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Designing Engineering Education; Development of Design Education Model for Engineers

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1. Introduction

Educational circles in the area of engineering have recently been strongly requested by privately-led and enterprise-led specialist organization in engineering education such as Accreditation Board for Engineering and Technology (ABET) in US and Accreditation Board for Engineering Education of Korea (ABEEK) to cultivate engineers equipped with interdisciplinary team working skill and efficient communication ability on the basis of creativeness. Such requests are not possible in existing engineering educational program without fortification of design and practical work education, as well as cultivation of teamwork and leadership. Furthermore such requests suggest that creative engineering education contents and method, and project based learning format based on performance must assertively be integrated into existing educational program. From such perspectives, existing engineering educational institutions are executing programs for fostering of creativity such as subject on 'Creative Engineering Design' by focusing its application on newly recruited students, with gradual increase in its numbers.

The School of Mechanical-System Design Engineering at Hong-ik University attempted experiment of teaching the engineers in new format of enabling professional product designers to plan and manage the newly established 'product design' class, which is one of prerequisite subject for students majoring in the field, by expanding and fortifying 'creative engineering design class' aimed at freshmen students. Introduction of project based learning, which is based on enhancement of creative thinking and studio experience that are being emphasized in the new engineering educational program, is an issue that has been emphasized for a long while in the traditional design pedagogy. As Owen (1998) has illustrated in his book, engineering and design, from the perspective that they have relatively strong similarity in comparison to other disciplines in their source of value and its measure, are rational means of approach.

However, because it is a fact that product design and engineering have belonged to different worlds from each other, in the realm of academics, in the reality, there exist difficulties in effective communication and

conveying of knowledge system. Processes and techniques that can minimize such difficulties from that perspective shall be introduced in detail through explanation on educational models to be mentioned later.

2. Engineering thinking & design thinking

Ferguson (1994), through his one of representative literary works, "Engineering and Mind's Eye", explains, in detail, the core value system and characteristics of engineering thinking that engineering has in distinction to other areas. According to him, engineering was creating activities of human kind based on traditionally concrete image, that is, visual thinking, more so than on the basis of symbols and language as found in mathematics and science when viewed from the basis of historical study on technology. In addition, he expressed that engineering, unlike the viewpoint of existing Engineering Scientist, has more similarities, in its nature, with arts or invention, which are based on visual thinking, rather than with science and mathematics. He asserts that such inherent values of engineering has been reduced and disparaged in the educational program due to the influence of engineering science, which is caused by analytical thinking that has rapidly grown after the 2nd World War, and came to be what it is today. It can be inferred through such assertions, that engineering was a integrative and holistic behavior of concurrently executing synthetic thinking based on visual language as well as logical, mathematical and linguistic thinking.

Researches on characteristics of design thinking have been conducted by numerous designers and psychologists thus far. Tovey (1986), particularly in his literature dealing with activities of car designers, claimed that designer concurrently executes Visuo-synthetic thinking symbolized by the right halves of the brain along with verbal-analytic thinking by the left halves of the brain, and presented 'Dual mode process model' that illustrates that they think through active exchange of information between the 2 cognitive systems. This model(Fig.2-1) is coherent with 'the Creative sandwich model(Fig.2-2)' that Archer (1965) had been asserting since the date of establishment of theory of design methodology, illustrating an example that one does not dominantly use cognitive pattern of one side only.

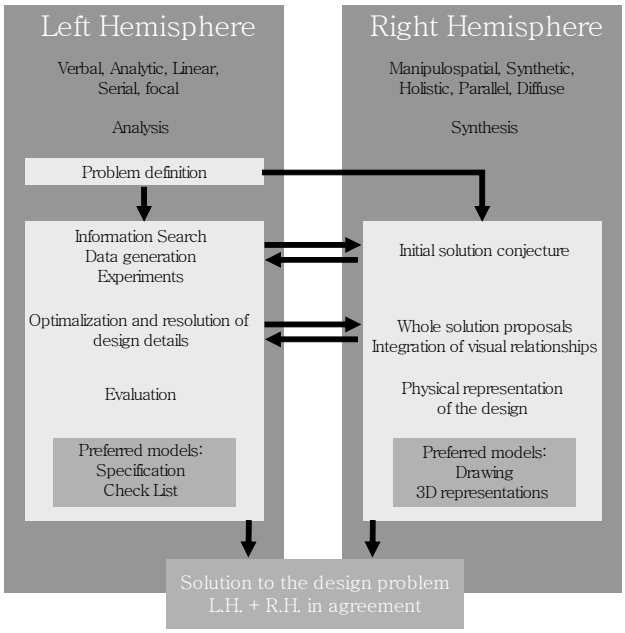

Fig.2-1. Dual process model , Tovey (1986)

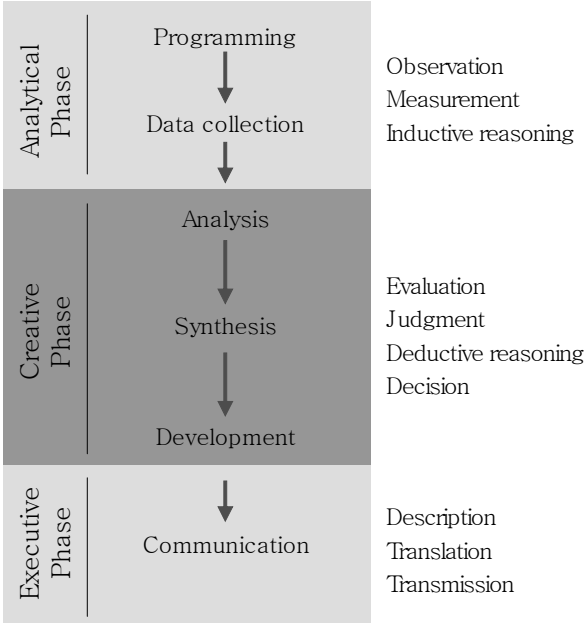

Fig.2-2. Creative sandwich model, Archer (1965)

As mentioned above, it was found that there are structural similarities in the cognitive system of engineering and designing. When such concept is expanded onto the perspectives on education, useful insight can be extracted. This can be materialized through the clarification that Middletone (2005) has made on education on design and arts. According to his literatures, the design problems, as asserted by Cross (1982), are wicked

issues in which the issues to be resolved are indeterminate, unlike natural science and mathematics. As such, He suggested that process(Fig.2-3) to be modeled with the concept of zone rather than resolving the issues with the concept of point on the process. This illustrates that design process at times must freely traverse between convergent and divergent thinking. He, on the basis of such viewpoint, emphasized acquisition of knowledge through visual thinking and tacit knowledge through experience as means of application on educational area of design. It can be seen that such assertion is in agreement with the statement made in the introduction on improvement of creativity and provision of project based learning experience which are core values required as means of reform of engineering education.

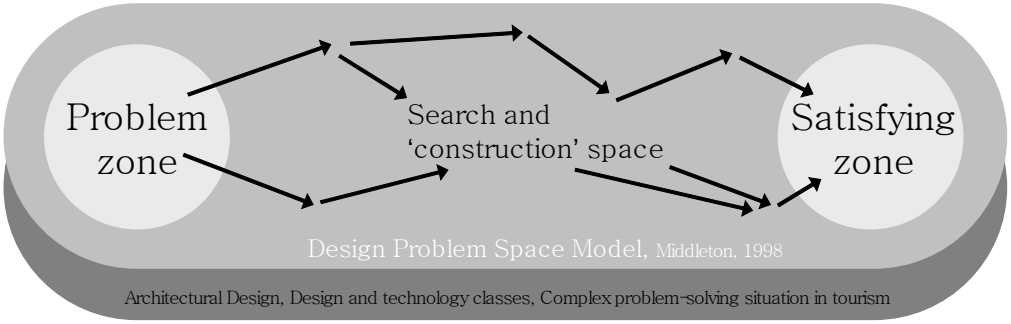

Fig.2-3. Creative thinking process model, Middletone (2005)

Useful model for effective education of such core values of design for students learning engineering can be found more easily in the design industry rather than in pedagogical area. Although there is 'Systematic engineering design process' that has been proposed by Phal and Beitz (1997) through their literature, it is somewhat too broad and its application to case study and practical team project practice from the perspective of education. Studio learning method of existing design schools with focus on arts area are closer to an atelier with strength in visual expression and stylistic viewpoint, and as such, there are much difficulties in applying them to engineering students as they are. On the contrary, IDEO Product Development, which is developing new products with multi-disciplinary approach, is providing relatively useful framework in accommodating design concepts in engineering education. Kelly (2001) and Moggridge (1993), through their literatures, are simply and clearly presenting the role and technique of design thinking necessary for innovation from well-balanced viewpoint. Educational model based on such approach is now being specifically presented by the Design Institute recently established in the Mechanical Engineering Faculty at the Stanford University.

3. Pedagogic Development

This curriculum for product design class (Fig.3-1) has been composed on the basis of the educational model of Design Institute of Mechanical Engineering Faculty at the Stanford University. Design activity has been divided into 2 stages, namely, Problem Finding and Problem Solving, which are further subdivided into 4 sub-stages of (1) learning, (2) observation, (3) visualization and (4) evaluation. Fundamentally, each stage was designed to enable students to personally experience them by transforming the complexity and specialization of existing engineering design process into simplified process easy to understand, and by concurrently executing lectures and practicum for each stage. Also curriculum has been devised with 2 projects to which 4

separated processes can be integrated. The design team was composed of 3 students in order to cultivate efficient communication ability and leadership, which are one of the directions for innovation of existing engineering education. Students are asked to solve the problems ranging from learning of each detailed stage to execution of the final project.

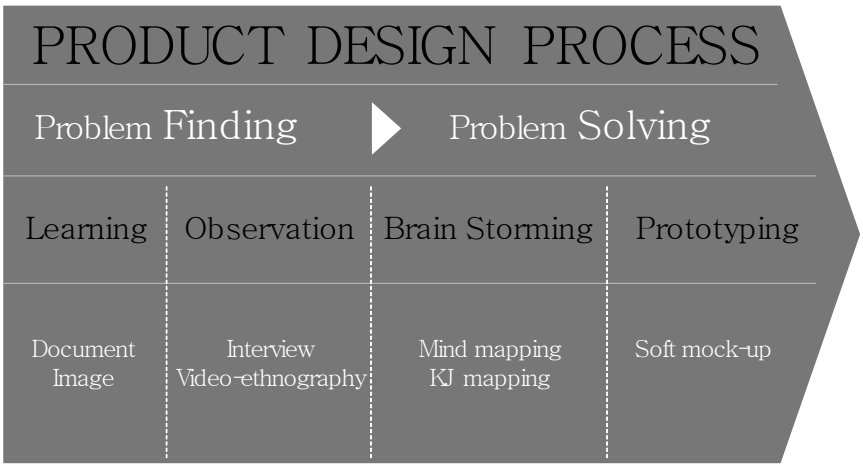

Fig.3-1. Product design course structure, Kim (2005)

3.1. Learning and Observation Process

Learning and Observation Process(Fig.3-2) as the stage of discovering the core problem in a given task emphasized the need for in-depth understanding on the situation. In this process how to observe is particularly being trained. As Fulton Suri (2005) had mentioned in her literature, students were required to pay attention to seize various behaviors and circumstances in which users perform unconsciously. Method of video ethnography was presented as specific technique and bus station, vending machines and benches, which are familiar environments in which student normally live, were suggested as task also.

Fig.3-2. Observation practice results from students

3.2. Brainstorming Process

Brainstorming substituted methods of rational and logical concept selection method such as 'Objective tree technique' and 'Morphological chart technique' often used in existing Systematic engineering design method with creative conception technique represented by Synectics. Brainstorming session(Fig.3-3) was proceeded in

the sequence of freely expressing, communicating and improving concepts by using casual tools such as Post-It among the 3 composition members and finally deducing solution after having categorized and analyzed through KJ-map format. It is a stage that requires strong and effective communication ability. Tasks on experience of using popular products such as cellular phone and mobile MP3 that are close to daily lives of students were given.

Fig.3-3. Brainstorming session in the class

3.3. Visualization Process

As Ferguson (1994) mentioned, training on visualization has been substantially reduced in the existing mainstream engineering education system and has the limitation of training on visualization with emphasis on the expression on the final outcome rather than concept generation and development. This process focused on strongly highlighting advantages of development and improvement of concept through visualization to students who are familiar with developing of concept only through mathematical and linguistic means without personally realizing the advantages of visualization. Prototyping technique was presented as convenient skill to materialize concepts very quickly to the students who became familiar with workshop training based on traditional metallic material that requires highly advanced training, which is somewhat difficult for students, and highly advanced 3-dimensional engineering modelling software. Students are then induced to experience the process of testing, improving and correcting on the basis of the outcome made of soft materials.

Rapid Prototyping based on soft material (Fig.3-4) is a technique used for a long while in the process of traditional product design education. Achievements and experiences accomplished in such aspects were effectively introduced.

Fig.3-4. Visualization session in the class

3.4. Evaluation Process

Core task in the evaluation process (Fig.3-5) was having diverse range of viewpoints on the designed outcome and the effective presentation skill on designed outcome. Functionality, which is an important task of engineering, economy that can support the realization of such functionality, and human factor as the aspects on human psychology and behavior which is the ultimate subject of such functionality and economy have been set as the 3 criteria of evaluation standards. This is based on literature of Dreyfuss (1955) who specifically expressed 5 Point Formula as conditions of Good Design and Weiss (2002) who mentioned about product innovation through design, refers to evaluation as good design in which innovation is accomplished in the domain where these 3 factors are maximally intercrossing. Furthermore, class has been designed to enable evaluation and presentation simultaneously by intercrossing for each team in order to induce learning communication technique as an essential capability of engineer who makes effective presentation to the target audience with the design results.

Fig.3-5. Evaluation and presentation session in the class

4. Result

4.1 Class overview

Product design class of mechanical engineering course that was conducted for duration of 16 weeks in the 1st semester as the following schedule (Table 4-1) was conducted in the format of personally experiencing each stage of design process by concurrently executing lectures and practice for each stage in detail, and execution of 2 independent team projects on the basis of such. Since the physical environment of existing engineering education is somewhat alienated from the studio environment which is useful in exchanging knowledge, information and experience of constituting members, on-field lessons were frequently given, existing large capacity lecture rooms were used after changing the lay-out it in the case of brainstorming, and hardware machine shop of existing mechanical engineering department was used in the case of Soft Prototyping. 10 teams with 3 students per each team were in a class, making it impossible to prepare physical Studio Environment. As such, website through Internet was established in order to enable interaction of information and experience between team members in the virtual Internet studio at all times.

Table 4-1. Product design course plan

W.	CONTENTS
1	What is design and product innovation? : Product Design and development Process
2	What is design and product innovation? : Product Design and development Process
3	Design understanding : Observation, Data analysis and Brainstorming
4	Design understanding : Observation, Data analysis and Brainstorming
5	Design understanding : Observation, Data analysis and Brainstorming
6	Design action (making things) : Visualization, Rapid Prototyping
7	Design action (making things) : Visualization, Rapid Prototyping
8	Design action (making things) : Visualization, Rapid Prototyping
9	Evaluation and making an action plan : Design Evaluation and Planning
10	More understanding : Theoretical Review
11	Action : Studio practice
12	Practice Mid term presentation
13	Action : Studio Practice
14	Presentation preparation and Discussion
15	Final course presentation

4.2. Findings

Empirical study within limited range was executed through observation on the activities of students and interaction among team members during class along with survey using questionnaire. Discoveries through survey and observations were limited to operation of the class. As such, it is difficult to see them as generalized findings. However, in the reality of pedagogical area in engineering in which attempts, such as this project, are rare, it would be able to provide useful insights and knowledge to the researchers in the areas of engineering and product design who are planning to implement similar projects.

In summarizing the findings, firstly, it was found that students have actively used various digital media tools at each stage. Various specialized technologies used in the existing design practice have become generalized due to rapid progress and popularization in various tools and technology. It appears that design process, which otherwise could have been unfamiliar, was made easy to understand to the engineering students through this.
Secondly, as the class, which commenced in Team Project Format, gradually progressed, it was found that successful teamwork was being accomplished including creating of specialized areas and division of work among the members of the team. For example, it was found that each member of the team became specialist in the specific skill in design process.

Thirdly, it was found that students were using diverse range of visual expressions (Fig. 4-1) in order to accomplish effective communication in the process. Numerous and wide variety of sketches were frequently found not only in the prototyping process as well as in the brainstorming process. It is deemed that students have come to realize that concrete visual language is more effective than mathematical and symbolic language

through teamwork experience. More in-depth additional research on the role of visualization in design process would be necessary in the future.

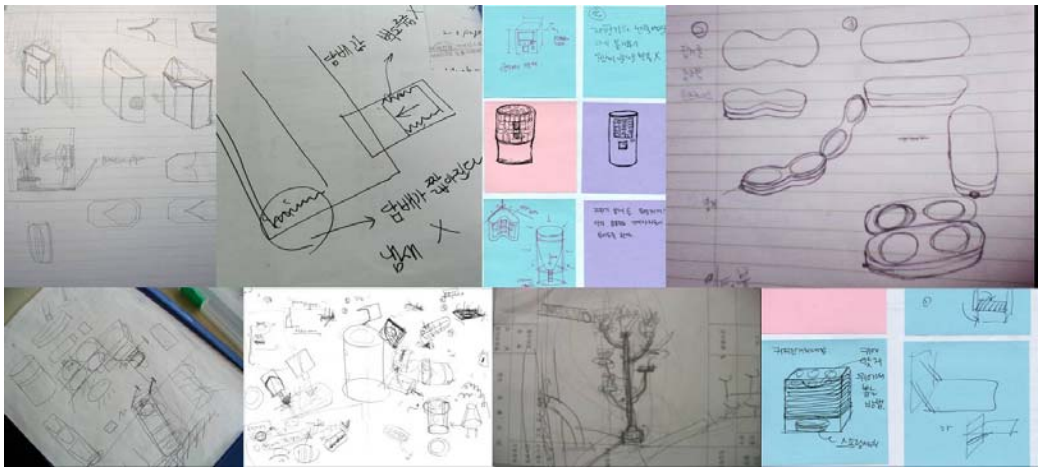

Fig.4-1. Students' sketches as visual language used in design process

Fourthly, it was found that engineering background at times interfere with manifestation of creativity. For example, it was often found that opinions of the team members in the Brainstorming process were interfered in its free evolution through presentation of problems on the feasibility suggested by other members. In consideration of the situation in the educational system of Korea in which disciplines such as natural science, engineering, humanities, arts and physical education are being taught separately since the high school level, it is the reality that truly multi-disciplinary higher education is not easy. It would appear that aforementioned problem suggests that proper understanding and training, particularly on brainstorming, is necessary in order to enable knowledge and experience of each student to act as synergy in multiplying the creativeness rather than interfering with it.

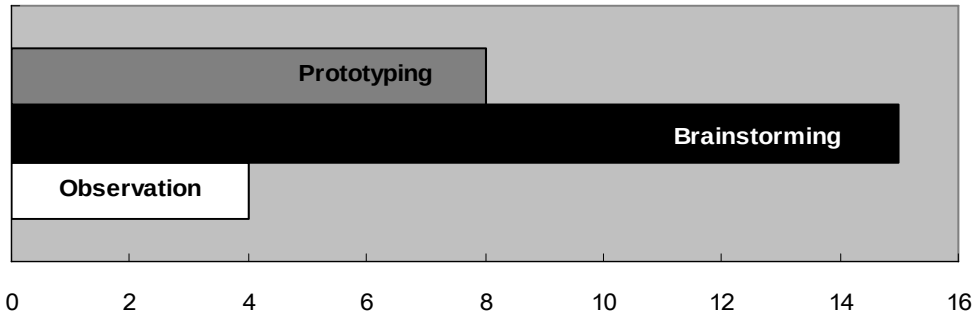

Fig.4-2. Survey result on special interest in design activities

Majority of students who participated in the class, the outcome of the survey (Fig.4-2) illustrates, has shown more interest in Brainstorming and concept development process than others. It appears that it was able to

provide strong interest and motives for students in engineering, from long-term perspective, as a compensative program for existing engineering education centered on analysis.

5. Conclusion

This research was an experimental attempt at systematically integrating the design thinking as specialized area of existing engineering education by teaching engineering students with specific activities of design process after having segmented them into sub-set of stages and had students to execute independent projects by integrating these specific activities. However it was implemented with the goal of accomplishing integrated experience of project based learning and studio experience. In-sufficient class time and absence of independent space is obstacles to quality achievements. Nonetheless, it was able to induce broad range of interest of and strong learning motivation in students towards engineering by highlighting the merits of project based learning to students. It is anticipated that relationship between learning performance levels of this product design class and other analysis based engineering class, and relationships between interaction and creativity among constituting members under the team working conditions need to be researched in greater depth in order to execute more systematic and segmented specialized research by further advancing the future case study. If the design in the past, as an area of academics, has concentrated on strengthening of internal structure by borrowing the knowledge system of other areas, then the study of design in the new era, in the format of Design Thinking, is expected to make contribution towards progress of other academic fields and play the role of core facilitator in execution true multi-disciplined research from long-term point of view.

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