AC 2012-5299: PRODUCT REALIZATION EXPERIENCES IN CAPSTONE DESIGN COURSES

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Product Realization Experiences in Capstone Design Courses

Abstract

Product realization is the main objective of most engineering processes. While the realization concept is mostly limited to the physical build of a product, the root of any realization process starts at the conceptual level of the individual or engineering team. Considering that engineering capstone design courses are usually centered on open- ended design projects, to provide students with team work and realistic design experience, it is imperative that both the concept of realization and the product development process be well understood when designing or teaching these courses.

In most engineering settings the boundaries between design, problem solving, and research are not defined due to overlap and interconnectedness between all three activities. In capstone design courses, it is imperative to understand the nature of the three activities, and when a transition from one to another has occurred. In this paper, an expanded concept of realization is presented to identify the roles and transitions of the three activities. Also to improve the realization experience, in capstone design courses, the product design and development processes are revisited. Clear understanding of these processes in relation to realization is vital for having realistic expectations, and achieving the course outcomes. Several examples are presented to illustrate the concepts and processes discussed.

Introduction

Growing number of national reports and articles stress the need for incorporating innovative forms of teaching[1,2]. In response, there is a need to redesign, reform, and continuously improve engineering educational programs and experiences. Capstone design courses, being the last educational experience of most programs, must reflect these improvements through innovative teaching that include current engineering developments and practices.

In a recent study, the concept of realization was expanded to include the virtual and perceptual realities as valid domains of the product realization process[3]. These domains of realization and their interactions with the physical reality were studied. Also, the relationships between research, problem solving, and design were examined in the context of engineering product realization. Considering that engineering capstone design courses are usually focused on product development, the expanded realization concept could be used to guide the design and implementation of these courses. Also, since capstone courses are usually the last educational experience in engineering programs both the development and validation of different educational elements are usually present during the experience. The realization concept can assist in identifying these development and validation elements of the capstone experience. In the following, the expanded realization concept will be discussed and used to guide the capstone design courses design and implementation. Different course aspects such as focus, process thinking development, basic skills validation, and creativity will be addressed.

Product Development and Realization Concepts

Depending on the product, a development process usually has different activities and interactions. To understand the basic elements of the process, one person natural product development sequence from an idea to a physical prototype is illustrated in Fig 1.

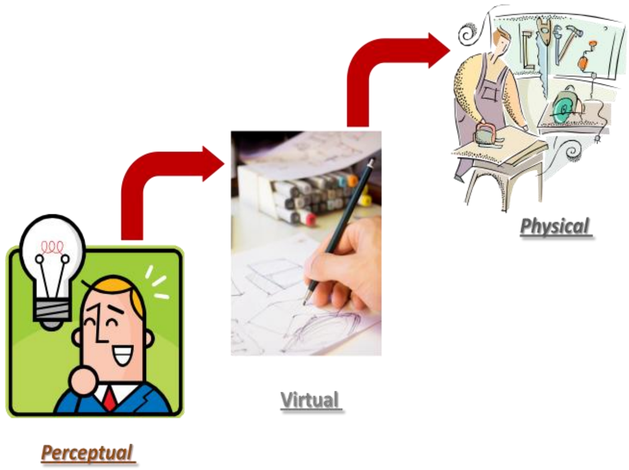

Figure 1 - One person product development sequence

From Fig 1, it is clear that the development process proceeds from inception, in the perceptual domain, of the developer to conception, in the virtual domain, to a prototype in the physical domain. Based on this natural development experience, the concept of realization could be expanded to include the perceptual and virtual domains, as well. It is also clear that the definition of reality could be expanded to include domains that go beyond what is physical. Among these domains, the following three are considered[3]:

1. *Physical reality*: represented by the physical universe we live in and can be realized with the senses.
2. *Perceptual reality*: represented by the individual paradigms or the internal image of other realities.
3. *Virtual reality*: represented by the virtual modeling and simulation of other realities.

It could be observed, by examining all three realities, that the perceptual is the domain where the individual realization is being formulated (developed and validated). The virtual domain is the domain where collective and shared perceptions are being formulated (developed and validated). The interaction between the three reality domains occurs through mapping. To map objects and their environment between different realities using modeling and simulation requires deconstructing and reconstructing using analysis (for deconstructing), and Integration (for reconstructing).
Both analysis and integration use modeling and simulation at different degrees[3]:

A model: is a representation of an object.
A simulation: is the act of an object or its model performing in an actual or simulated environment.

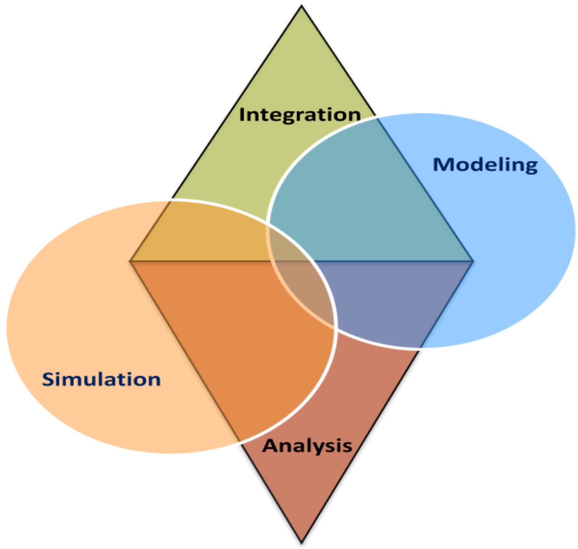

Figure 2 – Different realization tools[3]

As shown in Fig. 2, analysis is performed with mostly simulation and some modeling. Integration is performed with mostly modeling and some simulation. It is also obvious that both analysis and simulation are mostly logical and analytical in nature while modeling and integration are more holistic and creative in nature.

Realization Activities

The main objectives for interacting with any reality are:

1. To understand it (know it)
2. To utilize it (use it)
3. To improve it (alter it)

These three objectives are interconnected and overlapping because utilizing or altering a reality requires an understanding of it. Also, utilizing or altering a reality brings a better understanding of it. In addition, these three objectives create the following three distinct but interconnected activities:

1. *Research:* aiming at understand reality
2. *Problem solving:* aiming at utilize reality
3. *Design*: aiming at improving or altering reality

These activities could be performed across all three realities. Also, the aim of each activity does not preclude the activity from achieving other objectives. In addition, understanding of a reality may engage the others. For example, performing research in the physical domain may require the use of the virtual domain, to improve understanding in the perceptual domain. Each of the three activities starts due to one of the following states and ends after reaching another state, as shown in Fig. 3[3]:

1. *Unacceptable Reality*
2. *Acceptable Reality*
3. *Improved or altered Reality*

As shown in Fig. 3, research starts due to unsatisfying state of understanding in the perceptual domain and ends by reaching a state of improved understanding at the perceptual domain. Problem solving starts due to unacceptable state (things are not the way they should be) at any of the three domains and ends by reaching the desired state (things are the way they should be). Design starts from a state of acceptable reality, due to the desire for improved reality in the physical or virtual domains, and ends by reaching a state of improved or altered reality.

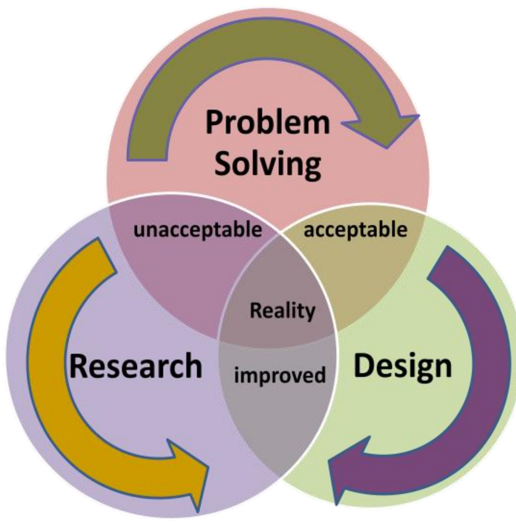

Figure 3 – Beginning and end states for different activities[3]

It is important to recognize that while the starting domain can be different, for each activity, all three activities are conducted by the perceptual domain. In the following, each of the three activities is further explained.

Research:

Research is an activity initiated and conducted by the perceptual domain aiming at understanding any of the three reality domains. While a research activity may utilize the virtual or physical domains, the goal state is always an improved state at the perceptual domain.

The processes to perform research are mainly analysis and integration. Analysis is mostly conducted in the physical by the perceptual with the help of the virtual domain, as needed. The gained insights are usually integrated by the perceptual domain and communicated through the virtual domain. Both analysis and integration use modeling and simulation, at different degrees, across the three domains as sub-processes. For example, research was needed to improve the efficiency of a product. This research would start due to unacceptable state of understanding for the product performance and the parameters affecting it. This research would be conducted until a desired improved state of understanding is reached, before attempting to change the current design. Utilizing the perceptual domain of the researcher(s) and conducting research in the physical and /or virtual domains, through testing physically simulated models and /or virtually simulated models of the product, could produce an improved state of realization in the perceptual domain of the researcher(s). If the research results are documented and communicated or published an improved state of realization, in the virtual domain, would result, as well.

Problem solving:

Problem solving is an activity initiated and conducted by the perceptual domain aiming at transforming unacceptable state of reality to an acceptable state of reality in all three domains. Problem solving activity may take place in the perceptual, virtual, or physical domain the goal state is always an acceptable state at the domain of the starting state.

Similar to research, the processes to perform problem solving are mainly analysis and integration. Analysis is mostly conducted by the perceptual domain and executed in the physical or virtual domains depending on the problem context. In educational settings, solutions are usually performed in the virtual domains. The gained insights are usually integrated by the perceptual domain and used to solve the problem in the execution domain. Both analysis and integration use modeling and simulation, across the three domains as sub-processes at different degrees, until the acceptable state of the problem solution is reached. For example, during a research activity if an object is not working as expected, in any of the three domains, a problem is identified by the perceptual domain. Developing a solution may require the utilization of the virtual or physical domains, in addition to the perceptual domain, until a solution is reached in the same domain, where it was identified.

Design:

Design is an activity initiated and conducted by the perceptual domain aiming at altering reality from an acceptable state of reality to improved state of reality in the physical and/or the virtual domain. While design activity may take place in the perceptual, virtual, and physical domains the goal state is always an improved state at the domain of the starting state.

The processes to perform design are mainly integration and analysis. Integration is mostly conducted by the perceptual domain and executed in the physical or virtual domains, depending on the desired end product context. In educational settings, designs are usually performed in the virtual domains. The problems or lack of understanding faced during integration are addressed through problem solving and research, performed using analysis and integration. Perceptual domain creativity is usually utilized to solve the design integration issues. Integration and supporting analyses use modeling and simulation, across the three domains as sub-processes at different degrees, until an improved state of reality with a new product design is reached. For example, utilizing the improved perception during a research activity to design a new product can produce an improved performance in the physical domain.

It should be noted that while an initial state may trigger an activity, the other two activities may be needed to achieve the end state. For example, some research and design activities may be needed to solve a problem. In fact, some design engineers and researchers, due to their analytically dominated thinking and training in problem solving, like to start their design (a creative activity) by defining what they call the design problem[3].

Product Realization Process

Based on the realization concept discussed and the one person product development sequence shown in Fig 1, a complete product realization process can be outlined. Such a process is usually a multiphase process with different realization activities and reality domains interaction as shown in Fig 4.

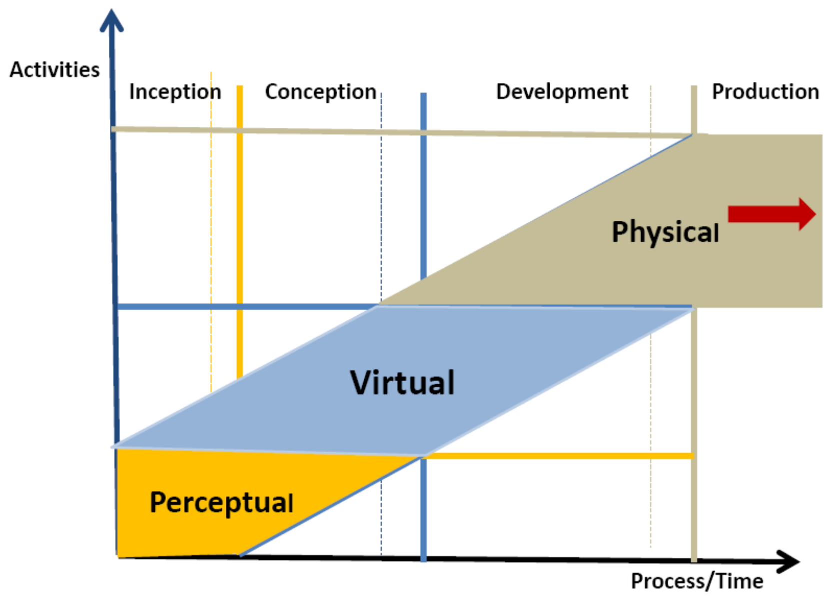

Figure 4 - Product realization process activities[4]

The process phases flow from inception to production through conception and development. The process activities flow through the three main reality domains perceptual, virtual, and physical for achieving the desired product attributes. In terms of the traditional product development processes of planning, design, and manufacturing the perceptual domain activities includes the planning and conceptualization phases. The virtual activities, during the development phase, represent the design activities. In other words, design is the virtual activity of the product development process. All physical builds including physical concept development, physical testing and validation, and production represent manufacturing.

Realization and Capstone Design Experience

Understanding the reality domains and realization activities is important for the design and development of a highly effective engineering education programs and courses. Since all realizations are conducted by the perceptual domain, it is important to focus on how perceptions are formulated. In other words, how physical and virtual realities are mapped, modeled, and simulated. Both teaching and learning are perceptual domain exchanges between teachers and learners. These exchanges are usually shaped by the educational process objectives and goal state. In the following, the insights gained from understanding the realization process will be utilized to guide the engineering capstone design experience.

Based on the understanding of the realization concepts discussed so far, it could be stated that a typical product realization process from inception to a physically produced object spans all three realization domains. The realization process starts from inception and conceptualization at the perceptual domain to design and development in the virtual domain to validation and production in the physical domain. Therefore, the following actions should be considered for achieving a complete and effective capstone experience.

1. **Focus on students' perceptual development:**

From the engineering practice aspect, as shown by the realization process presented in Fig. 4, the interaction between the three realization domains is initiated and propelled by the perceptual activity. As shown in Fig. 5, the three activities are integrated and span the realization process with the perceptual reality as the foundation, virtual reality or design as the bridge and the physical reality or manufacturing as the peak of the process[4].

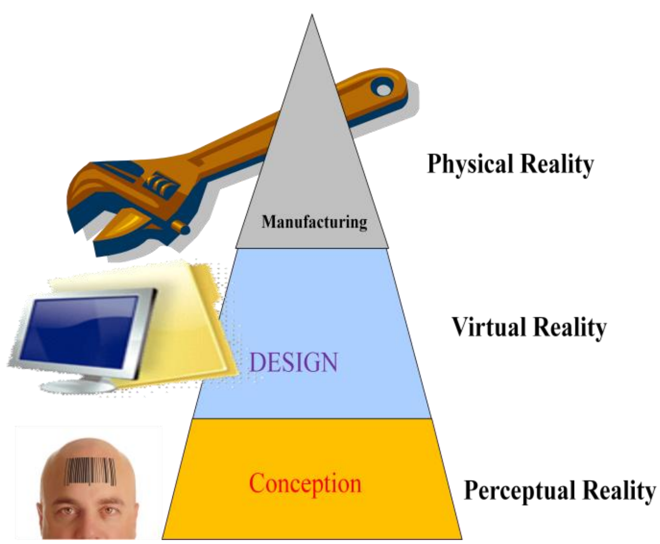

Figure 5 – Realization process and reality domains[4]

From the educational aspect, all educational experiences are perceptual domain exchanges. The goal of any education activities is the cognitive development resulting in fully developed perceptual realization of the field of study. In this regard, capstone experience does not only present an educational setting for providing the final touches of students' professional development and validation, of what they have learned, but it is also presents the setting for providing students with the perceptual validation in their own ability to practice and achieve.

<u>Example 1:</u>

In an alumni survey, for assessing the increase in ability due to classroom and cooperative education learning experiences, the roles of problem solver, designer, researcher, analyst, practitioner, and achiever were studied[5]. The results are shown in Fig 6.

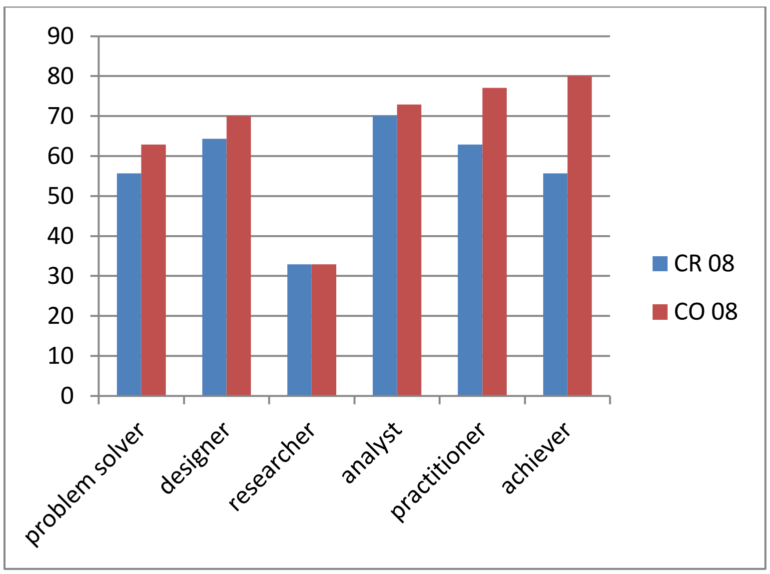

Figure 6 – Setting accounted for a large increase in ability[5]

As shown from Fig 6, while the cooperative education experience provided slightly higher increase in the ability than classroom experience for both problem solving and design with equal ability for research, the largest perceived increases are in the abilities of being a practitioner, and achiever. Therefore, for education programs depending on classroom settings alone, a successful capstone experience is necessary for closing these gaps.

2. <u>Develop realization process thinking and practice:</u>

Providing as much of the product realization experience as possible is the key for students' professional development and success. Process thinking combined with current practices in the field can provide the synthesis and cementing of all program learning experiences. In fact, process thinking and applications must be one of the main contributions of any capstone course to integrate segmented knowledge and skills provided throughout the educational program.

Some important factors, for success in providing the experiences, of different realization phases and activities, in a capstone course development and implementation are:

a. Define the capstone experience scope, learning objective, outcomes, assessment, and evaluation measures in the context of the different realization process domains and phases.
b. Set priorities for the experience objectives and outcomes. Depending on the capstone course objective and focus there is usually a conflict between what a student team can physically build and complexity/creativity. For example, emphasis on achieving physical build usually limits the complexity and creativity of students during capstone experience. Students will tend to select projects that they can build within the course time and the program physical build capability.
c. Set realistic achievement goals for each realization phase. In most cases the experience even with the physical realization is usually limited to proof of concept especially for products that lend itself to mass production due to course time, students' skills, and program physical build limitations.

Example 2:

During a one-term capstone course, a team of students elected to design and develop a 30 KW wind turbine. Because of the time and capability limitations, the realization experience was achieved through fully developed and simulated full scale virtual model and physically correlated scaled model.

3. Validate students' realization skills:

As discussed previously, all engineering activities such as research, problem solving, and design use analysis and integration through modeling and simulation to achieve desired outcomes. These basic skills are the fundamentals that should be developed and mastered by each student during the education program. Capstone courses provide the opportunity for performing analysis and integration through modeling and simulation with the recognition of when each of these skills is needed and should be engaged. Therefore, capstone courses are the logical settings for validating these skills. Capstone experience could also, with the instructor's guidance, provide students' with the ability to recognize the beginning and end of each realization activity as demonstrated in the following example.

Example 3:

During the wind turbine project discussed in example 2, the perceptual domain realization activity for understanding the lift and drag forces on the turbine blades was identified as one of the planned research activities early in the project. After performing the experimental research activity using the wind tunnel with a scaled physical model, the problem of sizing the turbine blades was solved using hand calculations. The final power output was validated using Computational Fluid Dynamic virtual simulations.

4. Restore and foster creativity:

Creativity in performing all aspect of realization activities from designing to conducting research and solving problems is one of the most desired attributes in engineering practice. While this may seem trivial and assumed, in any engineering education program, it is usually unachieved. Most engineering programs are designed around analysis and simulation. In fact, most engineering models are mathematical in nature causing the modeling process to be more analytical. Adding to that the common thinking preferences of engineering faculty and the majority of students are analytical it becomes clear that creativity could be absent.

Example 4:

Studies on the thinking preferences of engineering students, based on the HBDI model shown in Fig. 7, were conducted at the University of Toledo[6], and the University of Pretoria in South Africa[7]. Both studies concluded that diversity exists in profiles, but these profiles on average tend to be triple dominant with the primaries in quadrant A, then D and B and secondary in C as shown in Fig. 8.

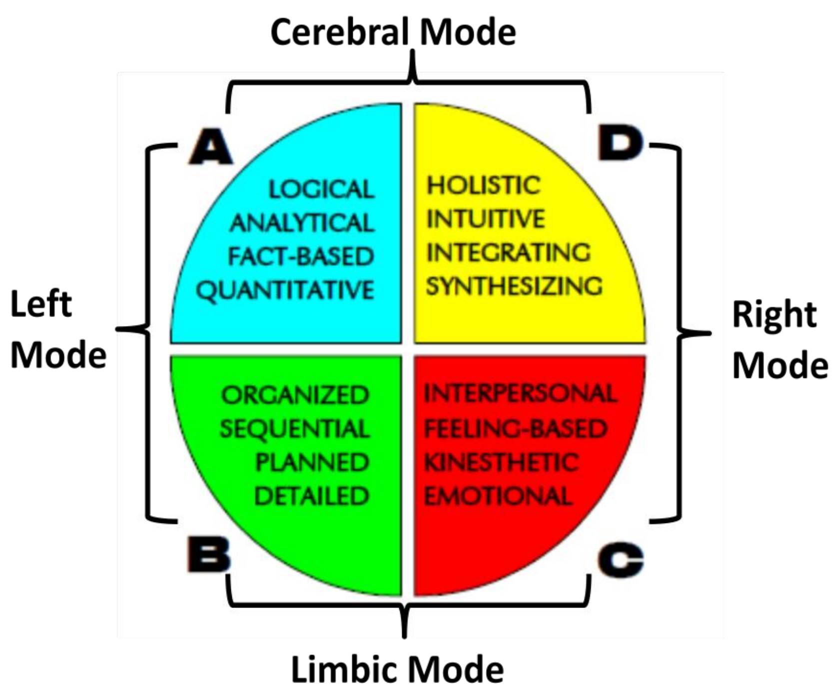

Figure 7 - The Herrmann whole brain model[7]

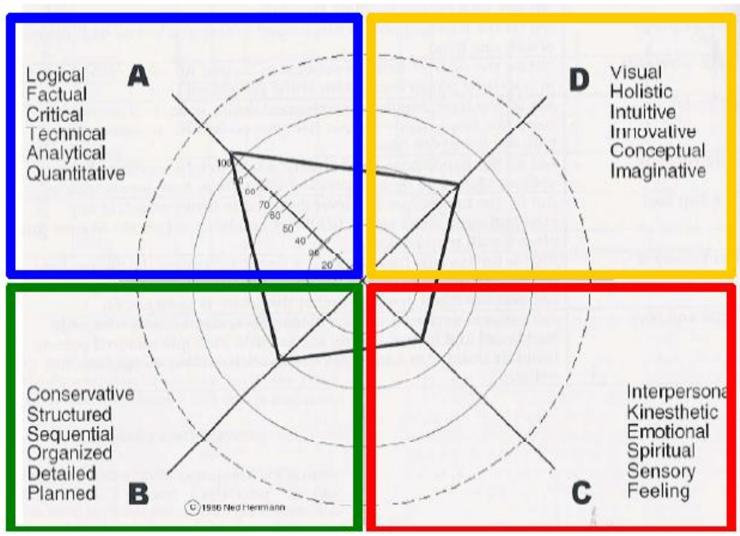

Figure 8 - Typical HBDI profile of an engineering student[7]

From this example, it is clear that creativity can be increased through understanding of each student preferences and learning style. In addition to brain preferences, understanding the different educational activities and when creative or analytical skills are needed during the realization process can result in a higher level of creativity.

Modeling and integration should at least have equal presence to analysis and simulation, throughout the capstone experience, to foster students' creativity. From research efforts on creativity[6,7], induction of creativity in the classroom becomes successful when modeling and integration activities are emphasized. Students are inspired when their creative abilities are engaged and developed, during the quest for different alternatives such as better models, other integration strategies, and different solutions. Capstone does not only provide the natural setting for such activities, but it is also the last chance to provide these experiences.

Conclusions

The term realization in product development is usually constrained to the physical reality. However, perception is also a form of reality for each individual. In addition, to share their perceptions, humans introduced virtual reality as a third domain for communication. This virtual reality represents the collective perception domain for humanity. Therefore, a better understanding of different realization tools, activities, and processes could be developed by expanding the concept of realization to include all three realities. For example, the similarities and differences between research, problem solving, and design as realization activities could be recognized. In addition, while being performed in different domains, all three activities use analysis and integration through modeling and simulation. The recognition of these similarities and differences is necessary for achieving enhanced realization in any education experience, particularly the engineering capstone courses.

Understanding realization domains and activities can guide the development and implementations of the capstone courses, and improve the design experience. Considering that teaching and learning are perceptual domain exchanges, the focus of any capstone experience should be on the development and validation of students' perceptual domains, as the main objective. The capstone design project should be considered as the means for achieving such objective. Both development and validation, of different educational elements, are essential aspects of the capstone course experience. Since most engineering programs are designed with a focus on the basic knowledge and skills, of realization elements such as analysis and simulations, the validation effort during the capstone course should be directed to these elements. The development efforts during the course, however, should be directed to the full realization experience, process thinking, and creativity. Conducting individual and team brain storming activities, in addition, developing different models and integration strategies can assist in restoring and fostering creativity through the capstone experience.

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