

## LEARNING THE FUNDAMENTALS OF DESIGN THROUGH THE AXIOMATIC DESIGN PROCESS: A CASE STUDY ON ED100 AT KAIST

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### ABSTRACT

In this paper, we review the course ED100 “Introduction to Design and Communication” offered at KAIST. This course instructs the students on the basics of design using the Axiomatic design process, a unique course structure, and multiple sources of information. We review in-depth the correlation between the Axiomatic Design Theory and curriculum, the behaviour of students in response to the course material in a semester framework, and the impact of the course on the students by using our project as an example: the design of a vaccine delivery system to developing countries.

**Keywords:** Vaccine, KAIST, Education, Curriculum, Design, Communication

### 1 INTRODUCTION

The first introductory course to design theory for any student is of great importance, and can greatly affect his or her academic career because it has the ability to shape the students approach to design. This work examines the design process of a vaccine delivery system for developing countries in the course framework of ED100. We discuss the suitability of applying the Axiomatic Design Theory to an introductory design course and explore the course’s impact on the students and the success of the course.

### 2 BACKGROUND

Each student who participates in the class ED100 is allocated a project, linked to a department at KAIST, and is asked to conceive, design and develop a specific product or service based on the constraints and requirements offered by that specific project.

The semester-long course has three basic components: main lecture, design labs, and communication labs. The main lectures are designed to instruct the students of theory and

concepts, while introducing design to the students in context of its ambiguous nature. The design labs, are instructed by professors from a specific department, and are intended to guide students in a more specific and reduced scope for technical guidance concerning the project the student is given. Mated with these lectures and design labs are communication labs, a session intended to assist in the design process by allowing communication and interaction between students to optimize results of the coursework. Teams are formed, generally with four to five students in one team. Team forming activities are also implemented to assist the students who are in participating in the project. The most visible milestones and deliverables in this project are homework assignments, design reviews offered by ED100 lecturers, and finally the end of the semester poster fair, where we present our final projects.

### 3 METHODS

#### 3.1 GENERATING CUSTOMER NEEDS

Each homework, lecture, and design lab correlates to a step in the process of Axiomatic Design. Our design lecturer, Prof. Mary Kathryn Thompson or Prof. Taesik Lee, would instruct the students on the concept or process of the week. Our project adviser, Prof. Jung Kim from the Mechanical Engineering Department, would instruct us on a technical concept related to the project, and we would use these concepts to complete the task required by the course. The earlier portion of the course in the timeframe of the semester is used to generate customer needs for the design process. In our case, a problem was presented and constraints and regulations given early on. These constraints and problems were provided by our project advisor.

Our problem was to deliver vaccines into remote areas of developing countries where ground transport was not available. The vaccines had to be air dropped to their final locations, had to maintain a certain temperature for the vaccines to maintain their integrity, and also signal the recipients on the ground. The largest problem was that the

containers had to withstand the impact of being airdropped onto unknown terrain. The project also contained other built in constraints. The amount of ice able to be used in the container was limited to one kilogram. The use of parachutes was prohibited. The overall volume of the container was limited to ten liters. Finally, the container had to contain six vaccines with specific dimensions.

These constraints generated functional requirements on their own, but the course proceeded to guide us to explore other sources of customer needs. This process was started by allowing us to define the customer, client, and end user. We were also encouraged to explore the relationship between each stakeholder, define the stakeholders, and come up with specific survey questions and interviews to produce the best set of customer needs we could generate with given resources. In our case, we conducted surveys amongst fellow students, and interviewed industry professionals to come up with data for our customer needs.

### 3.2 GENERATING FUNCTIONAL REQUIREMENTS

The course, after generating customer needs, asks us to create the functional requirements of our design based on the customer needs we have created. We enter the mapping process and generate a complete list of functional requirements. The specifics of how to create functional requirements are taught in lecture, and are refined by communication labs and design labs. We had to analyze each customer need and regulation/constraint to generate corresponding functional requirements (Table 1). In our case, we had three main functional requirements. Our team, had a slightly different approach to generating functional requirements, as the many of the regulations and constraints given by the project guided the functional requirements of the product. This forced us to create a set of non-functional requirements, generated by surveys and interviews to help us design the product.

### 3.3 GENERATING DESIGN PARAMETERS

Our team thought that the process of generating design parameters required the most creative thinking, while encouraging us to find ways to improve upon existing design. This portion of the course is where the literature search and background research helped the most, as we created concepts and design solutions for each functional requirement. The course required us to create multiple concepts for each functional requirement, resulting in a set of design parameters for each functional requirement.

A selection criteria lecture gave us the tools to come up with a selection method for choosing design parameters for each functional requirement, resulting in a fully mapped list of design parameters at the end of this process. In our case, we decided to implement the “3c STP 4p framework from Marketing. Using this framework, we generated solutions and definitions for the 3c: our company, client, and competition, STP: segmentation, targeting, and positioning, and 4P: product, placement, promotion, and placement. This framework helped us generate specific

strategies for marketing, based on customer needs, surveys, and our product to assist in the selection criteria for our design parameters. This process also allowed us to integrate “non-functional” requirements into the design process, and constant revision of our strategy allowed us to remap and revise the functional requirements and design parameters for our final set of design parameters.

**Table 1. Functional Requirements by Stakeholder**

People in the Design Process		Requirements			
Generally	Specifically	Active “to do”		Passive “to be”	
		Functional	Aesthetic	Financial	Other
Clients		FR1-1	FR5-3		FR5-1,FR5-2
Upstream	Suppliers	FR1-1			
Development Team	Design Team	FR1-2,FR2-1,FR2-2,FR3-1,FR4-1,FR4-2	FR1-2,FR5-3	FR1-1	FR5-1,FR5-2
	Manufacturing Team	FR2-1,FR2-2,FR3-1,FR3-2,FR4-1,FR4-2	FR1-2,FR5-3		FR5-2
	Packaging Team	FR1-2,FR2-1,FR3-1,FR3-2			
	Marketing Team	FR1-1			
	Financial Team	FR1-1			
Downstream	Shipping Contractor	FR1-2			
	Retailer	N/A			
	Repairer	N/A			
Customer(s)		FR5-1,FR5-2	FR5-3		
User(s)		FR4-1			
External Influences	Government	FR1-1,FR2-1,FR2-2,FR3-1,FR3-2,FR4-2	FR5-3		FR5-1,FR5-2
	Society	FR1-1,FR2-1,FR2-2,FR3-1,FR3-2,FR4-2	FR5-3		FR5-1,FR5-2
	Environment	N/A			
Externally Influenced	Primary Effects				
	Secondary Effects				
	Tertiary Effects				

### 3.4 GENERATING PROCESS VARIABLES

The revised mapping between the functional requirements to the design parameters coupled with the revision of the customer needs based on our marketing strategy generated new process variables for our design. In this process we considered manufacturing and logistics, using design aids such as finite element analysis to come up with specific methods on how to create each subsystem of our product. Great assistance was needed from our project advisor for technical assistance on the mechanics of our design, and although the course only required literature search during the earlier parts of the course, continued research and benchmarking was required for us to gather knowledge on how to create feasible process variables.

### 3.5 DESIGN AIDS

In order to generate the most practical design without compromising creativity, the students were encouraged to implement a broad spectrum of tools to assist in the process of Axiomatic Design during the course. The course not only required us to use this process of design to create a product or service, but it also was asking us to manage the team, while managing other coursework and activities. There were group meetings outside of class, and design challenges that were difficult to solve as freshmen, requiring knowledge and assistance from other disciplines as well. In our case, our team experienced immense schedule conflicts and difficulties in identifying variables that would ameliorate our design. This is why we implemented a strategic framework from other disciplines. The aforementioned strategic framework from marketing was used to generate non functional requirements for a more comprehensive customer need matrix, while we researched project management disciplines to help us manage

conflict and the project as a whole. The act of participating in the class was a project in itself, and we applied knowledge from the study of project management to help us complete tasks on time with maximum possible quality. There were also problems in the physics and mechanics of our design as we felt that simple physics equations that we were limited to because of our limited knowledge would not be able to solve every variable. This is why our team also decided to learn how to operate 3D prototyping software and Finite Element Analysis tools to use as preliminary design aids to create more specific and practical design parameters and thus process variables.

## 4 RESULTS

### 4.1 DELIVERABLES

0415593274 There were three major deliverables for the course. The first was the mid-term design review. This was a chance for the students to present their designs to the lecturers of the course and receive feedback and advice on how to improve the design and design process. The second was the end of the semester design poster fair. This was a chance for the students to get together and view all the projects of the students. It was also an opportunity to be evaluated by the communication lab advisors and lecturers on the quality of the end product or service and posters that explained the project of the team. The last major deliverable was the final paper which was a comprehensive report on the semesters work including the final design and each step that led up to the final design. Other minor deliverables included homework issued by both the project advisor and lecturers, and deliverables defined by the students themselves such as reports and notes used to communicate amongst each other. For example, our team generated reports for chemical experiments, finite element analysis results, and marketing strategy reports amongst the team members to inform each other of the improvements and findings found in each section before integrating the results into our design.

### 4.2 DESIGN RESULTS

Our final design based on the customer needs and functional requirements was a vaccine delivery system that used an airbag system to reduce impact from the air drop. An ABS plastic, injection molded casing was used to shield the vaccines from heat. A temperature management system used an endothermic chemical reaction of ammonium nitrate and water to keep the vaccines cool. A signaling system using smoke generated by a combustion reaction of a potassium nitrate based fuel was used, and a corresponding prototype was created through the use of carbon composites and materials budgeted by the course. Our end product also provided a marketing strategy that was coupled to the product to maximize the distribution of the vaccine container, while also containing a sample case study on how the logistics of the distribution of the vaccine container would be carried out. In addition, the manufacturing of the vaccine container was designed in a mock up fashion to see if the manufacturing of the product would be possible, and also to find out how much it would cost to manufacture the product at certain volumes.

These specific solutions were generated by the design process and the final results were submitted to the lecturers for final grading.

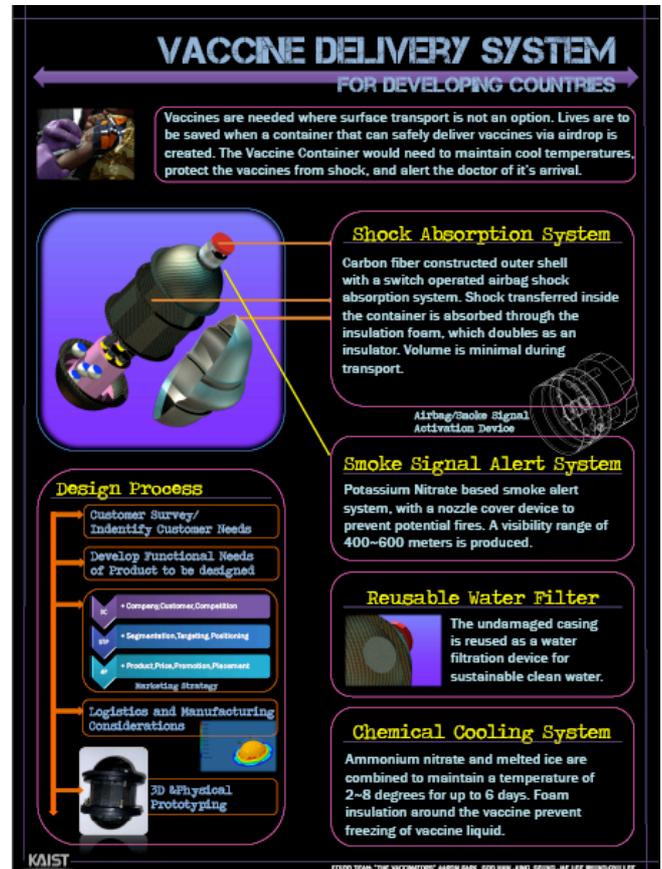


Figure 1. Final Poster for Vaccine Container Design Project

## 5 DISCUSSION

### 5.1 IMPACT OF ED100 ON FRESHMEN AT KAIST

Although we can offer only limited perspective as freshmen ourselves, we believe we may be able to offer some insight into the impact that this course had on the students in general at KAIST. Generally, the students at KAIST are considered to be highly competitive, motivated students, but there are also other characteristics of the students because they have adhered to the standard curriculum offered in South Korea. Although very strong in theory, the standardized curriculum somewhat molds the students into not being able to reach their full potential in terms of their ability to use creativity and problem solving skills. The analytical skills of the students here are sometimes limited because they have not yet had a chance to explore that portion of their academic ability. ED100 was generally considered a tough but fun course by the students, tough because it required them to deal with constraints and a design process that generated something real, and tangible. In order to successfully complete the steps of the design process, the students were pushed to consider as many variables of the design as they could, and pushed their creativity to a new level. The homework

mentality was broken, and rather than considering the tasks as a simple assignment, the students generally tried their best to create something to the best of their ability.

The students generally react to courses considering cost to credit/grade ratio, despite the course ED100 being another three credit course, students spent immense amounts of time and thought independently in order to improve upon their design, exploring possible applications of their design, and also exploring other possible applications of the design process. Even jokingly the students would bring up concepts from the lecture during casual conversation, indicating that the concepts and theory taught in during the course were deeply penetrating.

The competition, although subtle, was also a large factor in motivating the students to strive for excellence. Considering the grade/credit to time invested ratio, grades were not the cause for competition, especially because the projects were not graded on a curve. We were able to identify three major sources that created competition. The first was the potential recognition and award, highlighted by an award ceremony at the end of the semester. The second source was competition amongst the students across different projects, all striving to generate the best possible designs for each project. However, the strongest competition was between the teams that dealt with the same projects. This friendly, but fierce, competition motivated the students to come up with better and more creative solutions than the other teams, creating different types of satisfaction in the involvement of the course.

## **5.2 ACADEMIA VERSUS INDUSTRY**

Dealing with the industry proven design process of Axiomatic Design also had its merits of being applicable in the real world. Our experience with our education so far proved that the theory and material we experience in the classroom often is limited to theory itself. We usually do not deal with real constraints and limitations, and often benchmarking upon other's ideas is frowned upon. However, ED100 offered the students a chance to decide between improving upon existing ideas and creating something completely new. The design objective and selection criteria although self generated allowed the students to make decisions that produced maximum results, not maximum points. Although ED100 is an introductory course for freshmen, and consequently is not as in depth as it could be, it gives the student a comprehensive perspective on what it takes to create and design in the real world. It teaches us that simply generating random ideas that seem to be creative is not enough. We see the matrices and mapping generate real solutions for real constraints and needs, and the end product is evidence that the process works. This assurance motivates the students. This would have been best witnessed at the poster fair, where prototypes of the design were displayed, and refined concepts and ideas created a plethora of fantastic design solutions for existing problems. The real difference can be seen through the difference in what the students were doing in high school versus what they had created for this course. Although none of the students had taken any major

courses at KAIST, and general education was what the students were limited to, the quality of the ideas that were generated cannot be compared to what the students were generating in high school.

## **5.3 LEADERSHIP**

Another key merit of this course is the lessons it implicitly teaches in leadership. With most students holding a more than average workload with other classes, schedule conflicts and team management issues arise inevitably. Conflicts come in different forms, and conflict mediation and leadership is required by all the students to successfully complete the project. In addition, the workload of the course is designed so that not one but all students' participation is required for the completion of tasks, and higher levels of quality. In order to motivate everyone to participate, it is often required that all students demonstrate some sort of leadership. Whether this type of leadership involves serving other students by assisting, or managing the group schedule, or giving motivation to each other, each student has a chance to develop their leadership skills. Personally, our group had issues with the work load being concentrated on only one or two students the earlier part of the semester, and because the course load required all of us to work together, compromise and teamwork, but most importantly leadership was created out of the project.

## **5.4 TEAMWORK**

Most students, entering college have limited experience in participating in-group projects. It is often not required for the students especially in South Korea to involve themselves heavily in-group activities. Because of this ED100 offers students a chance to work in a team environment with a common goal. However, the unique characteristic about ED100 is that it does not allow the students to split the work load and work independently. It requires the students to work together. Our advising professor Jung Kim repeatedly informed us that collaboration and harmony would be required for the success of the project rather than equal distribution and specialization of the tasks. This was definitely true, and in the context of our education and the years to come in the academic setting, but most importantly industry settings, this type of teamwork and leadership is especially more valuable because it is encouraged early on.

## **5.5 BROADENED SCOPE OF STUDENTS**

The greatest advantage in our opinion in terms of the implementation of this course at KAIST was that the students gain a wider perspective on their academic careers. This is mainly because they see the application portion of theory, the need for other disciplines and most importantly the difficulties of managing a project. They experience the need for careful planning, quality, and the necessity of good advice and guidance. Moreover the experience also helps the students experience portions of multiple disciplines that will help them make decisions on what they want to do with their academic careers. Our overall opinion of this course is that it is

imperative for students to experience the Axiomatic Design process during the earliest part of their academic careers for maximum yield and efficiency of the students' careers

### **5.6 LIMITATIONS**

ED100 despite its merits also has its limitations. Often times the students feel that the workload is sometimes too high, mostly because the students often feel the need to spend excess time on tasks given by ED100 project advisors and lecturers. There are also limitations in that the students are unable to pursue deeper levels of understanding concerning axiomatic design and its applications because industry based examples are often too complex and difficult to understand at a freshmen level. Further instruction is needed to go deeper into learning, and because of this, application to other projects and areas of study for the student is limited to the content offered by the course. Moreover, students who wish to pursue patents and further development of their design are halted by the vacation at the end of the semester, and we feel that many ideas that should be made into patents and further developed are lost without proper attention.

### **6. CONCLUSIONS**

ED100 at KAIST was a defining moment in our academic careers, and will govern the way we perceive and analyze in our respective fields. It has been an excellent

experience for all of us freshmen, not only due to the coursework and activities distributed by the course, but also because of the entailing culture and interaction between the students that is created outside of the classroom. Although classes in the future may offer similar experiences, as freshmen it is a unique opportunity to experience such a class.

### **7. FURTHER RECOMMENDATIONS**

Our recommendations for the improvement of this course and the application of Axiomatic Design is to offer classes that follow a class like ED100, that allow specialization and deeper development of the products and services created in the classroom.

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