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TEACHING AXIOMATIC DESIGN TO STUDENTS AND PRACTITIONERS

Gyung-Jin Park
gjpark@hanyang.ac.kr
Department of Mechanical Engineering
Hanyang University
1271 Sa 3-dong Sangnok-gu Ansan City
426-791, Gyeonggi-do, South Korea

ABSTRACT

Recently, design education has been significantly emphasized in engineering schools because students can develop not only design skills but also creativity, an engineering philosophy, the right attitude for teamwork, etc. Design education is emphasized in industry as well. In the design courses, students or practitioners mostly carry out a team project for some design example and brainstorming is utilized in the thinking process. Generally, a specific method is employed in the detailed design process. However, they do not usually utilize design methodologies with a definite form in the conceptual design process. Instead, brainstorming and discussion between team members are adopted. Axiomatic design is an excellent candidate for a design method for conceptual design. This paper discusses experiences in teaching axiomatic design to undergraduate and graduate students and practitioners. In the undergraduate course, axiomatic design is taught and a team project is given to use axiomatic design. In the graduate course, students learn axiomatic design as a method for conceptual design while the methods of detailed design are taught as well. Engineers in industry learn how to use axiomatic design when facing problems. Syllabuses of the courses are introduced and project topics are presented.

Keywords: Axiomatic Design, teaching

1 INTRODUCTION

In the overall engineering process, the design process resides at the early stage because the plan for the product is defined. Although few resources and little budget are required in the design process, the impact of the outcome is substantial in engineering. In the past, activity to develop new designs was not very popular because a slight improvement of an existing design could make profit. As the competition grows in the engineering community, the concept of a new design receives significant attention. Even when design improvement is sought, this concept is important because considerable improvement is usually required.

During the past decades, analysis using mathematics and physics has been mainly taught in engineering schools and only intelligent engineers could usually manipulate the analysis techniques. These days, analysis techniques are easily used due to the development of excellent software. Even a novice can analyze an engineering system with sophisticated theories without much knowledge. According to this trend, synthesis (design) is quite important to exploit the analysis results. The emphasis of engineering education is being shifted from analysis to synthesis.

Design education should be newly developed for the paradigm shift. It is well known that the definition of a design education program is quite difficult. How to teach design is not rigorously established yet. When we ask "how do we teach design?" the answer is frequently "well." Two educators rarely agree on the topic. The reason is that design education is more like a philosophy and there are few pedagogical tools or methods. The design process is generally classified into three steps such as conceptual design, preliminary design and detailed design [Pahl and Beitz, 1984]. Conceptual design and preliminary design can be considered the same from the viewpoint of applying design methods [Park, 2007]. Education on detailed design is relatively well established since it is close to analysis. For example, optimization based on mathematics is popular in design education and easy to teach. Robust design, reliability-based design, etc. can be the other techniques in education. However, it is difficult to find good methods for conceptual design which has a lot more impact than detailed design.

Students are experiencing conceptual design through capstone design or external projects, and practitioners are frequently conducting conceptual design. Since they are used to analysis, they are complaining about the absence of a conceptual design method with a definite form. A design method for education on conceptual design should have the following characteristics: (1) The method should be simple enough to be understood in a short time. (2) It should have a rigorous theoretical background. In other words, it should be logical. (3) It should be able to be applied to both simple and complicated problems. (4) It should be globally applicable. (5) It should be usable for a new design and design improvement.

A few methods have been proposed for conceptual design and are being taught. One is a group of function-based design methods using the function structure diagram. The function-based design method designs a product using the function structure diagram. The function-based design methods of Pahl and Beitz [1984] and Hubka [1982], which represent European design research, have spawned many variant methods by Cross [1994], Ullman [2003], Ulrich and Eppinger [1994], and Stone and Wood [2000]. Regardless of the variations in the methods, all function-based design methods begin with formulating the overall function of a product. Then, the overall function is decomposed into small and easily solved sub-functions. Conceptual design can be obtained by defining sub-structures which satisfy the corresponding sub-functions and then summarizing the defined sub-structures into an overall structure. It is assumed that the designer knows the physical components for the sub-structures.

The other group uses a matrix representation, design structure matrix (DSM), based on relationships among the physical components [Steward, 1991]. Generally, DSM is constructed based on spatial, energy, material and information dependencies among components [Sosa, 2003, 2000] and numerical clustering algorithms are used to identify strongly related components and define modules in the physical domain [Yu, *et al.*, 2007]. It is assumed that the designer implicitly knows the functions of the physical components. Although these methods are excellent, it is difficult to teach them to beginners since they are complicated. Moreover, they can only be applied to the improvement of an existing design.

The third group uses TRIZ which is a Russian acronym for the theory of inventive problem solving. TRIZ was created and developed in the former USSR by the Russian engineer and inventor Altshuller. TRIZ is a science that studies evolution of technical systems to develop methods for inventive problem solving [Altshuller, *et al.*, 1998]. The TRIZ development group made a software system. However, it is difficult to use this technology for the design of a large scale system.

Axiomatic design (AD) is selected for a conceptual design method for design education [Park, 2007; Suh, 2001, 2005]. AD defined two design axioms: the Independence Axiom and Information Axiom. In AD, the design activity is carried out as an interplay between the functional domain and the physical domain. Functional requirements (FRs) are defined in the functional domain and the corresponding design parameters (DPs) are selected in the physical domain. The relation between FRs and DPs is expressed by a design matrix which should satisfy the Independence Axiom. That is, a DP is selected to independently satisfy the corresponding FR. When we have multiple sets of DPs that satisfy the Independence Axiom, the final DPs are selected by using the Information Axiom. AD can be applied to small-scale problems and large scale problems if we use the hierarchy of the system in a zigzagging process. Furthermore, it can be used for the creation of a new design as well as analysis of an existing design.

As seen in the title, this paper describes the teaching experience of AD. AD is taught to sophomore students in mechanical engineering. They have learned a little bit of engineering; however, they have not been exposed to the design world. At the beginning of the course, AD is taught as a design theory and a team project is given at the end of the course. The design project is given as a preparation for the capstone design course later. AD is also taught to graduate students from all the majors of science and engineering. Some of them are familiar with design and some of them are not. A few design methods are taught and AD is one of them. Design education with AD is given to various industrial practitioners as a short course. For practice, they try to use AD for their present problems. The syllabuses of the courses are demonstrated, and the advantages and difficulties are discussed.

2 AXIOMATIC DESIGN

Axiomatic design is a design methodology that was created and popularized by Suh [2001, 2005]. It gives the standard of a good design in an objective and rational way. Design is defined as a continual interplay between 'what we want to achieve' and 'how we want to achieve it.' 'What we want to achieve' is called functional requirements (FRs) and it is determined from customer needs. To satisfy the functional requirements, design parameters (DPs) must be selected by embodying them in a physical domain. The design process involves relating these FRs in the functional domain to the DPs in the physical domain. In other words, design is defined as the mapping process between FRs and DPs through the proper selection of DPs that satisfy FRs. The mapping process may depend on a designer's individual creative process. Therefore, there can be multiple good design solutions.

The domains and mapping process are illustrated in Figure 1. The customer domain is characterized by the needs that the customer seeks in a product. Based on these needs, the design engineers define the FRs in terms of uniformity and also the constraints. And then, DPs are determined in the physical domain to satisfy the corresponding FRs. Finally, to produce the product specified in terms of DPs, process variables (PVs) are defined in the process domain. FRs and DPs are decomposed into a hierarchy until designers obtain a complete detailed design or until the design is completed. A DP is determined by the corresponding FR in the same level and FRs in the next level are determined by the characteristics of the DP in the upper level as illustrated in Figure 1. This process is called the 'zigzagging process.' The zigzagging process is quite useful for large scale systems.

In axiomatic design, there are two design axioms. One is the Independence Axiom and the other is the Information Axiom. The Independence Axiom deals with the relationship between FRs and DPs, and the Information Axiom deals with the complexity of the design. The design axioms are defined as follows:

Axiom 1: The Independence Axiom
Maintain the independence of functional requirements.

Axiom 2: The Information Axiom
Minimize the information content.

The two axioms present the most fundamental means

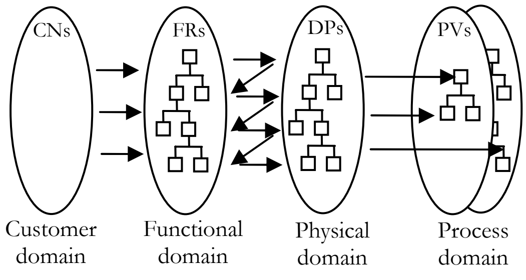

Figure 1. Concept of design, mapping and spaces [Suh, 2007].

needed to choose the best design. For a design to be acceptable, the design must satisfy the first axiom. If multiple designs are found to satisfy the Independence Axiom, the best one is selected by the Information Axiom.

As mentioned earlier, design is defined as the mapping process between the FRs in the functional domain and the DPs in the physical domain. This relationship may be characterized mathematically as follows:

$$\{FR\} = [A]\{DP\} \tag{1}$$

The characteristics of the required design are represented by a set of independent FRs. These may be treated as a vector {FR} with m components. Similarly, the DPs in the physical domain also constitute a vector {DP} with n components. $[A]$ is the design matrix which relates the components of the FR vector to the components of the DP vector. Design matrix $[A]$ is written as:

$$[A] = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix} \tag{2}$$

Each elements A_{ij} of the matrix relates a component of the FR vector to a component of the DP vector. In general, the element Aij is expressed as:

$$A_{ij} = \frac{\partial FR_i}{\partial DP_j} \tag{3}$$

Table 1 shows three cases of design according to the characteristics of the design matrix. When the design matrix $[A]$ is diagonal, each of the FRs can be satisfied independently by one corresponding DP. Such a design is called an uncoupled design. When the design matrix is triangular, the independence of FRs is guaranteed if and only if the DPs are determined in a proper sequence and such a design is called a decoupled design. If the design matrix is full, it is called a coupled design. The uncoupled design and decoupled design satisfy the Independence Axiom and the coupled design violates the axiom. When several FRs must be satisfied, designers must develop designs to create a diagonal or a triangular design matrix.

A simple design is a good one. From this, we may guess that a good design makes one DP satisfy multiple FRs. In other words, a coupled design looks better. This aspect is very confusing in axiomatic design. However, from an axiomatic design viewpoint, this is the case where multiple DPs are combined into a physical entity. That is, multiple DPs satisfy FRs of the same number. This is called 'physical integration' and recommended.

The Information Axiom states that among all of the designs that satisfy the Independence Axiom, the one with the minimum information content is the best design. The Information Axiom is related to the complexity of a design and implies that the simpler design is the better one. In the Information Axiom, the DPs are selected according to information content. The information content is defined by the probability of success to satisfy corresponding FRs. For example, the information content for the ith functional requirement is defined as:

Table 1. Relationship between FRs and DPs.

	Uncoupled design	Decoupled design	Coupled design
Design matrix	$\begin{bmatrix} A_{11} & 0 \\ 0 & A_{22} \end{bmatrix}$	$\begin{bmatrix} A_{11} & 0 \\ A_{21} & A_{22} \end{bmatrix}$	$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$

$$I_i = \log_2 \frac{1}{p} \tag{4}$$

where p is the probability of success for the ith functional requirement. The total information content is the summation of the information quantities. Calculation of the information for decoupled design is introduced in a reference [Park, 2007].

3 OVERALL DESCRIPTION OF THE COURSES

3.1 UNDERGRADUATE CLASS

Design is taught to sophomore students who have been somewhat exposed to mechanical engineering at Hanyang University, Korea. The title of the course is 'Introduction to Mechanical Engineering.' The students are taking some mechanics courses but have never taken any design courses. The purpose of this course is to inspire and train students on 'Design Thinking.' The general concept of design is sought and the thinking process is investigated. Axiomatic design is introduced as the general design theory. The materials are taught to two sections of the class. Each section has 20-30 students. Lecture notes are written for this course and the contents of the notes are shown in the Appendix.

The schedule of the course is illustrated in Figure 2. Since the students do not have a concept of design, design is explained in detail with elementary aspects. In the beginning, why we have to learn design is taught with the spectrum as

Week		Class activities	Term project
1	1	Welcome to the design world (I)	
	2	Welcome to the design world (II)	
2	1	Introduction of the project topics	Introduction of the project topics
	2	Formation of the project teams and project team meeting 1	
3	1	What is design?	
	2	Elements of design	
4	1	Elements in design	
	2	Introduction to Axiomatic design	
5	1	How to write the proposal, progress report and final report	
	2	Project team meeting 2	
6	1	Introduction to Axiomatic design	Submission of the proposal
	2	Project team meeting 3	
7	1	Axiomatic design (Independence Axiom)	
	2	Axiomatic design (Independence Axiom)	
8		Midterm	
9	1	Axiomatic design (Independence Axiom)	
	2	Project team meeting 4	
10	1	Axiomatic design (Information Axiom)	Progress report of the proposal
	2	How to make presentation materials (practice)	
11	1	How to make presentation materials (practice)	
	2	Project team meeting 5	
12	1	How to make presentation materials (practice)	
	2	Project team meeting 6	
13	1	Design examples (industrial design)	
	2	Project team meeting 7	
14	1	Design examples (industrial design)	Submission of the final report
	2	Project team meeting 8	
15	1	Presentation of the term project	
	2	Presentation of the term project	
16	1	Presentation of the term project	
	2	Presentation of the term project	

Figure 2. Schedule of the undergraduate course.

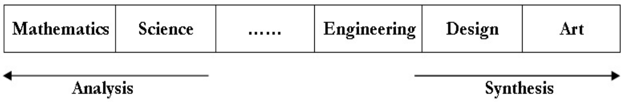

Figure 3. Spectrum between analysis and synthesis.

illustrated in Figure 3. Mathematics which the students are familiar with resides at one end of the spectrum. Engineering is located in the middle of mathematics and art, and design is between art and engineering. The students learn the elements of design such as customer needs (CNs), functional requirements (FRs), design parameters (DPs) and process variables (PVs) illustrated in Figure 1.

Functional thinking in the design process is emphasized. Functional thinking means that when we design a product, we have to keep FRs in mind without DPs. That is, we have to define FRs first and try to find DPs to satisfy the FRs. If we associate DPs first from an existing product, we cannot design a product in a solution-neutral environment. The Independence Axiom is emphasized in the mapping process between FRs and DPs. Functional thinking is adopted for this process. Because the students are novices for design, small scale design problems are introduced and they are selected from the text [Park, 2007; Suh, 2001, 2005]. The examples listed in Table 2. How we define FRs and DPs are presented and the zigzagging process for large scale problems is introduced a little in this class.

The Information Axiom is utilized to pick the best design out of multiple designs which satisfy the Independence Axiom. Since a one FR-one DP problem automatically satisfies the Independence Axiom, the Information Axiom can be directly used to pick the best one if we can find multiple designs. When we have multiple FRs or a large scale system, it is not easy to find multiple designs which satisfy the Independence Axiom. Moreover, the calculation of the information content is quite complicated for the decoupled design for a large scale system [Park, 2007]. Therefore, only the concept of the Information Axiom is introduced with a simple example with calculation of the information content. The concept of physical integration is explained with examples. It is shown that the information content can be reduced by physical integration.

The students are not familiar with writing a proposal and report and doing a presentation, but they have to do such activities for the team project which will be explained later. During the class, the instructor teaches how to write the proposal, the progress report and the final report for the project. The students submit a report for each progress as illustrated in Figure 4. The students learn how to make the presentation materials for the project and present the results as the final examination.

These days, aesthetic aspects are important in a consumer product design. Product engineers tend to ignore such points.

Table 2. Examples for the undergraduate class.

	Example
Small scale problems	Toaster, Refrigerator door, Water faucet, Bottle-can opener, Beverage can
Large scale problems	Lathe, Refrigerator, Laser marker, Automobile steering system

(a) Rubber band gun using chopsticks

(b) Water rocket with a launch pad

(c) Travel bag

Figure 4. Some results of undergraduate projects.

Industrial design is presented to students to complement this weakness. The history of industrial design is taught with case studies and sensibility is emphasized. Since the instructor is an engineer, some industrial engineers helped the instructor for presentation of the lecture materials.

As mentioned earlier, a team project is given to a team of 3-4 students. A teaching assistant (TA) is assigned to every 2-3 teams and the TA manages the teams for the progress of the work. The instructor used almost 10 TAs for this class and the TAs are educated during the vacation beforehand. As shown in Figure 2, a project team meeting is held as a regular class. The project topics are changed every year and the list of the topics is shown in Table 3. The topics are given by the instructor or the students can freely choose one. Mostly, the students take a topic from the instructor. Axiomatic design is recommended for the design of the project but not required. When a team makes a real product, the members receive a better grade. About $50 is provided to each team and the team should design and make a product within the budget. They should make an accounting book and submit it with receipts. The students are evaluated from multi-facets and the grading policy is shown in Table 4. It is noted that the team members evaluate each other.

Table 3. List of the class project topics.

Project topics
New keyboard design, Wine packing box design, Spring powered vehicle design, Balloon powered vehicle design, Rubber band gun, New chair design, Water rocket design, Cannon design, Bag design, Roller coaster, Balloon powered vehicle design, Cooking system using green energy, Design of an egg protection system, Design of a functional wastebasket, Wake-up system, Design of an elastic band power vehicle, Multi-purpose enclosure, Boat propelled by a candle, Multi-purpose bookshelf, Multi-purpose table, Portable chair for subway

Table 4. Grading policy of the undergraduate course.

Theory	Homework	25%	50%
	Attendance	10%	
	Midterm exam	15%	
Project	Peer evaluation	10%	50%
	T.A.'s evaluation	20%	
	Final presentation	20%	
Total			100%

3.2 Graduate Class

Axiomatic design is taught to graduate students of Korea Advanced Institute of Science and Technology (KAIST), Korea. It is taught in a core course of the Renaissance program. The Renaissance program is an integrated M.S. and Ph.D. degree program at KAIST. Students from any engineering majors can participate in the program. They have to take the core course of 4 credits (4 hours a week during a semester) and a departmental design course of 3 credits with other courses. Then they take two other departmental project courses (3 credits each). After the course work, it is recommended to write a Ph.D. thesis with the topics related to design of their expertise.

Most of the students of the core course are in the entry level of the graduate program. The name of the course is 'Collaborative System Design and Engineering.' The schedule of the course is illustrated in Figure 5. The class is held twice a week for two hours each and axiomatic design is taught during the quarter of the semester. As shown in Figure 5, some other design methods are taught as well. They are system engineering, collaborative design with creativity and the methods for detailed design such as optimization. Some of the students have heard of axiomatic design and some have never heard of it. Because they finished the undergraduate course, they have their own personal viewpoints on design. The instructor assumes that they do not know anything about axiomatic design. Therefore, the elementary aspects of design and axiomatic design are briefly introduced at the beginning.

Week	First class of the week	Second class of the week	Remark
1	Systems and Systems Engineering	Design as a Science and Principle-Based Design	
2	Systems Thinking, System Requirements and Functional Analysis	Fundamental Elements in Design	
3	System Modeling, Simulation and Analysis(I)	Axiomatic Design	
4	System Modeling, Simulation and Analysis(II)	Axiomatic Design	
5	System Integration	Axiomatic Design	
6	Systems Engineering Process Standard(I)	Independence Axiom	
7	Systems Engineering Process Standard(II)	Information Axiom	
8	Mid-term		
9	Collaboration and Sustainable Innovation	Optimization Methods	
10	Collaborative Learning and Learning Organization Models/Tools for Collaboration	Optimization Methods	
11	Collaborative Creativity, Methods of Group Idea Generation and Communication	Optimization Methods	Proposal of the Final Project
12	Computer-Aided Creativity as a Collaborative approach	Design of Experiments (DOE)	
13	Basis of Knowledge Creation, Whole Brain Theory and Creative Teamwork	Design of Experiments (DOE)	
14	Nonaka's Theory of Knowledge Creation	Approximation Methods of Optimization	
15	Nonaka's Theory of Knowledge Creation	Presentation of the Term Project	Final Report of the Term Project
16	Final Examination		

Figure 5. Schedule of the graduate course.

Table 5. List of examples for the graduate course.

	Example
Small scale problems	Toaster, Refrigerator door, Water faucet, Bottle-can opener, Beverage can, Refrigerator, Laser marker
Large scale problems	Software development using AD, Mobile harbor, On-Line Electrical Vehicle, TRIZ and AD

Functional thinking is emphasized when using the Independence Axiom. It seems that the students understand the concept of functional thinking better than the undergraduate students. When students learn axiomatic design, many design examples are demonstrated. Some of them are small scale problems from the textbook [Park, 2007; Suh, 2001, 2005] and some of them are large scale examples from the instructor's research. The examples are listed in Table 5. For small scale problems, how to define FRs and DPs is mainly explained to use the Independence Axiom. The zigzagging process is emphasized for large scale problems. As mentioned earlier, the FRs of a certain level in the entire hierarchy should be defined from the DPs of the upper level and DPs should be defined from the FRs of the same level. The reasoning process is explained with large scale examples.

Education for the Information Axiom and physical integration is carried out as well. It is basically similar to the undergraduate class. As shown in Figure 5, detailed design methods such as optimization and robust design are taught in the second half of the semester. The relationship between axiomatic design and detailed design is explained. Generally, we have a design variable vector which consists of many design variables. An FR of axiomatic design is equivalent to the objective function of a detailed design while a DP of axiomatic design is equivalent to the design variable vector of the detailed design. The detailed design process is a one FR-one DP problem from the axiomatic design viewpoint. Therefore, the Independence Axiom is automatically satisfied and the detailed design process is similar to the process of applying the Information Axiom. It is taught that the concepts of robust design and the Information Axiom are similar. Enhancing robustness of a system is the same as reducing the information content.

Term projects are given to teams of students. A design plan should be made by using any methods learned in class. A team is made by seven students because 7 people are required to use the method for collaborative design shown in Figure 5. Manufacturing of the product is not required. The load for the term project is lighter than the undergraduate course because many theories are taught. A list of the term projects is shown in Table 6. The topics are selected by the students. The students present the final result in the final class. It seems that about two thirds of the teams use axiomatic design for their projects. From this phenomenon, we can see that using axiomatic design is easy compared to other methods.

3.3 TEACHING PRACTITIONERS

Axiomatic design is taught to field engineers in Korea. Various companies invited the instructor for teaching axiomatic design. Generally, 20-30 engineers participate in the class. The engineers have some years of experience with design and are facing current design problems. Most Korean engineers took design courses when they were university students. However, they did not receive education for the modern concept of design. Therefore, they have some rough knowledge of design, especially on conceptual design. The duration of teaching varies according to the request. The period should be at least more than three hours to become acquainted with axiomatic design because there is lecture and practice time. The duration of the lecture is 2 hours, 3 hours and 8 hours. They can have a one week workshop. The longest period that the author taught is 8 hours. The teaching materials are varied according to the time and the materials are shown in Table 6.

Basic aspects of axiomatic design are taught in the two hour class. It is like a long regular seminar. The instructor can briefly introduce the concept of axiomatic design and have a short discussion. The engineers usually want examples of their expertise. If the instructor has such examples, it is easy to explain the technology. However, when the instructor does not have such examples, it takes time for them to understand the examples that the instructor has. In this case, small scale problems used in the undergraduate course are good candidates. The education for the Information Axiom is basically the same as the one for the undergraduate class. However, the instructor spends more time on physical integration. It seems that the engineers fully understand and agree with the concept of physical integration from their practical experience.

For the three hour class, the engineers can have a practice time to apply axiomatic design to their current problems. The time is not sufficient to finish the work or to have a long discussion. Some engineers send emails for questions after the lecture. Eight hours is appropriate for the class time. Other than the basic theories of axiomatic design, large scale problems with the zigzagging process can be demonstrated. One hour practice time can be given and the results can be discussed. For a one week workshop, a full cycle of education and practice would be possible.

4 SUMMARY

Axiomatic design is taught to university students and practitioners. The students are not familiar with executing a design while the practitioners are facing design problems. On the other hand, the students do not have a preconception of design but the practitioners have some. These characteristics have advantages and disadvantages, respectively.

The students expect some rigorous theories and processes like mathematics or physics due to their background. When they find there may not be such methods for conceptual design, some of them are disappointed. Even though a student may find mathematics and physics difficult, s/he becomes relieved to know that analysis is not everything. When we teach analysis to graduate students, the academic level should be a lot higher than that when we teach to undergraduate students. However, design education could be similar except for the scale of examples. In other words, some undergraduate students are better than graduate students if analysis is not involved.

Table 6. List of term project for graduate course.

Project topics
Software design from the axiomatic design viewpoint, Mobile harbor, Axiomatic design in metal forming, Fuel cell, Rocket design, Venture business, Haptics and robot design, Bicycle parking system, New panama container ship, Automatic management of a flowerpot, Design of a dining system, Automatic control of a closet

When the practitioners learn axiomatic design, it takes some time for them to understand. If they can agree with the value system of axioms, they can understand easily. Especially, the value system should be the same as their past experiences. Thus, axiomatic design should be explained in their value system and language. Because the instructors are generally scholars, discrepancies can occur. Many practitioners are confused by coupling and physical integration. It should be carefully explained that they are different so that physical integration satisfies the Information Axiom. Functional coupling should be explained well and the word "physical coupling" can be utilized instead of physical integration. Some practitioners come to the class to learn a design method which they can use right away. When they find that they need practice for efficient use of axiomatic design, some are disappointed. Some practitioners already have realized the value system of axiomatic design from the experiences although they did not explicitly express it. In this case, they are enthusiastic and passionate in learning axiomatic design.

There could be many controversies in design education. In many places, the design process is taught, a design project is selected and the students practice the design process. Most decision makings are made by intuition, experience or brainstorming. For scientific or objective design, axiomatic design is a good candidate for design education. Since the education is not made by mathematical formulae, appropriate explanation based on the background of the audience is quite crucial.

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APPENDIX: CONTENTS OF THE LECTURE NOTE FOR THE UNDERGRADUATE