AC 2009-2234: ENGINEERING DESIGN EDUCATION FOR INTEGRATED PRODUCT REALIZATION

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Engineering Design Education for Integrated Product Realization

Abstract

The term product realization has been used by engineers for the more than a decade to describe the outcome of production processes. While the use of the term, with this meaning, has been widely spread among engineers and researchers there has not been an in depth study for the relationship between realization and design. Considering that the term product realization means bringing a product to reality, which is the core of the full engineering process starting with design and development, there is a need to study how design education will be shaped if it was conducted as an integrated part of the product realization process. In this paper the realization process with its relation to design and design education is examined. The paper discusses the different domains of realization and their interactions. It also addresses the relationship between design, problem solving and research in the context of realization. The insights gained, from understanding design as a realization process, can guide engineering education in fostering creativity and identifying the required elements such as modeling and simulation. To illustrate the concepts, presented in the paper, several examples are included.

Introduction

Since the beginning of their life on earth humans have developed processes and Products, to utilize the physical world resources, for their own survival. As their understanding or realization of the physical world and themselves improved so did the processes and products they developed. It is the observation and learning, or in other words the enhanced realization, provided by the interaction with the physical reality that provided and still provide humans with great insights to develop their own processes and products. As a matter of fact humans have become very successful not only in creating their own processes and products but also in altering some the physical world's processes and products as well.

When interacting with the physical world humans have used their own perception of it as their own reality. Each individual has his or her own perception of this reality. In order to understand physical reality and collectively share their perception of it humans have introduced a third domain known as the virtual world. It is a domain where perceptions, hypotheses, observations, imaginations etc are shared. It takes the form of simple arithmetic, to complicated mathematics, movies, novels, drawings, internet, digital and computational worlds etc. In the following the human interaction with these realities will be examined as it relates to design education.

Theory of Realization

The term product realization, which means bringing a product to being in physical reality, has been used by engineers for the more than a decade to describe the outcome of production or manufacturing processes. While the use of the term, with this meaning, has been widely spread among engineers and researchers there has not been an in depth study for the relationship between realization and design. By using the word realization, in product realization, to mean

being in physical reality through production the contribution of design and its relation to realization is usually lost. To understand this relationship in depth, however, it is important to understand what the term realization actually means. Webster's Dictionary describes some of the use of the verb to realize as [1]: to make real; to convert from the imaginary or fictitious into the actual; to bring into concrete existence; to accomplish; as, to realize a scheme or project. Another source [2], reflecting the current use of word, defines realization as the act of realizing which is:

1. An act of figuring out or becoming aware.
2. The act of making real.
3. The result of an artistic effort.

Considering these definitions and to encompass all uses, it can be concluded that the act of realizing means interacting with reality and realization is the interaction to:

1. Understand reality
2. Utilize reality
3. Alter reality

In other words, realization is the interaction with reality to figure it out, utilize it to achieve desired results, and alter it by deleting or bringing new objects or to it. It is also clear from the previous definitions that reality includes other dimensions or domains that go beyond what is physical. Among these dimensions we consider three forms or domains of reality:

1. *Physical reality*: represented by the physical universe we live in and can realize with our senses such as seeing, hearing, touching, smelling, and tasting.
2. *Perceptual reality*: represented by our individual paradigms or the internal image of other realities.
3. Virtual reality: represented by modeling and simulation of physical, perceptual, and other realities.

It is important in this context to realize (be aware) that perceptual reality is unique for each individual. While it may be subjective, for each individual perception is reality. At any level of interaction more objectivity can be achieved by making the distinction between the different domains of reality. Examining all three realities it could be postulated that the perceptual is the domain where the individual realization is being formulated (developed and validated) and the virtual domain is the domain where collectively shared realization is being formulated and the physical domain is the domain where physical realization is being actualized. In all three domains of reality the interacting elements or objects are specified by:

- Forms (shapes and substances)
- Functions (purpose and performance)
- Interactions (actions and reaction) with other object through fields of activities (interaction fields).

The fundamental interaction between reality domains is through mapping. The main two elements for mapping are modeling and simulation.

A model: is a representation, or description created to show the structure or workings of an object. Depending on the reality domain a model is:

- A physical representation of an object (physical domain)
- A person's cognitive representation of an object (perceptual domain)
- An abstraction using mathematical language or computer programming to represent an object (virtual Domain)

A simulation: is an imitation of an object performance or interaction. The act of simulating an object generally entails representing certain key characteristics or behaviors. Simulation can be used to show the eventual real effects of alternative conditions and interaction. Simulation is used in many contexts of all three reality domains:

- Simulation of natural systems or human systems in order to gain insight into their functioning (physical domain)
- Simulation of roles for actors (perceptual domain)
- Simulation of virtual models for performance characterization and optimization (virtual domain)

Key issues in mapping through modeling and simulation between domains are:

- Acquisition of valid information about the object
- Selection of key characteristics and behaviors
- Use of simplifying approximations and assumptions
- Fidelity and validity of the modeling and simulation outcomes.

The skills (processes) to construct objects in different realities using modeling and simulation are:

- Analysis (decomposition)
- Integration (Synthesis)

The following example illustrates the realization concept discussed:

An object represented by a golf ball in the physical reality domain is made of a specific form and different materials interacted upon by a human who is interacting with it through the gulf club in the field of a golf course interacted upon by a 10 mile per hour wind in specific direction. The player perceives the whole physical in the perceptual reality domain through the perceptual modeling ability (interaction between physical and perceptual domain). She performs a perceptual simulation of achieving a hole in one before interacting in the physical reality with the ball, the golf course, the wind the audience...etc. Modeling the ball, the golf club, the wind, the grass, the hitting force, and simulating the interactions could be, within a certain degree of accuracy, performed through a mathematical or computational domain i.e. the virtual domain (interaction between physical, perceptual, and virtual domains). It could also be physically simulated in the lab through a scaled model (interaction between physical, perceptual, and virtual domains). Moreover while reading this virtual example, written in the physical domain, the

reader has formulated a perceptual domain image of the situation (interaction between perceptual and virtual domains). Before the word she was read the reader may have assumed the player was a male. If the reader was asked to draw a picture of the situation the physical piece drawn would reflect the modeling and simulation of the perceptual reality. The same would happen if the reader was asked to perform a computer simulation in the virtual domain. Finally, in this example if the player was a self programming robot, produced in a fully automated self programmed computerized facility, an interaction between physical and virtual domains could be achieved with no human interaction.

Realization Processes

Over the years humans have developed a great deal of perceptual, physically and virtually documented realization called knowledge. Knowledge is a major field of human interaction with reality domains. The knowledge field based on the context is classified into different subfields or disciplines. Some of these disciplines interact with physical reality such chemistry, physics, biology, medicine, and engineering. Some interact with virtual reality such as mathematics, arts, and computer sciences. Others interact with perceptual reality such as psychology and religions. In each of these disciplines different activities, processes, or methodologies are developed to achieve different outcomes when interacting with reality. While these activities or processes vary depending on the context, and the desired outcome they have common names and attributes among the disciplines. These major activities or processes are known as:

- **Research**

  Research is an intellectual investigation aimed at altering (enhancing) human perceptual realization of the whole universe. While a research activity may take place in the perceptual, virtual, or physical domain the goal state is always an enhanced realization at the perceptual domain. For example, conducting research in electricity have produced an enhanced of how electric currents can be utilized. As shown in Fig 1 research, in general, starts at the perceptual domain as unsatisfied reality of non-understanding of a specific object, function, or interaction in one of the three reality domains and ends at the desired or goal state of understanding of this reality in the perceptual domain. In other words, research and discovery are the basic activities for building the perceptual domain.

- **Problem solving**

  Problem solving has been defined as a process whereby a 'best' value determined for some objective or unknown, subject to a specific set of constraints and criteria. The problems that we focus on to solve are ones where there is no immediately apparent procedure, idea, or route to follow; if one has an idea of how to solve 'the problem,' then this problem is simply an exercise. What we call a problem is a real challenge; it is a situation where we really have to struggle to define it, figure out what it means, and resolve it [3]. In the context of realization problem solving aims at altering a reality to an expected state as shown in Fig. 1. For example, in the physical domain a problem exists if a car does not stop when the brake is applied. Here the goal state or expected reality is for the car to stop when the brake is applied. The process of fixing brakes, in this case, is altering the none-working brake reality

to the expected state of a working brake reality is problem solving. In engineering education, a Thermodynamics or Statics problem solving aims at an expected state of knowing all the unknowns in the virtual domain. In general, problem solving is conducted at any domain utilizing any or all of domains but usually starts and ends at the same domain.

- **Design**

Design is a creative and intellectual interaction that starts at the perceptual reality aiming at altering (enhancing) human physical and virtual realities by introducing desired objects. While the goal of research is to alter reality at the perceptual domain the goal of design is usually to alter reality at the physical or virtual domains.

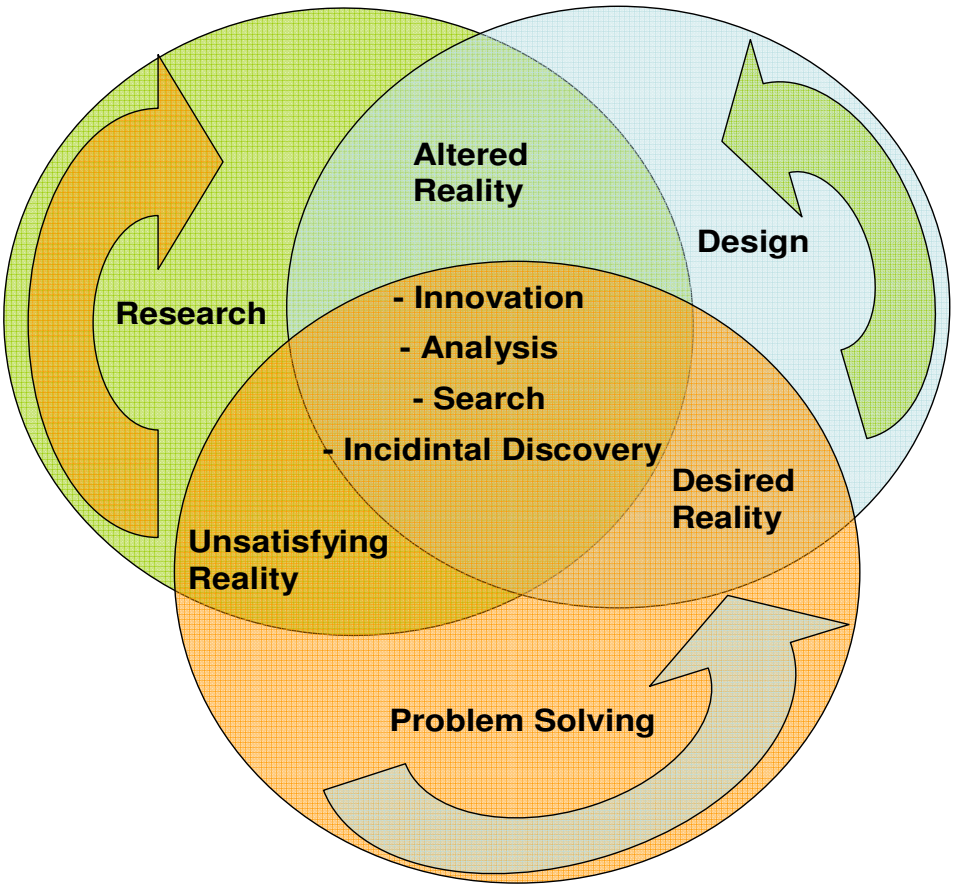

Figure 1: Starting and goal states for research, problem solving, and design.

The arrows shown in Fig. 1 indicate the direction from the beginning state to the desired or goal state for each of the three major activities. As shown in the figure the three activities are overlapping. For example, incidental discovery can occur during any one of these activities.

Realization and Design Education

While understanding research, problem solving, and design as realization processes will have impact on the education process for each, in this section only design education will be examined. The insights gained, from understanding design as a realization process, can guide engineering education in fostering creativity and identifying the required elements such as modeling and simulation.

Based on the understanding of the realization concepts discussed, it could be stated that a typical product realization process from a concept to a physically produced object spans all three realization domains. The realization process starts from conceptualization at the perceptual domain to design and development in the virtual domain to validation and production in the physical domain. In fact, it becomes clear that a set of design drawings is the virtual realization of a product. In addition, a simulated manufacturing process model, for product development, is an element in the mapping from the virtual domain to physical.

By examining the basic elements of product realization in the context of the discussed realization, the importance of conceptualization as the starting state of any product becomes very clear. It is in the perceptual domain that a product realization process begins. From the perceptual domain the concept is mapped to the virtual or physical domains. For complicated products requiring the input and skills of many, the virtual domain is the usually the shared domain for communication between the different perceptual realities until a common simulated model is developed and validated or in other wards a final design is realized. Once a final design is realized the mapping into the physical domain can be actualized.

Due to the importance of mappings between domains, during a product realization process, modeling and simulation should be the key elements in any engineering design education. It is also necessary to equally develop both analytical and integration skills during such education process. Also, since design starts at the perceptual domain, a design education program with attributes that foster creative conceptualization will always be in demand.

Considering the current reality of engineering design education, except in rare cases, most undergraduate engineering education programs emphasize problem solving and development of analytical skills. As for the state of design education:

- Integration skills are rarely addressed at the same level as analytical skills. These integration skills are usually acquired at the end of the education program, mostly in capstone classes.
- Most engineering classes focus on mathematical problem solving of governing equations instead of emphasizing modeling and simulation, as core engineering processes, and their role in different contexts.
- While Product realization is core activity in engineering and conceptualization is the start of this activity, education and training of effective conceptualization are not sufficiently addressed in most engineering education programs.

The following example illustrates the current state of design education:

Consider the Machine Element Design texts [4-8], used in the core machine design classes today. By examining these tests it becomes clear that the emphasis is on problem solving and analysis. It is rare to find any of the machine elements, in these texts, are being addressed in terms of simulated models instead of solving the governing equations. It is also rare to find architectural or performance integration issues, for different utilization of these elements, being addressed in theses texts. Finally, these texts rarely aim at fostering creative conceptualization of the use of these elements beyond the traditional and classical examples.

Conclusion

When interacting with the physical world humans have used their own perception of it as their own reality. In order to understand physical reality and collectively share their perception of it humans have introduced a third domain known as the virtual world or the virtual reality. This virtual domain serves as a shared transition between the individual perceptual domain and the physical domain. Examining all three domains it could be postulated that the perceptual is the domain where the individual realization is being formulated (developed and validated) and the virtual domain is the domain where the collective realization is being formulated and the physical domain is the domain where physical realization is being formulated. In other words there are three levels of realization perceptual (individual), virtual (shared) and physical (universal).

In product realization, design and development process from an idea or a concept to a physically produced product span all the three realization domains. It can be considered that design outcome is the virtual realization of a product while the development process is the mapping from one reality domain to another. As for design education, while problem solving and analytical skills are being emphasized through many engineering programs the understanding of modeling and simulation in addition to integration skills and conceptualization are rarely addressed.

Bibliography

1. Webster's Revised Unabridged Dictionary (1913 edition)
2. Wiktionary, the lexical companion to the open-content encyclopedia, Wikipedia.
3. D. R. Woods, An evidence-based strategy for problem solving, *Journal of Engineering Eeducation*, 89, 443-459.
4. Joseph Edward Shigley, Charles R. Mischke, Richard Budynas, Mechanical Engineering Design (7th Edition), McGraw-Hill, 2003
5. Robert L**.** Norton **,** Machine Design: An Integrated Approach (3rd Edition), Prentice Hall, 2005.
6. Bernard J. Hamrock, Steven R. Schmid, Fundamentals of Machine Elements, (2nd Edition), McGraw-Hill, 2004.
7. A. C. Ugural, Mechanical Design: An Integrated Approach, McGraw-Hill, 2003.
8. R. C. Juvinall and K. M. Marshek, Fundamentals of Machine Component, Design, Wiley, 2005.