

Green Design in Cornerstone Courses at KAIST: Theory and Practice*

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Environmental sustainability and eco-friendly design are becoming increasingly important in engineering today. This paper discusses green design in the KAIST Freshman Design Program. It is shown that students and faculty members tend to choose green design projects, even when not required. Students have successfully adapted general design processes and formal design theories to eco-friendly design projects by defining eco-friendly functional requirements, constraints, and selection criteria. The use of a more formal stakeholder analysis to address a wider range of environmental sustainability issues has promise. However, these benefits have not yet been reflected in freshman projects. Ultimately, ED100 may be a good model for incorporating green design in a general design course.

Keywords: green design; design education; design theory; first year

1. INTRODUCTION

DISCUSSIONS ABOUT ENVIRONMENTAL sustainability and the inclusion of eco-friendly or 'green' design projects are becoming increasingly common in engineering design courses. However, the field of green design is still relatively new and there is still much to be learned about environmental sustainability in cornerstone design courses. This paper discusses various aspects of green design in the KAIST Freshman Design Program, including the origin, nature and prevalence of green design projects and the way that green topics are handled in the course material. Three brief case studies from student projects are presented. Finally, the success both of individual student projects and of the course's handling of green topics in general are discussed.

2. FRESHMAN DESIGN AT KAIST

The Freshman Design Program at KAIST [1,2] consists of two classes: ED100: Introduction to System Design (3 units) and ED101: Communication for Design (1 unit). These two classes are taught as a single, unified 16 week cornerstone course, often simply referred to as 'ED100.'

At KAIST, ED100 is required for all incoming freshmen regardless of major. Approximately 400 students take the course each semester. The course is offered twice a year to accommodate the full freshman class. ED100 was first offered as a freshman elective in the Fall of 2007. The full scale version has been offered since Spring, 2008. (The Korean academic school year starts in the spring,

so the freshman design requirement was new for the class of 2011.)

ED100 is a project based course. Up to 20 different semester-long projects are offered each semester by KAIST faculty members. These faculty members can be from any academic department at KAIST and serve as the project advisers for the course.

Each design project is assigned 4–5 teams which consist of 4–5 students each. Students choose their projects by lottery. (In Spring, 2009 roughly 70% of the teams received their first choice in the lottery.) Each team is required to produce a presentation for a mid-term design review, a final poster for an end-of-term poster fair, and a final paper. Prototypes, demonstrations, or other types of visual aids are optional for all students, but may be required by individual faculty project advisers.

The course format changes slightly each semester. In general, students attend 1 hour of design lecture, 3 hours of design laboratory, and 2 hours of communication lecture and laboratory per week. Design and communication laboratory sessions are often replaced by individual team meetings or clinics with their professor or Teaching Assistants (TAs).

ED100 is intended to change the way that the students think, view education, view the world, and view their role in the world. The course tries to help students become conscious, rational, independent, systematic, and synthetic thinkers who can question, evaluate, and make decisions. It encourages students to teach themselves and to learn independently. It helps students to improve their teamwork and communication skills. Ultimately, it is hoped that the course will help students to recognize the value of their education and to understand that their abilities can (and

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Table 1. KAIST freshman design program overview

	Design	Communication
Week 1	What is Design? Why Learn Design?	Team Work and Team Communication
Week 2	Design Process Overview. Problem Definition	Professional Communication and Brainstorming
Week 3	Customer Needs and the Customer Domain	Background and Customer Research - Part 1
Week 4	Design Specifications and the Functional Domain - Part 1	Background and Customer Research - Part 2
Week 5	Design Specifications and the Functional Domain - Part 2	Visual Communication - Part 1
Week 6	Strategies and Design Concepts	Oral Presentations - Part 1
Week 7	Design Parameters and the Physical Domain	Visual Communication - Part 2
Week 8	Midterm Exam Week	
Week 9	Refining and Improving Concepts	Oral Presentations - Part 2
Week 10	Design Review Week	
Week 11	Concept Testing and Selection	Written Communication - Part 1
Week 12	Implementation and the Process Domain. Advanced Design Matrices	Written Communication - Part 2
Week 13	Special Lecture on Intellectual Property	Written Communication - Part 3
Week 14	Unscheduled. Work on Projects.	
Week 15	Poster Fair Week	
Week 16	Final Exam Week	

should) be used to make a positive difference in the world.

As a result, much of the course material is focused on promoting good design thinking [3, 4] through formal design theories and methodologies. Design lectures are primarily based on material from Axiomatic Design Theory [5] and traditional product design [6]. The lectures are also supplemented with materials from Altshuller [7], Pahl and Beitz [8], Simon [9], Suh [10], and others.

Weekly project homework assignments are given to all students in the course. These are open-ended assignments which require the students to apply the lecture material to their specific projects. These assignments help to guide the design process and prepare the final deliverables. Project advisers can assign additional homework if necessary.

The general course structure is shown in Table 1. No classes are held during mid-term or final exam weeks. Design and communication lecture and laboratory sessions are not held during the design review and poster fair weeks.

3. PROJECT THEMES

3.1 Influence of faculty on design project themes

Many capstone and cornerstone design courses set a theme for each semester's projects. In recent years, service learning and environmental sustainability have become increasingly popular.

In ED100, there is no single, unifying theme for the semester's projects. Instead, the project themes are determined by the individual faculty project advisers. Guidelines are provided to ensure that

projects are solution-neutral, offer a large solution space, and do not require too much domain-specific knowledge. However, there are no restrictions on theme or on discipline. Although the majority of projects are offered by engineering faculty and are related to engineering and/or product design, past and present topics have included a wide range of topics including design of governmental policy, educational curriculum design, and the design of systems or devices for more active and creative learning environments.

Despite the relative freedom in topic choice, there are clear trends in design projects. Of the 54 projects that have been offered to date, 20 (36%) have been directly related to 'green' or eco-friendly design. These projects include: design of guided natural light systems for the illumination of indoor environments; design for an eco-friendly home; design of an eco-friendly dishwasher; design of an eco-friendly air conditioner; design for an eco-friendly university campus; the design of systems to produce or use bio-fuel from organic waste; and the design of green energy systems for urban spaces. Some of these projects have been offered and counted multiple times.

An additional 15 projects (27%) have been indirectly related to green design. These include cell-phone user interface projects which encourage and improve access to public transportation and the design of corrosion protection systems where students must consider the environmental impact of their designs. In total, 63% of the projects offered to date have been related to green design.

15 projects (27%) have been directly related to service learning and 7 projects (13%) have included

an indirect service component. In total, 76% of the projects offered in ED100 directly or indirectly have a green theme, a service theme, or both. The rest are either based on pure product design (video games, water guns, etc.) or are related to the research of the faculty project adviser.

One of the benefits of having few limitations of the project topics is that the course naturally adapts to current needs and trends, including service learning and green design without a heavy handed approach.

3.2 Influence of students on design project themes

The faculty project advisers have a strong influence on the project theme and are responsible for much of the presence of eco-friendly or service learning projects. However, the influence of students on the project topics is growing with each semester.

Within each project, students choose a specific problem for their team to solve. For example, in the Fall 2008 semester a professor from the Civil and Environmental Engineering department proposed the 'Design of a Structural Health Monitoring and Inspection Robot' as his project topic. The five teams from that project tried to improve oil-pipe line inspection, dam inspection, bridge inspection (2), and the inspection and protection of wooden structures which are considered national treasures in Korea.

In ED100, we are seeing an increasing trend where students in a project which does not have an inherent green or service theme choose sub-problems which intentionally introduce those themes. For example, in the Spring 2009 semester 5 teams were given the task of designing an 'assistive robot.' Their project adviser provided several examples of assistive robots including automatic floor cleaning robots, robots that help the elderly walk or climb stairs, or robots that can help to reach high places in the kitchen. Instead, two of the five teams opted to design garbage sorting robots to make it easier to process trash for recycling. Two of the teams for 'Designing an Eco-Friendly KAIST Campus' opted to focus on garbage sorting and encouraging recycling. And, one of the teams from 'Design of an Eco-Friendly Home' picked garbage sorting for recycling. In total, 5 teams from 3 different projects will be working on garbage sorting this semester despite the fact that none of the faculty members proposed this as a project topic. (Garbage sorting and recycling activities are more extensive in Korea and solid waste is usually sorted into 5 different categories for recycling or disposal.)

Similarly, one team of students in the Spring, 2009 semester was asked to design 'pursuit-evasion games.' While the project seemed to have obvious military applications, the students chose to design software to help police locate missing children instead. They intentionally introduced a service theme into their project because it was something that they were interested in doing.

4. GREEN DESIGN IN A GENERALIZED DESIGN COURSE

Given the trends in project topic selection in ED100, it seems clear that green design considerations must be included in the course material. At the same time, there is little room for a formal discussion of subject specific topics (including environmental sustainability) in a generalized design course. In ED100, there are four ways that information about green design is incorporated into the course materials: additional lectures during design laboratory sessions; student background and customer research activities; definition of stakeholders; and the application of formal design theories to green systems.

4.1 Design laboratory sessions

Each week during project lab, students meet with their faculty Project Adviser. The first project laboratory session of the semester typically includes a one hour lecture by the Project Adviser to help familiarize students with the project. There is also time in the two or three sessions following to invite guest speakers, take field trips, or have additional lectures on subject-specific topics if desired. This time can be, and is, used by individual Project Advisers to teach students more about green design when appropriate.

4.2 Student research

During the semester, roughly 2.5 weeks are set aside for students to do background and customer research for their projects. This includes customer surveys and observations; customer and expert interviews; benchmarking; literature searches; and other related activities. Students in projects related to environmental sustainability learn more about green design through these efforts.

4.3 Stakeholder definition

In ED100, stakeholder definition is one of the main tasks performed in the Customer Domain. Unlike traditional product design which primarily focuses on the design result stakeholders (client, customer, user), ED100 has 4 categories of stakeholders:

- Development/Deployment Stakeholders (including individuals upstream, inside of, and downstream of the design process).
- Design Result Stakeholders (client, customer, and user).
- External Influences (typically society, government, and environment).
- Externally Influenced (sorted by primary, secondary and tertiary effects).

Making all of the stakeholders in the system explicit can highlight aspects of the environmental impact that students may otherwise overlook. A recent paper on sustainable furniture design highlighted four major areas for consideration: material selection; manufacturing processes; design for

disassembly (recycling); and reducing or eliminating furniture damage and returns [11].

Students always identify material selection as an important part of green design. Manufacturing is sometimes considered, but first year students usually do not have the knowledge and skills necessary to evaluate manufacturing processes. The last two areas (disassembly for recycling and protection during transit, delivery and storage) could and should be included, but typically are not because students do not consider the full supply chain of their design. These two areas can be identified and included by making the downstream deployment stakeholders an explicit part of the project.

Similarly, the environmental impact of large civil engineering projects, especially dams, was historically only considered as an afterthought. If the environment is included as an external influence in the design and the secondary and tertiary effects on local wildlife and the aquatic ecosystem are considered, it is likely that many of these problems could have been avoided in the past and can be avoided in the future.

4.4 Design lecture

In the formal design specifications produced in ED100, information about the project is effectively sorted into various 'buckets' including: functional requirements; qualities or non-functional requirements; constraints; selection criteria; and optimization criteria.

Initially, it seems that eco-friendly design cannot be reflected in the functional requirements. 'Green' is a modifier which describes how the functional requirements should (or should not) be achieved. It says nothing about what those functions are or what the design should actually do. Instead, it seems more like an 'extra-functional requirement' or a 'quality' which describes how the functions are achieved or what the properties of the final design will be.

However, upon closer inspection it is clear that there are often true functional requirements associated with qualities. Students nearly always identify 'easy to use' as one of their customer needs. That requirement is quickly relegated to the realm of qualities. But one aspect of ease of use is providing information (or 'signifiers' [12]) to the user so they understand how to use the system. 'Provide information to the user' is a true functional requirement.

Similarly, there can be true functional requirements associated with eco-friendly design. In the sustainable furniture example above, the furniture transportation and packing system had to 'protect' the furniture from damage. The furniture itself had to fully 'disassemble' into single material components for recycling. Other eco-friendly products may need to 'bio-degrade' at some point in the future.

Eco-friendly requirements could be considered constraints; i.e. only design options which are eco-friendly can be considered. They could be consid-

ered selection criteria where the most eco-friendly design option will be chosen. They could be considered optimization criteria where the values of selected design parameters are varied to maximize or minimize some metric (like carbon footprint). Or, they could be a combination of these options.

The proper way to handle green requirements in design lectures and projects is an on-going debate with our faculty. It is likely that there is no right answer. Instead, we encourage students to use their judgment and choose how best to include their eco-friendly considerations. However, we do strongly recommend that any considerations that are labeled non-functional requirements be re-examined to determine if they are actually hidden functional requirements, constraints, selection criteria, etc. and can be reclassified within their design process.

5. GREEN DESIGN THEORY IN PRACTICE

In ED100, students are not given a single design philosophy or design process to follow. Instead, they are exposed to different ideas, opinions, tools, and guidelines and encouraged to use, combine, or modify what they have learned based on their individual personalities, design styles, and project topics. As a result, different teams of students sometimes take very different approaches to the same or similar design tasks.

Examining student approaches to green design is a difficult task. Students do not always fully understand the course material and will sometimes make choices that clearly violate fundamental tenets of the design theories that are supposed to be guiding their efforts. Failing to have solution neutral or independent functional requirements is one common example. However, students' work can also be a fantastic source of new ideas and their mistakes can sometimes indicate the shortcomings of the material being presented.

Here, examples from three different projects related to eco-friendly design are discussed.

5.1 Eco-friendly dishwasher

In the Spring 2008 semester of ED100 four teams of students worked on the conceptual design of eco-friendly dishwashers. As part of their work, the students identified several eco-friendly functional requirements including:

- Catch the garbage (solid waste) before it reaches the drain.
- Decrease the use of . . . (detergent, water, energy, heat, etc.).
- Use eco-friendly materials.

The first requirement is important because the Korean waste water system is not set up for solids. Garbage disposals (as we know them) do not exist in Korea. The decomposed functional requirements indicated eco-friendly strategies were

being considered. Many of the designs focused heavily on delivering water and detergent directly to the dishes where it is needed, thus reducing the overall amount of water needed.

Eco-friendly considerations appeared as selection criteria including selection based on whether or not:

- The amount of water/electricity/detergent used is less than in current models.
- The design uses more eco-friendly raw materials than current models.

However, no eco-friendly constraints were listed.

The majority of the eco-friendly aspects of the design actually appeared as the design parameters. Specially designed dish racks that could accommodate Korean dishes and special water nozzle features were common features of the new dishwashers. Several designs also featured miniature dishwashers or adaptive dishwashers that only washed dishes where/when needed.

5.2 Eco-friendly home

The eco-friendly home design project is in its third semester of ED100. In the Fall, 2008 semester, one team of students chose to work on the conceptual design of a grey water recycling system. In this design project, every functional requirement listed was a true FR. Non-functional requirements were not used. The upper level FRs were:

- Recycle water.
- Keep water clean.
- Control water flow and storage.
- Ensure long life (sub-FRs included supporting the water weight in the tank and preventing leaks in the system).
- Use water only when appropriate temperature. (Cool, clean water which was not yet warm enough to be used in a shower, bath, or sink was stored in a separate clean water tank for future use in a sink, washing machine, or other lukewarm clean water application.)

This team listed ‘water-saving efficiency’ and ‘pollutant release’ as constraints. (Designs that did not increase water-saving efficiency or that released excessive pollutants into the environment were not permitted.) The eco-friendly selection



Fig. 1. Eco-friendly home grey water recycling system [13].

criteria were related to water usage efficiency and to grey water decontamination for storage and use.

Similarly, all 5 eco-friendly home teams from the Spring, 2009 semester listed only true functional requirements. The formulation of those FRs and the design parameters associated with them contained the majority of the green considerations for the systems. Eco-friendly constraints and selection criteria were also common.

5.3 Portable eco-friendly bench

In the Spring, 2008 semester, four teams also worked on the design of portable eco-friendly paper benches. Interestingly, the upper level (top-most) functional requirements for these teams are all classifiable as qualities or non-functional requirements. The ‘functional requirements’ listed in the project reports included:

- Should be eco-friendly.
- Should be portable.
- Should be comfortable to use.
- Should be safe for people to sit on.
- Should be enjoyable for user, etc.

Only one team listed eco-friendly constraints:

- Must use harmless chemicals.
- Must be made with recycled materials.

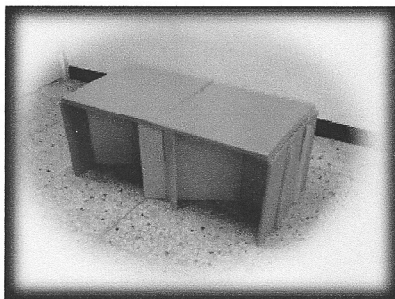


Fig. 2. Portable eco-friendly bench [14].

- Must be made with perishable (recyclable/biodegradable) materials.
- Must not make waste.

Environmental sustainability was listed as the 8th selection criteria for one of the teams. Using eco-friendly materials was listed as a selection criterion for two other teams. Despite the lack of any 'true' functional requirements, these were still excellent projects. The students' papers demonstrated good design thinking, a strong adherence to the lecture materials, and functional (and in some cases, very comfortable) prototypes which weighed less than the required 3 kg while supporting the weight of two full grown adults.

6. DISCUSSION

In all three of the projects discussed, students used a combination of functional requirements, non-functional requirements, constraints, and selection criteria to meaningfully include eco-friendly considerations in their design. The differences in the approaches that the teams took indicate that the students are adapting the course material to their needs rather than simply following instructions.

In the most successful projects, eco-friendly considerations were not segregated into one separate functional requirement or a single set of selection criteria or constraints. Instead, the influence of the eco-friendly theme was reflected all choices and all aspects of the project.

Interestingly, none of the teams discussed here derived additional green functional requirements, constraints, or selection criteria from their stakeholder analysis. The stakeholder analyses in ED100 are becoming more detailed and interesting over time. The Spring 2009 stakeholder definitions, especially in the eco-friendly projects, were much more complete and insightful than in previous semesters. However, that work is still not translating to functional requirements that reflect the needs beyond those of the customer and the user. It is possible that this will improve in the coming semesters. It is also possible that this is due to the limited time in the course and the relative inexperience of the students and will only improve in upper level design courses.

7. CONCLUSIONS

Environmental sustainability and eco-friendly design are becoming increasingly important in engineering today. This is often reflected in the themes for capstone and cornerstone design courses which are handed from the top down. However, it seems that the importance of and the interest in green design is also coming from the

bottom up. In KAIST's ED100 freshman design program, both the individual faculty project advisers and the students themselves are independently electing to offer or work on eco-friendly projects.

ED100 lectures and homework assignments do not directly address green design. Instead, they present a general design framework, guidelines for good design thinking, and information from a variety of formal design theories. Students are expected to adapt the course materials to their individual projects.

There seems to be no conflict between formal design processes and theories and green design. Students seem to be very successful in applying traditional design techniques to green design projects. Eco-friendly design considerations have appeared in the functional requirements, non-functional requirements, constraints, and selection criteria of various student design projects. The most successful projects seem to carry green design as a theme in every aspect of the project rather than segregating those considerations from the general functions and requirements of the original system.

It was hypothesized that a more careful and extensive stakeholder analysis would improve student design projects and lead to a more complete set of requirements, constraints and selection criteria. The overall quality of the stakeholder analyses is improving with time. However, those results are not yet translating to the design specifications or solutions.

ED100 is an example of a generalized cornerstone course which has naturally taken on a green flavor and is producing interesting and creative designs which reflect good design thinking. Ultimately, ED100 may be a good model for how to incorporate green design in a more generalized design course.

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