Some Philosophical and Psychological Aspects of Engineering Problem Solving

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ABSTRACT: *This paper contains comments about influence of philosophical and psychological knowledge on effectiveness of engineering problem solving. To illustrate those views, two examples are discussed. One describes advantages and dangers of psychological inertia in general engineering problem solving using BTIPS (Brief Theory of Inventive Problem Solving) and IM (Invention Machine) software [1]. Another concerns design of nano – machines and nano-mechanism [2]. It is presented with two goals in mind. First - in order to promote discussion and a deeper understanding of humanistic education of an engineer and cast some light on these "psychological and philosophical" design factors. Second - to call attention of educators and design engineers to problems of understanding psychological and philosophical influence on engineering design, usefulness and limitations of some methods as well as procedures in the engineering problem solving and conceptual design.*

1 INTRODUCTION

The importance of humanities in engineering education is widely known. All engineering schools are choosing the areas of humanities and recommending courses for engineering students. However what humanities would be useful for those students depend mostly on the area of engineering they are studying and intend to practice. The process of engineering creativity is not very much different in its nature than the creativity of a writer, painter, musician, or scientist. The success in generating engineering ideas depends on many factors. Some of these are psychological in nature. Others depend on knowledge of science and experience. An engineering design has two sides: a design science and a design talent.

A good designer prepares himself/herself for the design task by studying science. But he/she should also care about the other side of design ability, the talent side. It can be also developed by influence of environment, of other people, and of events and circumstances. A successful engineering designer who cares about his emotional design abilities, never neglects such factors as influence of environment, influence of other people, external impressions like passion for music, sight of landscape etc. E.D. Hutchingson in the Cambridge Psychological Laboratory [3] sent out a Questionnaire on Creative Effort. Among the responders were Adous Haxley, Arnold Bennett, Sheilla Keye-Smith, William Somerset Maughmam, Bertrand Russel and others. Most of the people were creators of humanities, literature, paintings and philosophy. It is amazing how their creative thinking and creative procedure was similar to those of engineering designers. But there is one advantage of the engineering creator over the other works. The engineer can build a prototype of his product and check it in a competition with other products created to achieve the same requirements and specifications. In order to make this check truly valid, it has to be done under the very same conditions for all the competing products. In such a study it is important that not too many factors can be checked at once. It is best if the study, can focus on one factor and eliminate other influences. In the described study, there were many problems observed, however this paper focuses in the system approach and degree of systems separation as factors of conceptual design.

In this paper, two examples of helpful usefulness of very basic knowledge of psychology and philosophy and some of their terms in the engineering design problem solving are discussed.

2 PROBLEM SOLVING

What is BTIPS?

The Brief Theory of Inventive Problem Solving, is based on the work that originated in Russia in 1944 and was called TRIZ. Its developer, Henry Altshuller [4] worked for many years in a patent office library. About a million patent descriptions went through his hands. He discovered that in those patents, there were only about 200 - 400 that were really original - opening new ways, bringing new qualities to technology. He discovered that many patents were developed following certain patterns, standards of thinking that he called Inventive Standards. He also noticed that following some principles of inventive thinking avoids generating useless solutions and approaches the desirable solution faster. These principles are called Invention Principles. The Invention Machine research team worked on it in the US and in Minsk and called it TIPS (Theory of Inventive Problem Solving [5]). At the University of Connecticut in the works of the author of this paper it was slightly changed, abbreviated and called BTIPS.

The Basic Concept of Inventive Design

Upon saying the word design, one understands a process leading to the description of a product to be manufactured. One can design the path pattern in a garden or sit down with a builder and design a new house using the catalog of solutions. These are designs, but not inventive designs that means not bringing anything new into existence. In these designs there are no conflicts to resolve. For example if there are no big cracks across the garden or the house is not located in the middle of swamps there are no conflicts to solve in the design of garden paths and there are no inventive situations. However, if we attempt to design a safe house in earthquake fault line or on eroding slopes of high a bank of a river, then there are many conflicts and plenty of room for inventive design.

Inventive design takes place in the case where there are strong conflicts that the designer has to resolve. For example, to design a friendly tailor needle, we have to solve the needle's eye conflict. The needle’s eye should be small enough to insure comfortable sewing and big enough to put the thread through. So the conflict is: the needle's eye should be small and big. This is a paradox, but analyzed in time the conflict can be solved.

Designing a foundation pile, one has to make it sharp when driving into the ground and dull after it is in position, so it can strongly support the foundation. So the conflict is: the pile should be sharp and dull.

Problem Definition and Basic Contradiction

A proper problem definition is the most important for successful design idea generation. In this definition the main conflicting property of designed system should be described as antonyms: stationary and moving, big and small, open and closed, deep and shallow, fast and slow, far and near, etc. Such property is called the basic contradiction. Solving the basic contradiction may lead to the satisfactory solution of the entire design task. At first such contradiction seems insoluble however it is amazing that in many cases there are possible ways to solve it. There are two steps in solving contradictions: first the rule of separation, second: use of three main BTIPS [1] and TIPS [5] resources (i.e. Invention Standards, Invention Principles and Scientific Effects). The separation rule says that in most cases contradiction phenomena can be separated in time or space or they are associated with changing fields, i.e. external influences. The same object may have different characteristics in different time, different location, under different pressure or in different temperature. The Basic Contradiction is a philosophical term and without knowledge of philosophy it is not easy to understand.

Preliminary Solution

It is a first solution that is generate using knowledge of the designer. It can be generated by psychological methods using Brain Storming based on Osborn’s proposal which takes its concepts from the works of Sigmund Freud [6].

Preliminary Solution should be chosen in such a way that it should solve the main problem to be solved. In most cases however, it solves the main problem, but creates other secondary problems. Solving the other problems may lead to the satisfactory solution of the entire design task.

Ideal Solution

The concept of an Ideal Solution could seem at first to be the irrational concept of a dreamer. However, it is incredible that it often turns into reality. For example, in the case of the needle, our parents were dreaming about a “friendly” needle that has a large eye when threading a small one when sewing. The discovery of new materials has made it possible and now we can construct such a needle using material when it enlarges considerably when brought close to light and shrinks when taken away. Similarly, in case of the foundation pile, one can construct such a pile whose sharp tip will deteriorate and turn dull after the pile is in place. The deterioration can be done by a proper construction of the pile before driving it into the ground and causing its change when it is in the place or by designing such a tip that can only withstand a certain amount of driving distance and will deteriorate after driven into certain depth [1], [5].

There is no limitation in choosing ideal solution in the thinking process. This is recommended to go as far as the designer's imagination can take him/her. The limitation will be realized during the design process when one will try to reach the ideal solution as close as possible. The limitations will be imposed by the real world, i.e., by limited accessibility of materials energy and knowledge eof physical phenomena, that is by the limits of technological development. Since technology is developing rapidly, it is recommended to check perhaps that it can already accommodate the solution within ideas of some dreamers. Ideal Solution may be developed from Preliminary Solution using BTIPS/TIPS tools, as for example principles (Table 1).

Table 1. Inventive Principles that Could Lead to the Solution of Standard Features Conflicts

Principle of:	
01. Segmentation	21. ≅ Skip≅ principle
02. Takeout	22. ABlessing in Disguise≅
03. Local Quality	23. Feedback
04. Asymmetry	24. Intermediary
05. Merging	25. Self-Service
06. Universality	26. Copying
07. ANested Doll≅	27. AService Life≅
08. Anti-Weight	28. Change of Mechanical Design
09. Preliminary Anti-Action	29. Use of Pneum. & Hydraul. Construction
10. Preliminary Action	30. Use of Flexible Shells & Thin Films
11. Early Cushioning	31. Use of Porous Materials
12. Equipotentiality	32. Change of Color
13. "The other Way Around"	33. Homogeneity
14. Spheroidality	34. Discarding & Recovery of Parts
15. Variability (Dynamism)	35. Change of Object's Physical or/and Chem. Paramet.
16. Partial or Excessive Action	36. Use of Phase Transition
17. Transition to Another Dimension	37. Use of Thermal Expansion
18. Use of Mechanical Vibration	38. Use of Strong Oxidants
19. Periodic Action	39. Use of Inert Atmosphere
20. Continuity of Useful Action	40. Use of Composite Materials
	41. Principle of miniaturization

One can see from Table1that understanding the meaning of some principles with the knowledge of humanities would be easier than without such knowledge.

Designed System

The Elements

Establishing a hierarchy of super-system, systems, subsystems in a clear way is a significant step in the process of solving contradictions.

Relations and Interactions

The precise definition of relations between the upper-system, the designed system, the subsystems as well as the objects is necessary to solve successfully the basic contradiction. They should be described as simply as possible. The systems' interaction can have three forms. The systems can be "hostile" or "friendly" towards each other or they can be "indifferent". Two systems of the same or different levels if not indifferent, can have reinforced positive and reduced negative actions. This may be the way of solving contradiction.

The Degree of Isolation

When one designs a house one may also design a garden around it with trees and, lawns and a pond. However if in designing a single house one also tries to design an entire neighborhood with roads, and communal installations, it would be to large scope of design, and except for some rare and unusual cases, a single house designer wouldn't be interested in it. The designed system should not include too large a portion of an environment. It should be properly imaginary extracted from its surrounding. This boundary should be chosen by designer and drawn in such a way that it serves properly the design purpose. In designing a window in a car door it is enough to take into consideration the door only. However if the design includes the door with its locks and suspending hinges, considering the parts of the chassis adjusting to the door from both sides is necessary. The art of determining the boundaries around the design system is called isolating the system from environment. The description of "how much" the system is isolated, is called the degrees of isolation of the designed system.

The degree of isolation has to be right. If it includes too large a number of systems and subsystems, the solution generation is complicated and doesn't see the design goals clearly. If the design system is too isolated, one might not have enough resources to develop the sought solution. TIPS gives guidance but doesn't formulate explicit rules on how large the degree of isolation can be chosen and leaves it up to the designer. In order to isolate the system properly, one has to realize how it is built, what its components are, what their functions are, what resources they provide, how they are related among themselves, and what their relations to super-systems and subsystems are.

Such concepts as Basic Contradiction, Ideal Solution, Degree of Isolation and other used in BTIPS (TIPS) have philosophical meaning and very basic knowledge of philosophy helps to understand them.

3 SOME PROBLEMS OF NANOTECHNOLOGY

Designing and Building Nanomachines

Design and Building a machine no larger than a speck of dust might seem an impossible task; however, closer examination reveals that evolution solved such problems a very long time ago. Living cells that contain all sorts of nano-scale gear trains, bearings, power screws, and other kinds of simple machines and motors made of proteins perform multitudinous mechanical and chemical functions. Primitive nano-motors and nano-robots with working silicon fingers 1/50 as thick as a human hair appear to perform some nano-scale operations. But what do those machines look like? How do they operate? Can their general functional rules be ascertained? How should they be designed, and how should the design for manufacturing look? What would be the process of manufacturing? These are not only engineering questions.

<u>Mega, Macro, Micro and Nano worlds</u>

In everyday life we live in macro world, and we usually don't think about all the objects that can be seen but they are distant or those that can't be seen with bare eyes because they are so small. But we are aware of other sizes like, micro, nano and mega. The micro world we can hardly see with bare eyes, so we use optical instruments to see the details. Our eyes can't see the nano world. Electron microscopes bring us closer to this world by 7,000,000 – 9,000,000 magnification however it still leaves us a factor of 1000 from the nano world.

In a similar way, optical and radio telescopes bring us closer to the mega world. So we live in macro, but going smaller we can reach micro and nano, going bigger we approach mega. Together with these directions either down or up, our way of thinking changes. We agreed that the quantity of units either multiplied or divided by 1,000 brings us to new quality. Obeying Hegels dialectics [8] the macro divided by 1000 brings us to micro, divided two times by 1000 brings us to nano. Multiplied by 1000 brings us to mega. With these qualities, new qualities come. In micro world, mass forces don't have such significant influence on structural behavior like in macro world. In engineering, we discovered it studying fatigue for example. There is difference in fatigue resistance of big and small structure (Deutschman A.D. et al., Machine Design, Theory and Practice, Macmillan Publishing Co., 1975, p. 110).

Einstein [9] discovered different qualities in mega world. (Relativity. The Special and General Theory. The Historical Society of Princeton, 1995 (http://www.princeton.com/histsocl). Behavior of mass in high speeds is different from this described by Newton (Principia Mechanica, [10]). Are we going to discover general laws governing nano world behavior. What are speeds in nano world? What is the significance of mass?

All these will have essential meaning in engineering, which is an application of physics, mathematics and chemistry to very practical purposes of making our lives easier and more comfortable. So it will have a significant influence on engineering designs of nano-systems, knowledge of which we have to start to build right now in order not to be “caught in the dark” later when this will be a “life or death” matter.

Visualization of Nano Machines

The point is here how one can visualize the machines needed to do such a job; little tractors with sticky wheels, connection struts and cables to other machines. Actually, most of this can be done today; only on a much larger scale and at great expense (this is where the novel economics of self-replicating machines plugs in). The transition for an engineer is using more machines with much smaller parts and the luxury of vast computing power. These differences yield vastly more utility.

How nano machines could be described?

Presently, nano-machines cannot be “thought of” nor pictured without the aid of computers, but is there a possibility of setting helpful rules for design of nano-machines?

The term nano-machines was used with the intention of their developers to show parallels which would allow the public to imagine the tiny structures and understand their performance in a simplified way. Nano-machines designed to be built of polymer molecules would appear different from those designed to be built of other materials. So the catalogs would give different data and provide different sample images for different materials and different rules.

Computer-Aided Design of Nano machines?

Rules, programs, and computers would allow the designers to combine the elements of simple machines into complicated sets. Those sets could then be analyzed, optimized for the desired performance, drawn to show their images, and described in the manner production would require. In other words, could CAD assist in designing nano-machines in the same analogous way the macro- and micro-machines are designed? Would it be possible to develop catalogs of simple nano-machines that would contain data for design of sets, trains, and complicated systems?

As one can see from the above to understand the terminology of nano world and location of this world in our reality without basic knowledge of philosophy is very difficult almost impossible. Especially determining the boundary between macro, micro, and nano worlds are almost directly built on philosophical concepts.

4 CONCLUSION

As one can notice the creativity in conceptual design problem solving is based on several fundamental concepts that are not always from the engineering world. Knowledge of psychology can help to understand that human subconscious could generate useful engineering solutions. It can also help to avoid psychological inertia in getting preliminary solution using BTIPS. Those concepts lead us into the world that is not understandable without at least very general knowledge of psychology. So the conclusion can be derived that a general knowledge of psychology is very useful in engineering design and certainly taking psychology courses should be recommended to engineering design students.

The new concepts of nanotechnology are simply impossible to understand without knowledge of philosophy accompanied by the strong knowledge of fundamental mathematics and physics. Hegel’s law of changing quantity into quality can help to understand why passing from deka into mega and giga world we have to obey quite different laws of physics. For example the speed of light has essential meaning in those cases. In the same way going from deka into nano world we no longer pay so much attention to speed and adhesive forces between atoms are essential in that case. So next conclusion can be derived that a general knowledge of philosophy is very useful in engineering design and certainly taking philosophy courses should be recommended to engineering design students.

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REFERENCES

[1] BZYMEK, Z. M., 2000, *Conceptual product Design Using BTIPS*, DE-Vol.109, recent Advances in Design for Manufacturing (DFM), ASME 2000.

[2] BZYMEK, Z.M., JORDAN E., 2001, *Some problems of Design for Nanotechnology* , Recent Advances in Design for Manufacturing (DFM), ASME 2001, (in press), New York.
[3] HUTCHINGSON, E. D., 1949, *How To Think Creatively*, Abingdon-Cokesbury Press, New York.
[4] ALTSHULLER, G.S. , 1987, *Creativity as an Exact Science: Theory of the Solution of Inventive Problems*, Gordon and Breach Publishers Inc., New York, 2nd Edit.
[5] TSOURIKOV, V. M. , 1994*, i M Course Notes, Invention Machine* , Cambridge, Mass.
[6] OSBORN, FAINCKEY, A., 1963, *Applied Imagination. Principles and Procedures of Creative Problem-Solving*, Third Revised Edition, Charles Scribner=s Sons, New York.
[7] HEGEL, G.W.F., *Elements of the Philosophy of Right*, edited by Allen W. Wood, translated by H.B. Nisbet, Cambridge University Press, 1991.
[8] EINSTEIN, A., *Relativity: The Special and General Theory*, The Historical Society of Princeton, 1995 (http://www.Princeton.com/histsocl).
[9] NEWTON, I., *Mathematical Principles of Natural Philosophy*, translated into English by Robert Thorp, 1969, Dawson of Pall Mall, London.