

## Introducing Engineering Design into the First Year Curriculum

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**Abstract** -- This paper describes the introduction of engineering design into a freshman level course using projects in toy design. Toy design was chosen because the course must motivate and educate students with limited technical backgrounds and diverse interests. Real-world, hands-on toy design projects aim at simulating a professional design environment. To familiarize students with concept generation and evaluation, on-line peer evaluations were conducted several times throughout the semester, which also encouraged students to share ideas and improve their own design concepts. To further interest students, the course was developed as a paperless studio, with everything from lecture notes to projects and evaluations performed and accessible on-line. This approach is highly portable, cost-effective, and emphasizes written communication and presentation skills.

Overall, the course was a success in a number of ways: (a) since its introduction as a toy design course, it has attracted enrollment from many students with non-technical majors who otherwise would be unable to participate in traditional engineering design courses; (b) student participation improved significantly as a result of peer evaluations; (c) professional toy designers who reviewed student work were impressed with the quality of student projects.

Further improvements are underway to randomize the peer evaluation process to reduce possible student bias, increase the number of design iterations, and improve on-line course material.

### Introduction

In some engineering programs, first and second year students primarily take introductory science and mathematics and non-technical course requirements, postponing the first technical courses to as late as their junior year. Consequently, students may lose interest in engineering early on. Some leave the field, while others develop "learn-and-forget" techniques, absorbing material to get them through exams but forgetting it almost immediately thereafter [1]. To combat this problem, first-year introductory engineering courses can be used to interest and retain students.

These courses offer an excellent opportunity to introduce engineering design to all students, regardless of

their major, since design is both essential for and universally applicable to all engineering disciplines. Because many first-year students are undecided about their major, exploring the technicalities of a specific engineering field may not appeal to them (see Table 1). But design skills are a creative, hands-on process that needs to be developed over the entire four-year undergraduate experience, and can be one way of keeping students interested in engineering as a profession.

When the concept of design is combined with the use of computers, students spend less time on processes that were drudgery without the computer and are less frustrated because the computer compensates for lack of technical skill. Computers allow for a paperless learning environment, with everything from class notes and projects to homework and presentations posted on-line. The possibilities for interactive on-line modules are substantial.

Most first-year students lack technical knowledge, and many are disillusioned about the engineering profession after being submerged in first-year math and science courses. An ideal introductory design course (a) must motivate and interest students with little or no technical background; (b) must have relevance to various majors since most first-years have not chosen one, and (c) the course content should be challenging but fun and interesting.

Toy design has proved to be the perfect subject for a first-year design course. It familiarizes the student with general techniques and methodology, and simulates a professional work environment. Methodologies for design of washing machines, jet fighters, and screwdrivers have much in common with toy design. However, unlike more traditional design subjects, toy design appeals to a multidisciplinary audience with little or no technical knowledge and even attracts students with no interest in engineering as a profession. Virtually all students are toy experts, having had at least 17 years of experience with toys of varying levels and complexities. Finally, designing concepts for toys distills design and creative thinking by eliminating the concern for practical implementation. For the purposes of introducing design into the first-year curriculum, toy design is a winner.

This paper discusses *E1102 – Introduction to Engineering Design*, a mandatory first-year design course at Columbia University's Fu Foundation School of Engineering and Applied Science. This paper is divided into two parts: the first will consider course structure and

projects, while the second will deal with the challenges of teaching design on the freshman level.

The goal of this paper is to discuss the benefits and challenges of using toys to teach design in engineering schools. It is a very promising, novel approach that has been relatively unexplored in engineering education. Because of rapidly changing computer technology and varying student abilities, the aim of this project is to establish a baseline for what can be done in a freshman-level design course. This paper is not a controlled experiment assessment but rather explores ways to motivate students and proposes a toy design-based course structure.

*Table 1: Class composition by Major. Note that the enrollment drops in the spring semester because most students for whom the course is mandatory take it in the fall*

	Fall '98	Spring '99
<b>Non-Engineering Students</b>	<b>2</b>	<b>15</b>
<b>Engineering Students</b>	<b>173</b>	<b>124</b>
Applied Math	6	5
Biomedical	32	16
Chemical	11	9
Civil/Eng. Mech.	6	7
Computer Eng./Com. Sci.	33	28
Electrical	20	15
Environmental	0	2
Industrial/Management	11	6
Mechanical	10	7
<b>Undecided</b>	<b>44</b>	<b>29</b>

## The Goal of the Course

In developing the course, the main goal was to familiarize students with basic design skills and methodologies. To accomplish this, a simulated professional design environment was created. Even though the specific skills designers use differ, the design process usually is the same [2]: Concept Development >> System-Level Design >> Detail Design >> Testing and Refinement.

Concept generation, as a rule, is the most creative phase of the process and, in many cases, the most difficult. Less emphasis is placed on concept generation in traditional engineering design classes, which aim to apply theory to design projects. In the authors' personal experience, most graduating seniors can easily apply their technical knowledge at later stages of design, but still struggle to generate original, unrefined concepts. Furthermore, most first-year students enter introductory courses with an educational background that emphasized solving analytical problems, while minimizing creative skills. Therefore, an effective way of introducing design to freshmen is to concentrate on the concept development, particularly on [2]: (a) identifying customer needs; (b) analysis of competitive products; (c) concept generation; (d) concept evaluation

The course was structured with this in mind and, as an added bonus, provided a good way to defeat the "learn-and-forget" trend since it encouraged students to apply design methodologies to projects.

## Projects

The curriculum for this first-year toy design course was developed using two separate projects, the second more advanced than the first. While collaboration among students was encouraged, design projects were individual; teamwork was not allowed. Since designing toy concepts requires no technical knowledge, the course allowed students freedom to design without worrying about practical implementation. Actual toys were used to demonstrate design methodologies and allowed the material to be presented in an interesting and captivating way. The toy design projects were created to emphasize concept development and to appeal to students with little technical background (see Figure 1).

For the midterm project, students were asked to develop a concept for a simple video game based on Bandai's Tamagotchi [7]. Required elements for the toy were a small LCD (1600 pixels max), simple audio (e.g. beeps and tones), and several buttons for the interface.

The final project was a second, more sophisticated, iteration of the midterm project. Students were required to apply their design experience to a project based on electronic games with a more elaborate interface, such as Radica's Bass Fishin', Tiger's TrailBurner, and the notorious Furby [8]. Pixel LCD as well as segment displays were allowed, along with more elaborate audio systems (e.g. audio recording and playback capability). With this type of game, various sensors and feedbacks were used to control it (e.g. light and heat sensors, tilt and acceleration sensors, force feedback, squirting water).

Since this final project allowed concepts with more elaborate interfaces, more emphasis was placed on hardware design (appearance) than for the midterm project, which mainly involved developing a storyboard (a series of images describing the plot of the game). Both projects followed a similar timetable:

- **Preliminary research (1 week).** Students were asked to research toys that were already in stores.
- **Preliminary concept generation (2-3 weeks).** Students were asked to formulate three different, preliminary concepts to encourage brainstorming.
- **Concept evaluation/selection (1 week).** After a meeting with the instructor, students selected one concept for further development
- **Peer evaluations (1 week).** Students evaluated each other's concepts on-line using the Evaluation Matrix technique [2]

Because most students lacked technical experience, hardware design was limited to the appearance of the toy and placement of LCD, speakers and controls.

### Use of Computers

A paperless studio environment was created using computers. All class material was posted on-line, and projects and homework were submitted in the form of web pages. Peer concept evaluation modules were on-line, making them quick and easy to complete, even from students' dorm rooms. Numerous interactive modules were accessible on-line – from class evaluations to frequently asked questions. In this environment, the instructor and teaching assistants were easily reachable outside class hours. The exchange of information and collaboration between students and faculty was made effortless. Class material could be easily modified, updated and ported to another computer system, if needed. Using computers in design eliminated the need for costly inventory necessary for traditional design courses and resulted in a highly portable and cost-effective course.

The new toy design course was taught at the Botwinick Gateway Laboratory, a powerful computer graphics facility with 40 Silicon Graphics O<sub>2</sub> workstations connected to the Internet. Because the operating system is UNIX-based, creating web pages was straightforward. Alias/Wavefront, a powerful 3D computer graphics software used extensively in movies and industrial design, was among the packages taught to students.

Use of computers allowed students to spend more time on design. For example, Alias could make up for a student's lack of technical skills by simplifying 3D visualization and modeling. Photoshop allowed students to lay out screenshots for their concepts with precision of up to one pixel.

### Class Structure

The class met once a week for two and a half hours. There were five sections (one every day of the week), with a maximum of 35 students in each section. Class material fell into two general categories-- design and software. While the primary emphasis of the course was on design, a substantial amount of class time was spent on teaching software tools. Mastery of the software was expected by the time the midterm project was due. Review sessions were held for the remainder of the semester to assist students as they used the software to create their designs.

Design lectures were presented throughout the semester and concentrated on issues that arose as the students worked on their projects. The following topics were discussed:

- **Analytical vs. design problems.** The ill-defined nature of design problems, the need for customer needs analysis and customer satisfaction models were covered.
- **Customer needs.** A lecture on analyzing customer needs was followed by an assignment.
- **Design methodology.** Design freedom and knowledge about the problem was discussed vs. time into the development process
- **Evaluation matrix [2].** An effective concept evaluation method was discussed within this topic area that was later used for peer evaluations, and involved evaluating several concepts based on various criteria (see Table 2). The sum-total of grades in each criterion was the total score for the concept. In order to minimize bias, all concepts were compared to a reference concept (e.g. the original Tamagotchi) and given a relative grade (-2=much worse than reference, 0=same as reference, +2=much better than reference). The following type of matrix resulted:

Table 2 : Evaluation Matrix

Criteria	Concept A (reference)	Concept B	Concept C
Criterion 1	0	+2	-2
Criterion 2	0	+1	+1
Criterion 3	0	-1	+2
<b>Total</b>	0	+2	+1
<b>Rank</b>	3	1	2

About 50 percent of class time was designated “design time”. During this time, students worked on their projects and were assisted by the teaching staff (one instructor and two teaching assistants per 35 students per section). It was common for students to collaborate and assist each other during this design time.

All project presentations were evaluated by students using an on-line module similar to that used to evaluate the preliminary concepts. Following these evaluations, 10 to 12 concepts receiving the highest score and judged to be the best were selected to be presented to professional toy designers.

### On-Line Modules

A number of CGI-based on-line interactive modules were used in the course:

**On-line Course Evaluations.** Students' feedback on the progress of projects, amount learned and general structure of the class was elicited on-line. These modules were quick to set up and allowed for anonymous class evaluations to be conducted several times throughout the semester. Student comments were found to be an indispensable source of information, especially during the curriculum development stages.

**On-line Quick Comments.** This module supplemented the required Course Evaluations and allowed students to post anonymous comments for the instructor at any time.

**On-line Frequently Asked Questions.** Answers to common questions further simplified student-faculty interface. Students checked the existing list of questions and answers, or added a new question to be answered on-line.

**On-line Grading Module.** This module simplified grading and grade posting. Students were required to use standard file names for the presentations and homework. This module automatically brought up web pages one by one for grading. As soon as a grade was entered, it was posted on-line, so students could log in and check their grade.

**On-line Peer Concept Evaluations.** This was possibly the most important module. Here, students could anonymously evaluate each other's concepts (30 per student) using the evaluation matrix described earlier. While using the module, students reinforced the evaluation techniques learned in class. They also saw concepts developed by other students and were able to form judgments about what constituted an effective presentation. Most importantly, since evaluations were conducted based on several criteria (e.g. how interesting the concept was, the effectiveness and clarity of presentation, and the degree of realism), students were able to determine what elements of their project needed improvement.

### Challenges

The first challenge in teaching toy design is to change the established way of thinking for most students. First-year-engineering students tend to have an analytical mindset, since most of them concentrated in mathematics and physics in high school. They are accustomed to solving problems that are clearly defined and have only one correct solution. One student's comment in his course evaluation is typical of the problem: "I find the assignments somewhat ambiguous. It is not clearly stated what is required and how they are graded." In other words, students wanted to be told exactly what to do in order to get a good grade. This is impossible in the context of a design class where, by its very nature, students must become comfortable tackling ill-defined problems with multiple satisfactory solutions.

Students who are grade-conscious usually panic when they realize that they cannot get an "A" simply by doing what the instructor tells them to do. They tend to put in long hours and concentrate on the presentation rather than the design process. Frustration is not an uncommon reaction; some students get easily discouraged by low grades and simply give up instead of taking the instructor's suggestions into account.

Another difficulty in teaching design at the freshman level is pinpointed by the following comment: "The whole product design phase of the course should be scrapped, and we could create some really cool graphics." Students often

do not see the relevance of design projects. A crucial part of teaching design is to repeatedly emphasize that, by learning to design toys, a student is learning an understanding of fundamental design principles.

A third difficulty is helping students who lack creative skills. These students tend to have great difficulty with design projects. Instead of trying to brainstorm and explore, they approach the problem the same way they would an analytical problem: they look through solved problems, find a similar one and repeat the solution with necessary modifications. It is important to encourage students to think creatively. One way was to ask them for multiple preliminary concepts. Another way was to provide examples of how existing products have been drastically improved through creative thinking rather than minor modifications (e.g. old-fashioned dolls vs. Furby).

### Resource Requirements

Table 3: Approximate Human Resources Breakdown

	Fall '98	Spring '99
<b>Curriculum Planning</b>		
Faculty	15 hrs	5 hrs
Graduate Student	50 hrs	10 hrs
<b>On-line Material</b>		
Faculty	10 hrs	
Graduate Student	200 hrs	50 hrs
<b>On-Line Modules</b>		
Graduate Student	10 hrs	5 hrs
Undergraduate Student	50 hrs	15 hrs
<b>Class Time (incl. grading)</b>		
Instructor (graduate student)	500 hrs	500 hrs
TA (undergraduate students)	350 hrs	350 hrs
<b>Total:</b>		
Faculty	25 hrs	5 hrs
Graduate Student	760 hrs	565 hrs
Undergraduate Students	400 hrs	365 hrs

In comparison with analytical courses, teaching design usually requires more preparation at the beginning of the semester, especially when on-line materials need to be developed. Once the semester was underway, most of the instructor's and teaching assistants' time was devoted to grading and helping students with design projects. The availability of class material on-line significantly decreased time in lecture.

Two professors, a graduate student and an undergraduate student were involved in the development of the toy design course at Columbia Engineering. Table 3 shows the approximate breakdown of human resources in preparation and teaching of the 14-week course. Modifications to the class curriculum and material for the Spring '99 semester were significantly less time-consuming than development of the original course for Fall '98.

## Course Outcome

Based on students' and professional designers' input following the final presentations, the course was judged a success. Toy designers were generally impressed with the quality of student presentations. In particular, they pointed out that students produced "slick-looking" projects. While not all concepts were fully developed, the student presentations were extremely professional. Several concepts attracted the attention of toy designers because they were similar to those under development by the designer's own company. A few other concepts that were developed by students can be found in recent Radica and Tiger Electronics catalogues that were not available at the time the students were working on their projects. The toy designers explained the similarity between student work and concepts currently under development in the industry by the fact that both professional designers and students are influenced by the same ideas already in the market; this similarity was reassuring. Kiscom, a toy concept development company is currently working on marketing several student projects.

Students' reaction to the course was mixed, although for most, the course was a positive experience. Their comments showed that using toy design allowed for an interesting and fun way to introduce new material: "The course is one of the most interesting and important courses I have taken.... The class was generally fun, and I think I've learned a lot." "Overall, the class was helpful and useful for engineering design, and to an extent for the marketing of a product," said another. Several students saw the relevance of the course clearly: "This was a good class to take as long as the design skills we acquired will be built into the future classes."

Other students, however, failed to see the relevance of the design projects. One commented, "As a freshman engineer, I've found the projects in this class to be more of an inconvenience than a worthwhile experience." Several students questioned the fairness of peer evaluations, with such comments as, "I've found peer evaluations to be completely useless [because] I do not trust the evaluations of my peers; they are not qualified enough to be judging me on material they have no experience with." The instructor found that, when speaking to students, new and improved design modifications often came as the result of peer interaction.

## Conclusion

Introductory first-year courses are necessary to interest and retain engineering students who have varying interests and limited technical background. These courses can be used to introduce students to design early in their educational career, since basic design skills are important to engineering professionals in all fields. Toy design is an ideal subject for

such courses because it requires no technical background and has a built-in appeal to students. Concentrating on the concept development stage of the design process encourages students to learn necessary methodologies while eliminating concern for practical implementation.

In teaching design, especially in an engineering school, computers should be used to their fullest capacity. Computers with sophisticated software allow students to spend more time on design by compensating for limited technical skill while at the same time providing a flexible, portable platform for class material, enabling educators to create and use interactive on-line modules.

While computers are essential in the implementation of this course, the importance of the instructor and his role in the teaching process cannot be underemphasized. Instructors must frequently and repeatedly communicate the importance of the goals of the course. In addition, instruction should include: (a) an in-depth discussion of the differences between analytical and design problems; (b) an emphasis that the design process is the same, whether the subject is a new airliner or a new toy; and (c) a realistic balance must be attained between over-constraining design projects, where little is learned about design, and failing to give students enough information, which is likely to result in widespread frustration.

Design skills are invaluable to all engineers. By giving students the opportunity to solve design problems early in their education, they will acquire technical knowledge that they can readily apply to real-life problems.

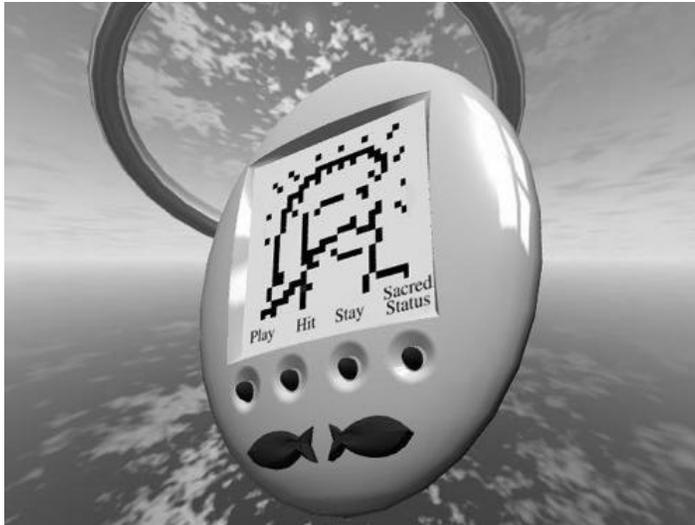
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### Sample Students' Work



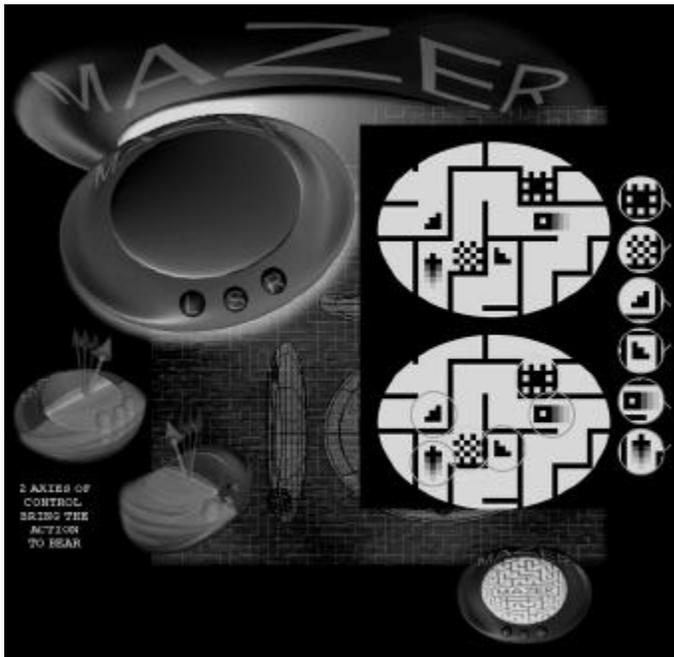
#### Tama-GOD-chi

This game allows the player to establish a personal relationship with God. The relationship begins with a game of cards, which being omniscient, God always wins. God also likes to play “dress up” game, where the player has to match a celebrity’s name to God’s disguise. As you play with God more and more, your “Sacred Status” will rise from “Holly Disdain” to “True Love”.

As your status rises, God will ask for your help with more and more important decisions: from Earthquakes on Oscar night to fate of celebrities. If you make all the right decisions, God will fall in love with you, and you will have to decide whether to accept or decline. What will happen? Only one way to know!

This game is innovative because it pushes the virtual pet concept to “divine” level. The “dress up” game imbedded in the plot is interesting in itself.

Figure 1 : Sample Student Work (Final Project, Fall '98)[5]



#### Mazer

This is the electronic equivalent of the classic game where a user guides a ball through a maze by tilting the game. This particular game utilizes uses an LCD to display a labyrinth; a virtual ball is guided through it using sensors which determine tilt.

Because the game is electronic, once the maze is solved, a new one is generated. Each labyrinth contains multiple levels, which would be impossible in the conventional game.

Toy designers said the concept is “so good, it is, in fact, included in this year’s Tiger Toys catalogue.” This was one of the concepts that was similar to newly developed toys or concepts the toy designers themselves were working on at the time.

Figure 2 : Sample Student Work (Final Project, Spring '99) [6]

Other students' concepts included:

- **Perfect Match:** a game where young children are challenged to match an animal’s head with its proper body and legs
- **Zoids:** loveable virtual creatures “live” in each game and interact with each other
- **Voice Splash:** a karioke-like game that splashes the singer with water if he/she is off-key
- **Prize Puzzle:** this game has a secret compartment containing a prize, which opens when a puzzle is solved