Increasing the Rigor of Freshman Design Education

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Abstract: The past two decades have seen a revolution in the field of design with increasing interest in the design as a science and a rigorous field of its own. This work discusses some of the challenges for increasing rigor in design education in general, and in freshman design in particular. A model which contains strategies for a more rigorous freshman design course is presented. It is shown that many of the challenges can be overcome by a careful choice of course goals, course material, and a more rigorous evaluation system. There seem to be no problems with introducing higher level design material to first year students; however they sometimes have difficulty adjusting to the new modes of thinking required by the course. As a result, rigorous first year design courses seem ill-suited to engineering recruitment and retention activities, and less rigorous courses like freshman pre-orientation programs are suggested as an alternative to achieve the secondary goals of first year design courses.

Key words: First Year, Design Theory, Methodology, Assessment

1. Introduction

The past two decades have seen a revolution in the field of design. Researchers and funding agencies alike have been increasingly interested in the development of design as a science and a rigorous field of its own. The response from the design community has included the development of new design theories and methodologies including Suh's Axiomatic Design Theory [1], increased interest in existing theories such as TRIZ [2], the rise of 'design thinking' [3], and an increased interest in complexity in design [4-6]. During the same period of time, freshman design programs have becoming increasingly popular, aided in part by calls for improved engineering design education from the US National Science Foundation [7] and other researchers [8]. However, the goals and approaches taken in first year cornerstone courses and the rigor of those courses vary widely [9]. This paper explores rigor in freshman design programs. Challenges for increasing rigor in general design education and in freshman design programs in particular are discussed. The philosophy, logistics, and successes of the KAIST freshmen design program are then presented as an alternative model for a more rigorous freshman design program.

2. Challenges for Increasing the Rigor in General Design Education

There are a number of challenges associated with increasing the rigor in design education that go beyond the usual problems of funding, staffing, space, etc. These include preconceptions of the faculty and the students, difficulties in defining design, and misconceptions about how to increase rigor in design.

2.1 Faculty Preconceptions

Historically, design was taught primarily as an art or trade, learned only by experience. Design has come a long way in the past century, but those attitudes have left their mark on the design community. Design courses which are developed or co-taught with faculty who have been heavily influenced by the design-as-trade school are sometimes resistant to efforts to increase the rigor of freshman design programs or have significantly different views of what that means.

2.2 Student Preconceptions

Student preconceptions about design and learning in general can also be problematic. Design is not well suited to the traditional lecture/homework/test educational model, nor does it produce unique solutions. As a result, students sometimes have trouble adjusting to the ambiguity of project-based design courses. Initially, students also frequently believe that the thought processes, tools, and techniques taught to them in class are actually an impediment to the design process and that they would be better off spending lecture and lab time working on generating creative ideas and building prototypes. (Worse, individual faculty members sometimes agree with them.) To increase the rigor in design, it may be necessary to implement more stringent requirements for the application of the course material to projects and the evaluation of its use. This is especially true in very large courses with localized (section-based) grading.

2.3 Defining Design

There is no single universally accepted definition of design, perhaps in part because design is a huge field. The enormity of design is a challenge for faculty who are not (and cannot be) experts in all areas of design and may not even be aware of the full extent of the field. It is also a challenge for students who are often completely unaware that the field of design extends beyond the material taught in their design courses. To increase the rigor of design, we need to increase awareness of design and its sub-disciplines, especially when planning larger design sequences in the curriculum. We must also make it clear to the students what aspects of design are (and are not) being taught in a particular course so they know how to expand their design knowledge in the future.

2.4 Misconceptions about How to Increase Rigor

Rigor is sometimes automatically equated with determinism and mathematics. Many individuals in both academia and industry have long sought to make design more deterministic by focusing on optimization, design automation, and more. However, design and engineering are more than mathematics, and important aspects of both are lost when the qualitative aspects of the fields are removed. In addition, there is a tendency to replace less rigorous design course material with more rigorous subject matter from other design-related areas. For example, in mechanical engineering, machine elements, linear algebra, cost estimating, mechanics and strength of materials, and a whole host of other subjects have crept into design courses. Students learn a lot from these courses, but what they learn isn't always 'design.' Substituting design course material with information from related subjects where the rigor is better established adds to the confusion about what 'design' is without improving design education or expanding the frontiers of design knowledge.

3. Challenges for Increasing the Rigor in Freshman Design Programs

There are additional challenges associated with freshman design courses, including conflicting course goals, limited background of first year college students, and insufficient time to cover both design and design-related topics.

3.1 Conflicting Course Goals

The recent increase in first year design programs has been partly due to concerns about engineering enrollment and attrition. A number of studies [10-15] have shown a strong link between hands-on, team-based, and project-based first year courses and engineering recruitment, retention, and satisfaction. Since cornerstone design courses are well suited to these types of activities, they have become a common vehicle for the recruitment and retention of engineering students. In any type of program where recruitment and retention are key success metrics, there exists the potential for a serious conflict between the educational goals of the course and the recruitment and retention goals of the department or school. When such a conflict arises, there is a strong motivation to make the course fun and exciting at the expense of learning. In order to increase the rigor in first year design education, the conflicts between competing course goals must somehow be resolved.

3.2 Limited Student Backgrounds

Design has traditionally been used in capstone courses because it helps students to apply everything that they have learned during their undergraduate careers. First year students have little to draw on beyond their general high school educations. In addition, many first year students are also often undecided about their majors. These factors limit the technical level of projects that can be offered and also substantially reduce the amount of subject-specific material that the students can be taught or expected to use.

3.3 Sharing the Spotlight

Finally, it is impossible to teach all aspects of design in a single degree program, let alone in a single first year design class. But this situation is aggravated by the fact that freshman design courses have become hopelessly entangled in introductory engineering and general education. Design is often included as part of introduction to engineering courses [16-17]. Even stand-alone cornerstone design courses include an introduction to engineering tools, skills, and software (drawing, sketching, solid modeling, Matlab, etc.) [18-19]. First year design programs are also increasingly focused on introducing “soft skills” like communication and team work [20-21]. There is no doubt that these skills are important. But there is a risk that these supporting activities and skills will displace a substantial amount of the 'design' course material from the curriculum and shift the focus of the course.

4. Freshman Design at KAIST

The freshman design program at KAIST [22-23] was designed to avoid some of the common pitfalls associated with undergraduate design education, including those related to a lack of rigor in the curriculum. As a result, this course may be a useful model for how to increase the rigor and relevance of first year design education. The increased rigor of the course is most easily seen in the course goals, in the course material, and in student assessment which are discussed below.

4.1 Course Overview

The KAIST freshman design program (ED100: Introduction to System Design and ED101: Communication for Design) is required for all incoming freshmen regardless of major (~ 400 students / semester). The course format varies slightly each semester but in general, students attend 1 hour per week of design lecture and 1 hour of communication lecture. They also attend up to 1 hour of communication lab or clinic and up to 3 hours per week of design lab. ED100 is a problem based course and design projects may be offered by faculty members from any department. The communication component exists primarily to support the students and help them to prepare their design deliverables. This is especially important because the vast majority of students in the course are learning design in an EFL (English as a foreign language) environment. The two courses (ED100 and ED101) are taught as a single integrated subject and will be referred to here as "ED100" for convenience.

4.2 Course Goals

The stated goals of the ED100 are to:

- Introduce the fundamentals of conceptual design and critical thinking to students to produce a paradigm shift in the way students think, view the world, and view their role in the world.
- Introduce technical communication skills to permit students to work together and effectively express ideas in English.

It is hoped that the course will help the students to think like designers and to begin to take a more active role in their lives, their education, and their environment in preparation to become future leaders. The course also tries to encourage students to become independent learners and to recognize that learning also occurs outside of the classroom. The course makes no attempt to influence students' choice of major, although it does permit students to choose projects which are related to majors that they are considering. It does not serve as an introduction to engineering, nor is it sponsored by the School of Engineering. 'Fun' is encouraged but not required.

4.3 Course Material

Because of the limitations in student background, the wide variety of student interests and majors, and the focus on design thinking, ED100 focuses on the design process and design theory and methodology. The course material in ED100 is primarily based on a combination of Suh's Axiomatic Design (AD) Theory [1] and traditional product design [24] with additional material from TRIZ [2], Pahl and Beitz [25], Herbert Simon [26], and others. In the Fall 2009 semester, it is likely that human centered design will also be introduced.

The first lecture of the semester provides an overview of the sub-disciplines within design and how ED100 fits into the larger picture of design. Although ED100 is not a design survey course, students are exposed to a number of different design perspectives and design authors. This is partly to help them begin to appreciate the scope of the field, the limitations of current design knowledge, and the prevalence of opinion and ambiguity in design, and partly to encourage them to learn more on their own during or after the class. This is also done to help them understand that the course material is not something to be memorized, but something to be understood and then modified to meet their needs.

The focus on design theory is somewhat unusual for a design course in general, but is more so for a first year design course [9, 22]. Often these elements are not introduced until graduate level courses, if at all. Interestingly, the first year students in ED100 seem to have less trouble learning and using the design theory than equally inexperienced graduate students. (Graduate students with extensive experience in design seem to have little or no trouble at all.) Thus, there seems to be no reason to delay the introduction of formal design theories in design education.

4.4 Requiring Course Staff to Know the Course Material

Because projects may be offered by any professor at KAIST, often neither the faculty project advisers nor the student TAs have any previous experience with design and formal design theories. To provide the best support for the first year students, a workshop is held at the beginning of each semester to orient new project advisers and TAs and to introduce some of the fundamentals of the course material. New TAs are required to attend all design lectures. (TA attendance is taken.) All lecture notes are available online. Finally, online forums and weekly in-person staff meetings provide opportunities for questions and discussion.

4.5 Requiring Students to Apply Course Material

It is not enough to introduce the students to formal design methodologies (or any other type of design course material.) The students must also be required to apply what they have learned. In ED100, a weekly project homework assignment is given to all of the students in the course. This assignment is intended to (1) guide the students through the design process; (2) help the students to apply what they have learned in lecture and in their readings to their design projects; and (3) help the students to prepare the final deliverables for the course. These assignments include open ended questions which are provided by the design lecturers. Completed project homework assignments are uploaded into an online course management software program. Here, the faculty project advisers and TAs can view and grade the homework. The design lecturers can also view the homework to evaluate student learning and also ensure that grading is being done correctly and promptly.

4.6 Increasing the Rigor in Course Evaluation

Finally, the evaluation of the students must be tied to what they have learned. A number of steps have been taken to increase the rigor, consistency, and fairness of grading in ED100. These include a distributed grading system, non-numerical evaluation, an averaged grading system, a final technical evaluation, published grading guidelines, and an evaluation feedback loop.

4.6.1 Distributed Grading

Once a design class grows beyond 20 or 30 students, it becomes necessary to rely on multiple faculty members or teaching assistants to help run laboratory sessions and do grading. Usually, students are assigned to a section which is run by one or two faculty members and those faculty members are given the full responsibility of grading their students. This often leads to complaints by the students of unfair grading practices across various sections. It also occasionally results in a section leader who does not require his or her students to apply the course material to their project as rigorously as the other sections (or at all.) To address this, grading in ED100 is distributed over a minimum of 4 faculty members: the project adviser, the communication adviser, and the two design lecturers. The responsibilities for individual components of the final grade can be found in Table 1.

Table 1. Distribution of Grading Responsibilities

Project Advisers	Design Laboratory Grade	250	points	25%
Communication Advisers (CAs)	Communication Laboratory Grade	150	points	15%
Students	Peer Review	100	points	10%
Design Lecturers	Final Project Technical Evaluation	200	points	20%
Communication Advisers	Final Paper	200	points	20%
Design Lecturers & CAs	Final Poster	100	points	10%
Total		1000	points	100%

The design project laboratory grade is determined exclusively by the project adviser and project TAs. No grading guidelines are provided for project laboratory grades although the project lab grade is expected to include: attendance in design lecture and weekly design laboratory meetings; participation in discussion and activities during meetings; project homework assignments; additional design laboratory assignments (if any); and technical preparation for and performance during mid-term design review.

Similarly, the communication project laboratory grade is exclusively determined by the communication adviser and communication TAs. This portion of the grade includes (but is not limited to): attendance in communication lecture and communication laboratory sessions; participation; communication homework assignments; and the communication aspect of the mid-term design review.

The results of the design project constitute 50% of the final grade. The technical content grade is based on the rigor of the final design projects and is determined entirely on the information in the final paper. (No credit is given for work presented in previous homework assignments or other course deliverables.) The paper and poster grades are based on how well information and ideas have been communicated to the audience. The technical and communication deliverables can never be completely independent of each other, but a significant effort is made to avoid double jeopardy in grading.

4.6.2 Non-Numerical Evaluation

Design is, by nature, a highly subjective field. In the past, ED100 staff members found grading to be an arbitrary, difficult and tedious task when using a numerical grading scale (0 through 10, etc.). As a result, the majority of grading in ED100 is now done on a four point scale:

✓+ (Check plus: Excellent)
✓ (Check: Acceptable)
✓– (Check minus: Poor)
0 (Zero)

Numerical grades are only assigned during the semester for peer reviews. All other grades become numerical at the end of the semester. Numerical grades are assigned on a straight scale (90-100 = A, 80-89 = B, etc.). The course is not curved.

4.6.3 Averaged Grading

For major assignments or activities in ED100, students receive feedback from at least two course faculty members whenever possible. Mid-term design reviews juries consist of at least one member of the design faculty and one member of the communication faculty. This ensures that students receive comment from multiple perspectives. Final posters are graded by one design faculty member and one communication faculty member. Similarly, the technical evaluation of each final project is done by both design lecturers. The final poster grades and technical evaluation grades are an average of the two evaluations. The final papers in ED100 are not subject to averaged grading for logistical reasons, but will also be averaged in the future if possible.

4.6.4 Grading Guidelines

Grading in ED100 is taken very seriously. This can be great cause for concern in an open-ended course where students may be unaware of expectations and are very concerned about their grades. As a result, grading guidelines are published for every assignment and are available to both the students and the course staff. The grading guidelines for the Spring 2009 final technical evaluation are shown in Table 2. Note that the guidelines are sometimes intentionally vague to give the students the freedom to adapt and integrate the course material for their projects and their personal styles.

4.6.5 Grading Feedback Loop

At the end of each semester, the grades from the various components of the course are assembled into a single Excel workbook. Preliminary grades for all students are calculated, statistical information about each project and the entire course are prepared, and the spreadsheet is sent to the academic course staff. The course faculty and TAs review their students' grades and compare them to other projects. The course staff then has several days to change grades that they have assigned, to request reconsideration or re-grading of other course work including the final deliverables, or to request bonus point be added to individual students' scores. This helps to address some of the potential differences in grading between sections.

5. Discussion

Teaching a rigorous freshman design class is never an easy task. Initially, many ED100 faculty members thought that the course was doomed to fail. In the first six weeks of every semester, the students complain bitterly. Usually, a few students are still dissatisfied customers at the end of the semester. But overall the successes seem to outweigh the difficulties. Over the past 3 semesters, the average grade in ED100 was an 89.3/100 (A-/B+). These grades were not given – they were earned. In many cases, the technical level of the final reports is outstanding and some teams produce junior/senior level work. In the first four semesters of the course (including the pilot), student teams produced 4 conference papers, 7 conference presentations, 9 presentations in industry, 10 provisional patents, 1 award at an international conference, 1 honorable mention, and a number of fully functioning prototypes including a really neat slinky-inspired stair-climbing robot. Unsolicited feedback from both students and faculty has indicated a paradigm shift in their perceptions and in student culture [22-23] and support for the program continues to grow.

Table 2. Blank Technical Evaluation Sheet

Final Project: Technical Content Evaluation Form, Spring 2009
ED100: Introduction to System Design
Date and Time: ________________________
Project Name: ________________________
Team Name / Number: ________________________
Evaluator: ________________________
Final Grade: ________________________ / 200 points

Problem Statement: (_____ / 5 points)
The problem to be solved was clear 0 / ✓- / ✓ / ✓+

Background and Customer Research: (_____ / 30 points)
The type of background / customer research done was appropriate 0 / ✓- / ✓ / ✓+
The extent of background / customer research was appropriate 0 / ✓- / ✓ / ✓+
The importance of the problem / need for solution was clear 0 / ✓- / ✓ / ✓+
The stake holders (customer, client, etc.) of the design were clear 0 / ✓- / ✓ / ✓+

Design Process: (_____ / 25 points)
The design process used was clear 0 / ✓- / ✓ / ✓+
A rational, conscious design process was used 0 / ✓- / ✓ / ✓+
The needs (requirements / attributes) of the design were clear 0 / ✓- / ✓ / ✓+
Multiple design concepts were generated to satisfy the needs 0 / ✓- / ✓ / ✓+
The process and SCs for choosing between concepts were clear 0 / ✓- / ✓ / ✓+

Design Result: (_____ / 80 points)
The resulting design concept is clear 0 / ✓- / ✓ / ✓+
The resulting design addresses the original problem / needs 0 / ✓- / ✓ / ✓+
The resulting design is new / different / better/ interesting / unique 0 / ✓- / ✓ / ✓+
The novelty of the design was well explained 0 / ✓- / ✓ / ✓+
The resulting design will be technically feasible / successful 0 / ✓- / ✓ / ✓+
The potential technical success of the design was well explained 0 / ✓- / ✓ / ✓+
The resulting design will be economically feasible / successful 0 / ✓- / ✓ / ✓+
The potential economic success of the design was well explained 0 / ✓- / ✓ / ✓+

Risks and Countermeasures: (_____ / 20 points)
The potential failure modes of the final design were identified 0 / ✓- / ✓ / ✓+
The risks associated with implementation were identified 0 / ✓- / ✓ / ✓+
Ways to address risks and potential failure modes were presented 0 / ✓- / ✓ / ✓+

Axiomatic Design: (_____ / 40 points)
The FRs were clear, appropriate, and contained sufficient detail 0 / ✓- / ✓ / ✓+
The DPs were clear, appropriate, and contained sufficient detail 0 / ✓- / ✓ / ✓+
The constraints were clear and appropriate 0 / ✓- / ✓ / ✓+
The final design matrix was appropriate and correctly created 0 / ✓- / ✓ / ✓+

Comments:

Is it necessary for a rigorous first year design class to be difficult? Every semester the ED100 faculty strives to reduce the workload and the difficulty without reducing the learning, but there may be some fundamental level of difficulty associated with a rigorous treatment of design. It is, however, clear that ED100 would not be possible in combination with recruitment and retention activities. Freshman pre-orientation programs [27] and introduction to engineering programs seem to have fewer conflicts with recruitment and retention activities and are much better suited to promote those goals.

6. Conclusions

In this work, challenges for increasing rigor in general design courses and in freshman design in particular were discussed and a model which contained strategies for a more rigorous freshman design course was presented. It seems that many of the challenges can be overcome by a careful choice of course goals and course material, and through a more rigorous, centralized, and distributed grading system. There seem to be no problems with introducing higher level design material to first year students; however they sometimes have difficulty adjusting to the new modes of thinking required by the course. As a result, rigorous first year design courses seem ill-suited to engineering recruitment and retention activities, and less rigorous courses like freshman pre-orientation programs are suggested as an alternative.

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