's communication. We start the *exploring phase* by striving to describe and understand the need from various perspectives and make a provisional statement of the need. We become familiar with the nature of the problem and take a look at the existing solutions and their shortcomings. However, we need to take care not to be unduly influenced by the existing design solutions because they may impose premature pattern on our thinking. We analyse the need thoroughly so as to specify the physical and performance requirements of the solution that we propose to develop, and examine the resource requirements to develop the solution.
- In the *creating phase*, we make use of all our knowledge and skills, experience, innovative capabilities, insights and genius to think plausible schemes for achieving the desired results. All the information and other inputs acquired in the previous phase are soaked in our creative juices so as to be able to produce a large number of solution alternatives regardless of their feasibility. A large number of techniques have been devised to help us improve our creative thinking. It is in fact the most exciting and challenging stage of modern solution development/design process.
- In the *converging phase*, we consciously eliminate unworkable and not-so-good solutions generated during the creating phase. A good number of analytical and non-analytical techniques are made use of for examining the feasibility of alternative ideas from different perspectives. A more realistic and promising idea is further developed, and we test if it can meet all our expectations set out in exploring phase. If yes, the detailed design is carried out on that idea so that it can be implemented, else we loop back to appropriate stage for revision. We resolve the sub-problems that might have surfaced, and finally give it a form which best meets our needs.

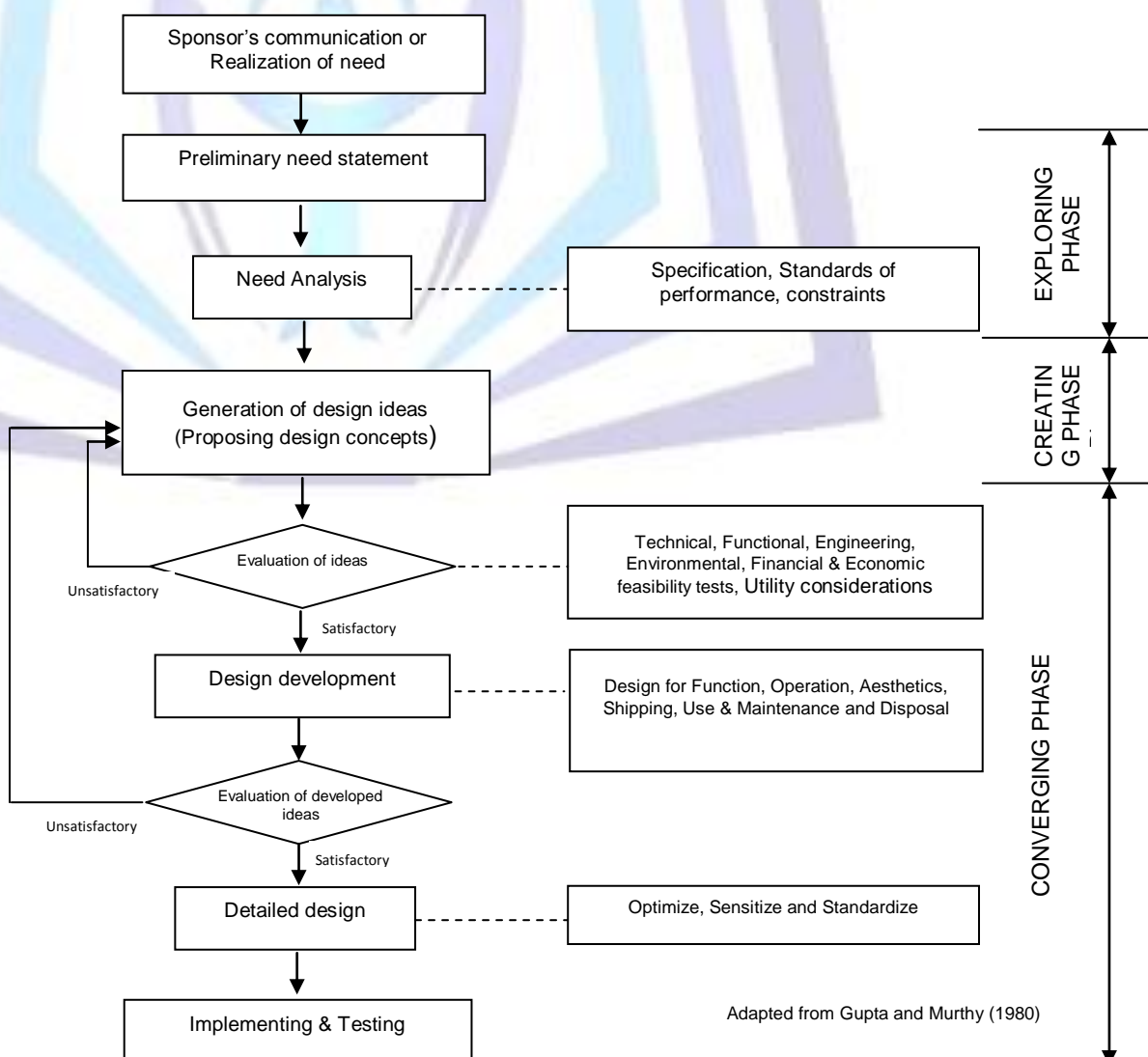


Fig 2. Detailed morphology of



In this solution development/Engineering design process, we may need to loop back to any of the previous stages to modify the idea as necessary to ensure that the final solution is fit for use and fully satisfies the need stated at the beginning. For being good designers of engineering products, services or systems, we need to develop capabilities to successfully pass through these phases. These capabilities can be called as exploring capabilities, creating capabilities, and converging capabilities. Now that we are aware of the abilities that serve as ingredients to innovate a good solution to a given problem, the next question to be answered is how to acquire them.

It is true that systematic engagement in these three phases increases our chances of hitting up on a good solution in a specific problem. However, strong intellect, skill and attitude that we develop especially, during our schooling, equip us with these capabilities with which we can reap much better design yields regardless of the area of problems. Although we can attempt to develop these capabilities at any stage of our life, there is no parallel for their planned and progressive acquisition during schooling because the design capabilities make great demands on conceptual and procedural knowledge which can be well met by appropriate curriculum (Roden, 1997). In fact, teachers, both at school and college should encourage students to appreciate the importance of acquiring such skills and capabilities for them to become better solution providers. In fact, most problem solving tools and techniques such as browsing, quality function deployment, brain storming, mind writing, morphological analysis, simulation, etc. can be very effective when used with a solid foundation of these skills built from childhood.

3. Taxonomy of Learning

Literature has suggested several educational models that aim to either describe (Roden, 1997) or enhance students' design capabilities (Mawson, 2003). However, most of them tend take a superficial view of the design process and fail to disaggregate the specific capabilities that comprise design excellence (Anning, 1997; Thorsteinsson, 2003). Many of them ignore ethics and values that should be an integral part of any design effort (ITEA 2000). In this paper, we will discuss how models of learning suggested by Benjamin Bloom (1956) and Anderson and Krathwohl (2001) can be adopted to enhance our exploring, creating and converging capabilities and groom ourselves to become good at engineering design. The outcome would be more fruitful if the adoption effort start at the early age of our life. These models of learning identify three broad domains in education namely, cognitive domain, affective domain and psychomotor domains. While learning in the cognitive domain is intended to develop intellectual ability (apparently relating to head), in the affective domain it is to shape the way we deal with things emotionally (apparently relating to heart); and in the psycho-motor domain it aims to enhance the physical co-ordination of senses and motor-skill areas (apparently relating to our limbs). Learning in each of these domains is observed to occur at several levels which are arranged in the ascending order of their levels of difficulty-to-master. That is, the first level is the simplest and last is the toughest. The earlier level can be thought of as a prerequisite for learning higher ones.

3.1 Relevant learning domains

As cognitive and affective domains play a key role in enhancing our capabilities to develop innovative solutions (Mourtos, 2011), we will focus on these two in this paper².

3.1.1 Cognitive domain

With respect to cognitive domain, the levels of learning as suggested by Bloom are knowledge, comprehension, application, analysis, synthesis and evaluation, in that order. However, Anderson and Krathwohl (2001) later revised the Bloom's unidimensional cognitive taxonomy into a two dimensional one, first of which described the type of contents (knowledge) to be learned, and the second described the actions (learning processes) concerned with that knowledge. Bloom's 'knowledge' category was actually a blend of *content* (i.e. type of knowledge) aspect and an *action* of remembering that content. The content aspect was structured as Knowledge dimension with its own subcategories namely, factual, conceptual, procedural and meta-cognitive knowledge. This formed the first of two dimensions in the revised taxonomy. The action part was renamed as 'Remember' which constituted the first level of learning on the second dimension (i.e. learning processes), while the remaining levels mapped with those of Bloom's model, but as their verbal equivalents. Further, the highest two levels of learning on this dimension in the Bloom's taxonomy namely 'evaluation' and 'synthesis' are swapped in the revised taxonomy. The revised taxonomy shown in Table 1.1 and 1.2 are adapted from Anderson and Krathwohl, 2001.

The two dimensions result in a matrix with learning objectives/levels ranging from simple recognition and recollection of specific factual knowledge to complex creation of knowledge of appropriate knowledge. These levels correspond to intellectual skills of increasing complexity that one needs to acquire through progressive learning. The objective of higher-end cognitive learning is much more than synthesizing out-of-the-box solutions.

² Cognitive and Affective Domains can adequately address the innovative design environment. Psychomotor Domain apparently deals with the development of skills relating to manual tasks and movement of body members, and hence not considered relevant here.



Table 1.1 Cognitive Domain: The Knowledge Dimension

Specific ↑ ↓ Abstract	Factual	Knowledge of terminology, specific details and elements
	Conceptual	Knowledge of classifications, categories, principles and generalizations, theories, models and structures
	Procedural	Knowledge of specific skills, algorithms, subject-specific techniques and methods, criteria for determining when to use appropriate procedures
	Meta-cognitive	Strategic knowledge, knowledge of cognitive tasks including appropriate contextual and conditional knowledge, self knowledge

Table 1.2 Cognitive Domain: The Learning Process Dimension

Lower order thinking ↑ ↓ Higher order thinking	Remember	Recognizing, Recalling	Identifying, retrieving
	Understand	Interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining	Clarifying, paraphrasing, representing, translating, illustrating, instantiating, categorizing, subsuming, abstracting. Generalizing, concluding, extrapolating Interpolating, predicting, mapping, matching, constructing models
	Apply	Executing, implementing	Carrying out, using
	Analyze	Differentiating, organizing and attributing	Discriminating, distinguishing, focusing, selecting, finding coherence, integrating, outlining, parsing, structuring, deconstructing
	Evaluate	Checking, and Critiquing	Coordinating, detecting, monitoring, testing, judging
	Create ³	Generating, planning and producing	Hypothesizing, designing, constructing

3.1.2 Affective domain

ITEA (2000) remarked ‘To become literate in the design process requires acquiring the cognitive and procedural knowledge needed to create a design, in addition to familiarity with the processes by which a design will be carried out to make a product or system’. We know that an innovative designer and his/her innovative solution both have to succeed in the societal/industrial environment. Hence, we strongly believe that sensitivity to human life has to be an integral part of the design process. This demands the innovative designer to be sensitive to human feelings, apart from being technically competent. The sensitivity is an outcome of our emotional elements such as feelings, values, beliefs, attitude, behavior and motivation, which are typically a matter of interest in the affective domain. Quite often, these elements strongly influence the designer’s perceptions and choice of problem, his approach to solve it, interpretation of findings, and trade-off he does during selecting solution (Clifford, 2007). Inadequate effort by designers to internalize these skills has cost the society dearly. Table 2 lists the levels of skills to be learned in this domain as described by both Bloom’s, and Anderson and Krathwohl’s models. The affective skill categories range from simple skills to receive inputs from the outside world to complex ability to view and act from the internalized value perspectives.

³ Not to be confused with the Creating phase of the solution development process.



Table 2. Levels of learning in affective domain

As suggested by Bloom (1956) and Anderson and Krathwohl (2001)

Sl. No.	Level	Components	Generic explanation
1.	Receiving phenomena	Awareness, willingness to receive, Controlled or selected attention	Be aware of or sensitive to the existence of certain ideas, material, or phenomena; be attentive to changes; listen to others, observe developments, anticipate moves. Examples: to differentiate, to accept, to listen
2.	Responding to phenomena	Acquiescence in responding, willingness to respond, Satisfaction in response	Commit in some small measure to the ideas, materials, or phenomena; involve by actively responding to them; participate in a discussion; make a presentation; intervene to clarify; ask to get clarified; criticize or defend certain views. Examples: to comply with, to follow, to commend, to volunteer, to acclaim.
3.	Valuing	Acceptance of a value, Preference for a value, Commitment	Willing to be perceived by others as valuing certain ideas, materials, or phenomena; believe in democratic process; sensitive to poverty; speak out one's feelings; commit to social justice; work for group interest. Examples: to increase measured proficiency in, to relinquish, to subsidize, to support, to debate.
4.	Organization of Values	Conceptualization of a value, Organization of a value system	To relate the value to those already held and bring it into a harmonious and internally consistent philosophy; be open to learn new things; balance between freedom and responsibility; manage time and other resources between conflicting requirements; accept responsibility for one's behavior; adopt ethical standards; prioritize proposals based on values. Examples: to discuss, to theorize, to formulate, to balance, to examine
5.	Characterization by values/value set	Generalized set, Characterization	To act consistently in accordance with the values he or she has internalized; develop a value system; respect others' values; exercise self-restraint; exhibit consistent and predictable behavior; be objective in approach; work with professional ethics; revise judgement based on new evidence. Examples: to revise, to require, to be rated high in the value, to avoid, to resist, to manage, to resolve

We must appreciate that affective skills intertwine with cognitive skills in our effort to develop best solution. They are not sequential, but concurrent, i.e., they run along the entire solution development/innovation process hand in hand. A very important aspect is that only when skills blended from both these two domains are in full play, an effective solution development is possible.

This paper presents a framework that brings out the correspondence of the three capabilities in the solution development process - exploring, creating and converging capabilities - that we are interested in, with the levels of cognitive and affective learning in Anderson and Krathwohl's model. Figure 3 shows the schematic diagram of the framework. It is important to note here that one needs to progress from lower levels of learning to higher ones to grow as matured designers.

4. Correspondence Between the Three Capabilities and the Levels of Learning

The extent of correspondence and contribution of the levels of learning to innovative design capabilities is delineated below.

4.1 Exploring ability

As potential innovative designers, we are essentially exploring the problem situation with a clear purpose of bringing something new into being to best solve it, i.e., to design and innovate. Naturally, we should be curious and inquisitive both in our thinking and action which call for keen observation of things around us. Ability to question what, how and why of these things, and search, understand and remember the related information is a must to acquire a broader knowledge-base which is the first requirement to be creative and innovative. This strengthens our ability to identify the problem, comprehend and define its nature and scope.

The first two categories of the Anderson & Krathwohl's cognitive domain namely, 'Remembering' and 'Understanding' clearly contribute to this capability. Remembering and understanding the terminology (factual knowledge) used in problem area, the related principles, models and theories (conceptual knowledge), and envisioning the larger system in which the



problem is a part (meta-cognitive) are essential to explore the problem on hand. Recognizing and understanding problem's contextual and conditional information, and knowing problem-specific skills and techniques are important to place the problem in proper perspective. Today's web resources, digital libraries, internet and information and communication technologies have come in very handy to acquire this ability. Learning these two skills helps us to: (i) be aware of the interests of stake holders, (ii) search, remember and understand right kind and quantum of information, (iii) critically examine the current problem solving approaches (procedural knowledge) with their strengths and limitations, and (iv) view the problem in a broader perspective. In other words, we should be able to explain the problem and its environment, frame a preliminary need statement, prepare specifications and standards to be met by the aimed solution, make a good estimate of resources needed, and recognize design constraints, all of which are the key ingredients of successful exploring ability. This ability comes in handy while seeking approval from the sponsor of the project, if any.

Further learning to receive information from external world - without being blind to anything significant - and engage in an interactive communication is a must if one is serious about striking at the right problem. A precise statement of the problem in the exploring phase is possible only when we keep channels of communication with all related stake holders open and active. Willingness to listen to all the stakeholders, empathize with them, cross-check/verify the observations for correctness and completeness, carefully note newer developments, and appreciate different points of view is the key to gather accurate information on the problem, provisionally set the specifications and standards of performance for plausible solutions. This is what the first level of Anderson & Krathwohl's affective domain namely 'receiving phenomena' intends to contribute to. Constrained/biased effort limits the quantity, quality and timeliness of information collected and may eventually lead to poorer decision decisions. The information acquisition skill goes a long way when we to consult experts, lead users, stake holders, libraries and other sources of information to know more about problem environment, opportunities to deal with it, and environmental and resource constraints. This ability to open up oneself to allow all pertinent information to flow in is a hall mark of exploring phase.

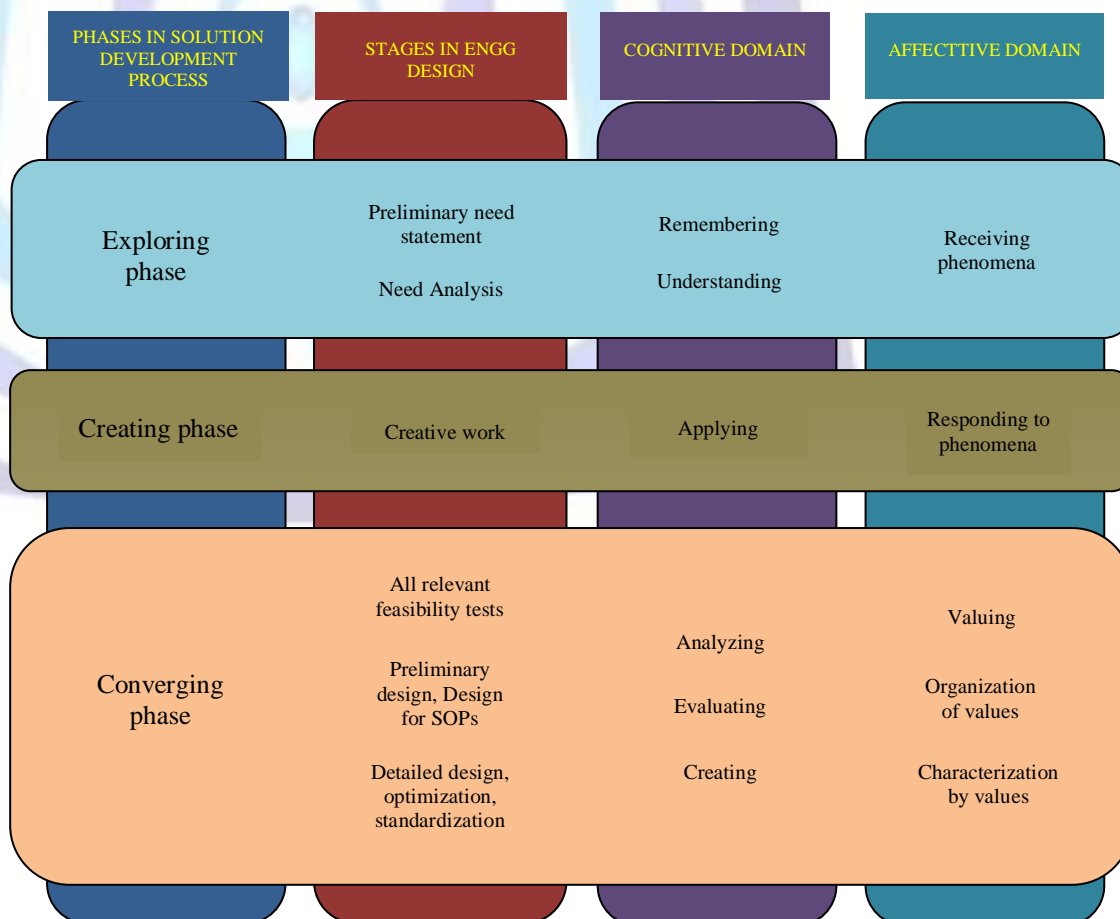


Fig. 3. Framework relating the solution development capabilities and the Stages in engineering design with the Domains of learning

An education eco-system that encourages us to be inquisitive, open to all channels of communication from the external world, and unbiased in perception and internalization of problem specifics, and enables us to acquire, understand and remember adequate amount of problem-related knowledge is a must to build our exploring capability. Unfortunately, in India, most of our class room teaching (often, at all levels of education) and evaluation struggle to go beyond imparting explorative abilities. Our education system seems to be oriented towards teaching a lot of 'what', less of 'how', and least of



'why' of anything. Thus questions even in secondary or tertiary examinations often begin with verbs such as explain, discuss, describe, state, compare, etc. They mostly test the ability of the student to recall the memorized stuff. This bears testimony to why our children are short of creative and analytical skills. Anyway, for us to be innovative designers, this ability is very much necessary but not at all sufficient. We have to use this ability in conjunction with the creative and converging abilities.

4.2 Creative ability

Having explored the problem environment with intense motivation, made a provisional statement of our need, soaked our mind fully with problem-related information, and examined the currently available solutions with their pluses and minuses, it is time for our creative ability to come into play so as to churn out as many plausible alternative solutions to the problem as possible. Believe it! All of us are creative to varying extents and a huge scope exists to improve this ability. Generating alternative solutions requires the creativity of individuals/teams to be fully unleashed. Lot of parallel thinking, also called lateral thinking, is to be done. The major hurdle for us to be creative is mental rut, which means that our mind keeps shuttling among only known and commonplace ideas/solutions, when a radically new one is desired. Our positive attitude, motivation, perseverance and a bit of knowledge of how our mind engages in creative process help us in overcoming this impediment. We can also use many techniques such as brain storming, brain writing, synectics, morphological analysis, attribute listing, SCAMMPERR, lateral thinking, etc. to improve the flow of creative juices in our brain. This would help us break the pre-set mental patterns and self-imposed restrictions. They free up our mind to make unusual connections among pieces of knowledge from various subject areas. Anderson and Krathwohl's skills to 'Apply' are intended to enable the prospective designer to see the problem from very different and hitherto unexplored perspectives, apply the technical (factual and conceptual), procedural, and intellectual/meta-cognitive knowledge gained at various levels of education, and produce a large number of ideas without much concern about their feasibility, as judging their feasibility is a matter of interest only in the converging phase. Thus mastering application skills would enable us to imaginatively utilize the knowledge drawn from a variety of domains (at times seemingly unrelated), to churn out novel ideas to tackle the problem. While abstract thinking is at the core of this phase, systematic documentation and categorizing of ideas generated often throw light on the hidden structure of the problem itself.

Normally, application of our knowledge, i.e., our response, to a given problem situation is greatly influenced by our perceptions, beliefs, values, attitude and past experiences. These can constrain or unleash our creativity. When we allow them to impose restrictions on our thought process, it would result in a very limited space to search for solution. Our mind keeps shuttling between the known and commonplace ideas in this limited space, when we are desperate for a radically new idea. In other words, we get into a mental rut, unable to break away from this fixity. Novel and unusual ideas don't pop up at all. However, we can both enlarge the solution space as well as increase the probability of hitting upon a good solution there, through building our 'skills to respond' to the problem environment, by training ourselves to have an open and unbiased mind with no self-imposed restrictions, helping ourselves to develop positive and creative attitude, and experimenting with unusual thinking, and practicing creativity improvement techniques. Anderson and Krathwohl's second level 'learning to Respond' transforms us into a *free, flexible, unbiased and persevering individuals who can create unique ideas*. These skills determine the quantity and quality of the solutions we generate. Nevertheless, the skills to receive and respond remain crucial throughout the process of solution development and implementation.

Is our education system nurturing creativity among students? How much of teaching and evaluation are designed to achieve this? Do we engage children in practical problems, encourage them to interact in class, cultivate creative attitude in them, credit them for creative thoughts and work? Has our one-way teaching, and half-yearly or year-end examination system succeeded in making children to think abstract, free-wheel their mind, churn wild and crude ideas, refine them, combine or build on each others' ideas, accept and respect unusual thinking? We know the answers well. An education system inclined to highly structured thinking, undisciplinary approach, and premature judgement on the practicality/goodness of ideas is set to create obstacles to children's creativity. Further, the fear of ridicule is so widely prevalent in our society that a majority of us hesitate to think, let alone act, in unusual ways, which is why radically new ideas are rare to come by. Anyway, once we have a lot of ideas, generated by individual or group effort, we need to ascertain their feasibility from the required perspectives and shortlist only a few most promising ones for implementation. This ability to converge from a large number of plausible ideas to one or a few most acceptable is discussed below.

4.3 Converging ability

The output of the creating stage is a pool of sketchy ideas/concepts which are to be screened. All of them may not be equally feasible to be developed into an effective solution. Only those few solutions that are technically realizable, economically feasible, financially viable, environmentally compatible and safe deserve to be further developed. Evaluating ideas from these perspectives needs a considerable amount scientific, technical and engineering knowledge (concepts and relationship between them, modeling, resource requirement and availability, project management, economics, etc.) as well as analytical, computational and simulation skills (knowledge of solution procedures, their assumptions and limitations, etc.). The objectives of the three levels of learning namely, 'Analysis', 'Evaluate' and 'Create (i.e., synthesizing best solutions)' in Anderson and Krathwohl's model are to impart exactly these knowledge and skills in us. We are expected to acquire these skills happen mostly during our secondary and tertiary levels of education. This ability will enable us to sieve out impractical ideas and converge to one adjudged as the most promising solution. Evaluating and synthesizing best features of many solutions into one, integrating various points of views of stakeholders are the characteristic features of this stage. This handpicked solution needs complete development from the points of view of function, performance, handling, use, confidentiality, safety, security, transport and maintenance as applicable. Alternative



materials and implementation methods are evaluated. Ease with which it can be produced, assembled, implemented, installed, networked, or disposed is also kept in mind.

Once development is complete, a detailed design of the solution is to be worked out where physical, engineering and performance specifications are finalized. The processes of production, assembly, networking, etc. are to be chosen. The optimized design is produced and tested for performance parameters specified during the exploratory stage. The solution's sensitivity to the variation in the inputs, operating procedure, and environment are examined. Mathematical techniques such as calculus, mathematical programming, probability and statistics, optimization methods, simulation, etc. would prove very helpful here. Of course, one needs to know what technique to use, when, and also their assumptions and limitations. The choice of right technique for analyzing alternative solutions, the right method of its application, and correct interpretation of results and hence choice of right solution to the problem all depend on the robust analytical skills, and evaluation and synthesizing capabilities learned at higher levels of the Anderson and Krathwohl's taxonomy. Above all one should also be able to analyze the impact of the solution on its operating environment and justify its acceptance.

Choice of a solution exclusively based on analytical results can be a disaster if justice and human values are ignored. Choice shouldn't depend only on analytical skills, but on ethical concerns too. Believing in something socially acceptable and morally correct ensures value-based right from the statement of the problem through creative thinking to the choice of best solution and its implementation. This valuing ability gets strengthened with active interaction with the external world. However, we encounter a number of situations of conflicting value ideals in our design and development work, especially while evaluating alternative solutions available in the enlarged solution space and choosing one as the best. We should develop an ability to prioritize values so that the conflict could be resolved. Coaching the prospective designers to believe in democratic principles, ethical standards and social justice, helping them develop sensitivity to others' feelings, and enlightening them on the balancing act between conflicting interests will enable them to judiciously hand-pick solutions for further development. This is exactly what the Anderson and Krathwohl's higher order affective skills namely, valuing, organizing the value system within oneself, evaluating the external event and activities based the internalized value system are intending to achieve. Learning to balance between conflicting resources, interests and values is the key for her/his design solutions to be socially widely acceptable. Experience over time should help us to mature with broader outlooks, self-restraint, consistent judgement and above all, a solid value system. It is needless to stress that any amount of cognitive skills will be meaningless if not ingrained with affective skills, and that skills in cognitive domain will be effective only in the presence of skills in affective domain.

The cognitive and affective skills required for converging, and the process of learning them are quite complex and intensive. They are thus regarded as higher order capabilities needed of an innovative designer. Nevertheless, the successful innovation of the modern days cannot even be imagined without them.

Most agree that education in India, at all levels, focuses relatively more on mathematical and scientific tools and techniques, but often, with sparse knowledge of their real life application. When Mathematics and Science are learned as one more subject rather than as a means of understanding, representing explaining and predicting the real-world phenomena, problems or solutions, it is no surprise if one forgets Mathematics and Science after having passed the examinations. Relating mathematical and scientific techniques to real life through their practical application is very important to infuse confidence in students to deal with modern day systems. Further, value-based exploration, creation and convergence capabilities are the need of the day for sustainable and inclusive growth of the economy. Developing in us the attitude to continuously improve the systems we have lived with or create a radically new one we want to live in, is very important. Most developed countries, for quite some time, have adopted education systems (from primary to tertiary) that are highly interactive, practice oriented, self-learning and outcome based. Some have found it useful to provide pre-engineering orientation to higher secondary students (Douglas, *et al*, 2004). Of late, National Board of Accreditation, New Delhi, has embarked up on insisting such an education system in engineering colleges in India. It is a tall order to achieve this unless the primary and secondary education is revamped to adopt the learning hierarchy models discussed above.

5. Conclusion

Most of the problem situations we started off this paper with are a result of our weak solution development capabilities which are of course due to our inadequate cognitive and affective skills. The above discussion attempted to show how the key capabilities needed of an innovative designer feed on the various levels of learning prescribed by Anderson and Krathwohl's cognitive and affective domains. We have seen how the various skills suggested in these domains map with the development of design capability in an individual. Hence, to be a good designer, innovator or solution provider, one has to learn these skills in the suggested order and use them appropriately along the solution development process. Learning to harmonize the application of cognitive with affective or human skills in a problem situation can elevate an amateur designer into a professional one. Working to acquire these capabilities can help us enjoy the challenging journey of an innovative designer, and enable us to pitch in our novel ideas to solve societal and industrial problems.

While the prime purpose of this paper was to bring out the correspondence between capabilities to solve engineering design and the learning schema, its intention is also to draw the attention of primary and secondary school educationists to heed to the issues raised in the paper while designing and delivering the school curriculum and evaluating the students. An education system that progressively, from the primary education itself, trains children in cognitive and affective skills - level by level - can build in them capabilities to explore, create and converge so as to innovatively and satisfactorily solve any kind of problem, be it technical or social or socio-technical in nature. Supporting material to aid these efforts are widely available (Pohl, 2000). It is important that teachers make their students appreciate why they study what they study, how those courses can together make them complete innovative designers and how their educational training enables them to



provide solutions irrespective of the problem area. Only then we can expect to enjoy better products, systems and services.

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