

An Interactive Textbook for Introductory Engineering Design

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Abstract: Touchscreen computers hold great promise as educational tools. Many universities, high schools and elementary schools are working to create curricula that exploit these devices. An important part of this work is the development of textbooks that move away from the static display of words and figures to include interactive components such as videos and interactive simulations. We present such an interactive textbook, developed for an undergraduate course in mechanical engineering. We describe the course for which it was developed and the interactive components of the book. Student evaluations of the textbook are presented and discussed. Finally, we offer suggestions for additional steps that can improve interactive textbooks for use on tablet computers.

1 INTRODUCTION

Instructors in science and engineering courses rely on textbooks. Textbooks aid instructors in organizing material, they provide students with information that cannot be covered in lectures, and they provide examples that should assist students in solving homework problems. However, science and engineering students frequently express dissatisfaction with their textbooks and commonly ignore them. Numerous studies of introductory physics courses show that undergraduate students complain about the cost of their assigned textbooks, and that they seldom read these textbooks, leaving them poorly prepared to understand their technical lectures (Stelzer et al., 2009), (Podolefsky and Finkelstein, 2006), (Chen et al., 2010). Much recent innovation in classroom methods and technology addresses this problem of student motivation and preparation in the sciences.

This issue of student preparation is commonly treated as a problem of engagement with the textbooks and the material. Many instructors have approached this problem by adjusting the way they manage their classrooms (Brewer, 2008), (Laws et al., 1999), while others have explored technology to promote active learning and engagement. Zacharia and Anderson (Zacharia and Anderson, 2003) developed computer simulations to address specific student misperceptions. These simulations were integrated with laboratory exercises and produced a positive impact on student learning. Bonham et al. (Bonham et al., 2003) introduced computer grading for

physics homework problems and obtained positive results in student satisfaction, as well as student performance. Although the grading system did not provide problem-solving guidance, the system responded quickly enough to enable students to identify and correct their own errors.

Textbook publishers have approached the engagement problem by adding electronic supplements to their textbooks. Cengage Learning (www.cengage.com), for example, provides web supplements for some of its print textbooks, and at least some of the electronic textbooks produced by Pearson Publishing (www.pearson.com) are integrated with websites. However, our experiences with commercial e-textbook web supplements have been disappointing, as supplementary resources appear still to be in early stages of development.

To address the problem of student engagement with textbooks, we have chosen to move away from the resources provided by traditional publishers and towards mobile touchscreen devices such as iPads. These devices are poised to have a significant impact on the way textbooks are prepared and used in college science and engineering courses. In experiments with notebooks and tablet computers, for example, instructors have found iPads to be very effective classroom tools when projects can be developed and programmed entirely on the devices (Liu et al., 2011). When class-specific resources are not developed on the tablet devices, students have been found to enjoy classes that provide them with, for example, iPads, even though the devices themselves have not

had a demonstrable impact on student learning (Perez and Paso, 2012), (Perez et al., 2011), (Sloan, 2012), (Van Oostveen et al., 2011), (Weisberg, 2011).

Student engagement may be a function of how richly a tablet device addresses the students' activities in a class. As yet, few textbooks have been developed that exploit computers' ability to provide interactive demonstrations and exercises for the students. It has been argued that publishers have been reluctant to reconceive and redevelop their textbooks to provide such interactivity; Chesser suggests that publishers prefer to port existing books to the tablet devices simply as page images or pdfs (Chesser, 2011). This under-utilizes the computer's ability to provide compelling educational resources to the student. To take advantage of the iPad's potential to engage students, we think that it is important to provide interactive supplements, including simulations, video clips, and homework tools. To directly engage students, these interactive supplements should be tailored for the subject matter of the class, and the book into which they are integrated should speak to student concerns about expense, convenience, and pertinence (Acker, 2011), (Hellman, 2011).

In this paper, we present an electronic textbook that takes steps towards that goal. Our textbook provides simulations that respond to student input, it provides video demonstrations, drawings that the students can manipulate, and design planning tools that students can modify. We have developed this book in an effort to stimulate student engagement while keeping costs low. We will describe the course in which our interactive textbook is used, the particular interactive features that we consider to be novel for textbook authors and compelling for students. We will present student evaluations of this interactive textbook, and we will comment on the future path of development for interactive textbooks.

2 AN UNDERGRADUATE ENGINEERING CLASS

Our interactive textbook was developed for the course Creative Decisions and Design, a sophomore-level engineering design course at Georgia Tech. Enrollment is commonly over 200 students per term, but the students are grouped into studio sections that typically have 20 students per section. The course introduces engineering students to a set of simple tools that address engineering design, teamwork and technical communication. These tools include charts that students fill out in order to better understand the design problem, to partition the problem and to develop

conceptual solutions. The tools also include evaluation matrices that support orderly comparison of design concepts. We present these tools in lectures, then students use them to address design projects of increasing complexity. The student project work culminates in the design and fabrication of a mechatronic device using electronic components that we supply. Students demonstrate their devices in an end-of-term design contest. The course has a technical communication component, such that student designs are evaluated according to their presentation in written reports. While student tournament scores are factored into their grades, their grades depend heavily on the written and oral presentation of their work.

Before tablet devices became widespread, the authors developed a print textbook, which was used in this class for several years. As iPads became widespread, we chose to redevelop the print textbook for display on iPads, with the goal of developing supplementary interactive elements to augment the presentation the course material.

3 DEVELOPMENT OF AN INTERACTIVE TEXTBOOK

To convert our print textbook to an electronic book, we chose to use the editor iBooks Author, as it accommodates a large variety of display types and it is relatively easy to use. This program enables authors to insert the usual array of static displays, such as, photo galleries, presentation slides, and photos with interactive labels. It also allows authors to insert more visually compelling displays, such as videos and 3-Dimensional interactive images that readers can manipulate. Most importantly, it also allows authors to develop and deploy interactive components of their own design. In the following, we present and briefly discuss the interactive elements that we have added to this textbook.

3.1 Photo Galleries

Engineering students and professionals rely on photographs to document designs and to explain events. Engineering textbooks naturally rely on photographs, and instructors often wish to use their own photographs in the classrooms. In our textbook, we chose to use our own photographs because they illustrate our particular approach to the classroom topics and because they illustrate acceptable technical photography. The iBooks Author editor makes it very easy for instructors to add and rearrange photographs in the textbook.

The simplest interactive display provided in iBooks Author is a photo gallery, an example of which is shown in Figure 1. A selected figure is shown in the large, upper frame on the right side. Below it is a gallery of thumbnail images, showing other figures that are available for the reader to select. Galleries such as this save space, as they allow authors to assemble numerous photographs (or other images) in a single spot. This is good for readers, as it assures that photographs will always be displayed on the pages where they are cited. This is useful in engineering and science textbooks, where students are often asked to view groups or sequences of displays in order to identify trends or to understand complex concepts.

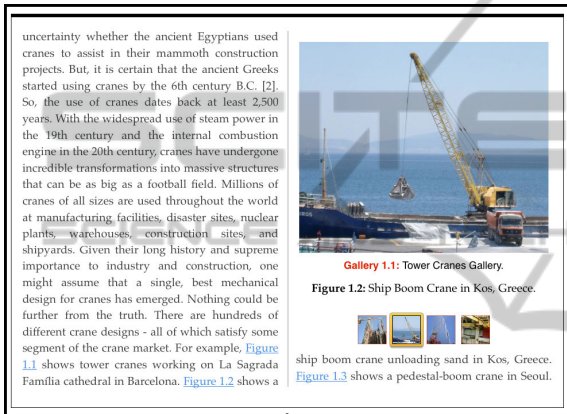


Figure 1: Photo gallery with four images.

3.2 Three-Dimensional Interactive Displays

Three-dimensional displays are particularly important in engineering classes, where students must visualize complex systems. In our class, students are expected to prepare professional-quality drawings and to learn how to understand drawings prepared by others. Engineering students are trained to prepare and use three-dimensional drawings, so the inability of print textbooks to accommodate 3-D displays has been a significant limitation for students and teachers alike.

Figure 2 shows three views of a 3-Dimensional drawing of a Segway personal transporter. As presented in our interactive book, this 3-Dimensional drawing can be rotated. View (a) is the appearance of the drawing upon activation by the user. In views (b) and (c), the user has rotated the drawing with a finger swipe. Using this interactive capability, users can examine objects from any angle, a capability that could never be achieved with a print textbook.

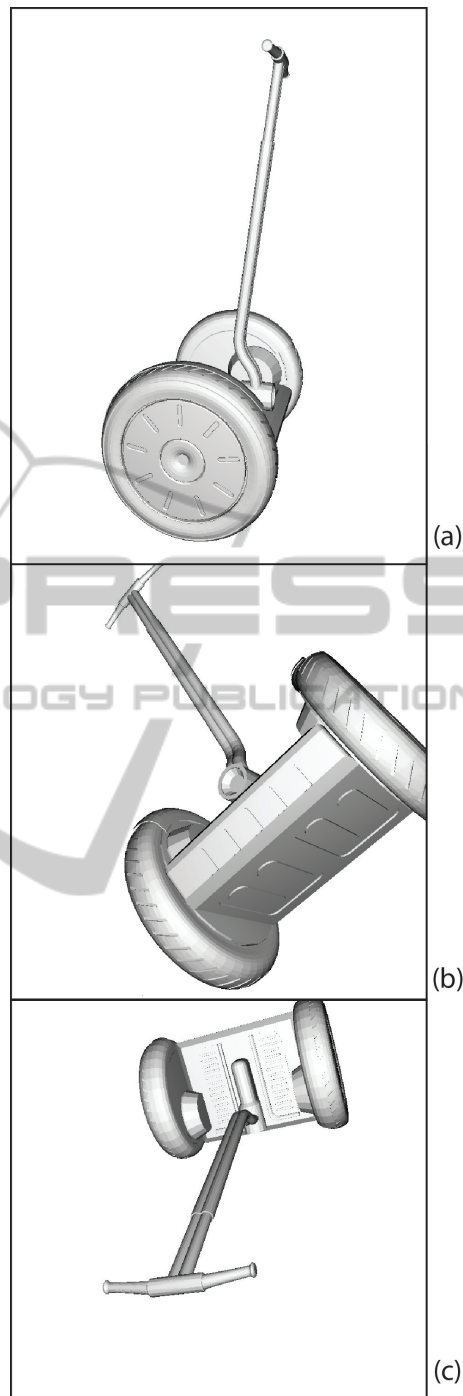


Figure 2: Various stages of an interactive 3-D drawing.

3.3 Embedded Video

Video is a powerful classroom resource because it can provide demonstrations that are more vivid than an instructor's descriptive words. Instructors in science and engineering courses now commonly post video demonstrations on websites. iBook tools allow in-

structors to embed such videos in the students' textbooks and to upgrade these easily as topics change each term. Figure 3 shows three frames from one of the many videos that we have inserted in our iBook. It shows one of our studio instructors falling from a Segway Personal Transporter, and it is used as part of an introductory project to help students develop customer requirements for the design of a personal transporter of their own.

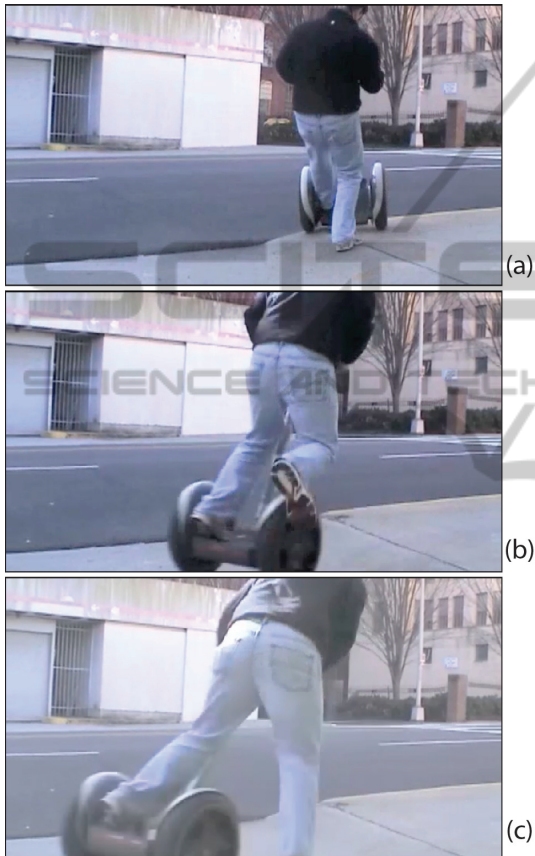


Figure 3: Frames from an embedded video.

3.4 Real-time Interactive Simulations

Real-time simulations can be as powerful as video demonstrations in improving student engagement with scientific subjects. The primary limitation of any print textbook is that the student must imagine how things move and change while looking at single images, diagrams or plots. iBooks Author enables users to code working interactive simulations that students can operate from the pages of their textbooks. In this section, we present two such simulations that we developed at Georgia Tech. One of these represents a bridge crane with a swinging payload, and the other represents an inverted pendulum. In each simulation, the user is asked to move the payload to a target area.

Figure 4 is a screen shot of the textbook showing a 3-D interactive drawing of a crane on the right side. On the left side is an interactive, real-time simulation of a bridge crane. In Figure 5, three screenshots show this simulation in use. It demonstrates the operator's challenge in controlling a swinging payload. At the top of the screen is a box-like representation of a crane trolley to which a square payload is attached via a cable. At the bottom of the screen are orange input buttons that allow the user to raise and lower the payload. Green input buttons move the crane left and right. When users press these control buttons, the crane moves, and the payload swings.

In this simulation, the payload movements are physically correct; the swing frequency changes as the payload is raised or lowered and as the crane is moved left and right. A user can reduce or increase the payloads swing by moving the trolley into or against the payload swings and by raising or lowering the payload. To make the exercise interesting and goal oriented, we have provided the users with an objective; they must deliver the payload to a target box marked by red lines at the right of the screen. A timer allows users to score themselves and to compete with friends.

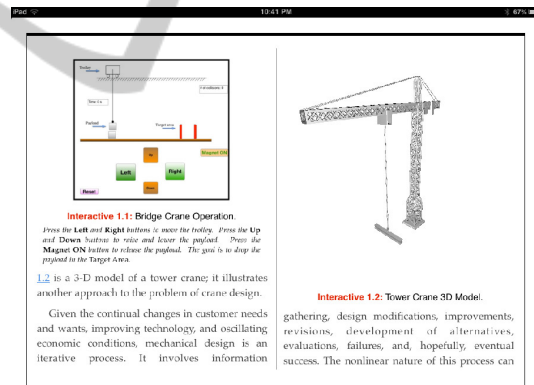


Figure 4: Page with crane simulation and 3-D drawing.

This simulation was developed in the Apple Dash-code environment. The resulting program was then exported as a widget, which is a small HTML snippet that functions like a mini webpage upon integration into an electronic book. This development point is significant; many faculty members have developed simulations as part of their work; our work demonstrates that these can be developed into compelling displays in electronic textbooks.

Figure 6 shows three screen shots of a related real-time simulation that is used in our textbook: an inverted pendulum. This simulation was developed to complement the crane simulation and to illustrate that the problem of controlling an inverted pendulum is

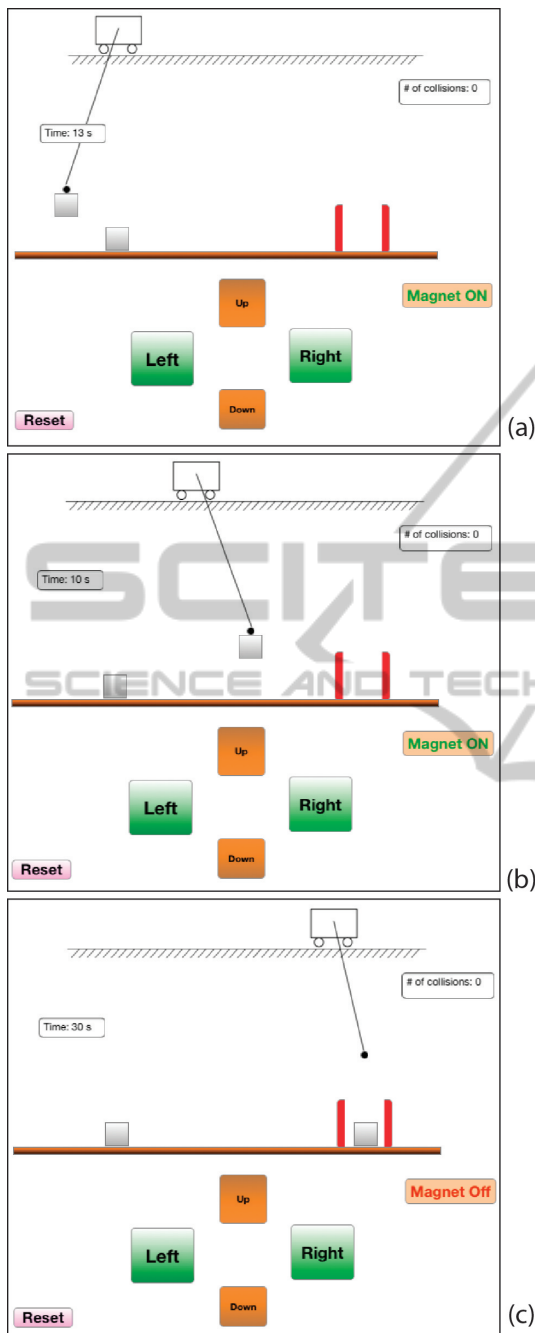


Figure 5: Real-time simulation of crane control.

more difficult than that of controlling the pendulum swing of a crane payload. This simulation is used in a class study of a commercially available inverted pendulum: the Segway Personal Transporter.

In this simulation, the user is challenged to do what a Segway control system is designed to do: maintain the mass stably above the center of gravity and transport it to a target, which is represented as the red area at the center of the screen. To do this,

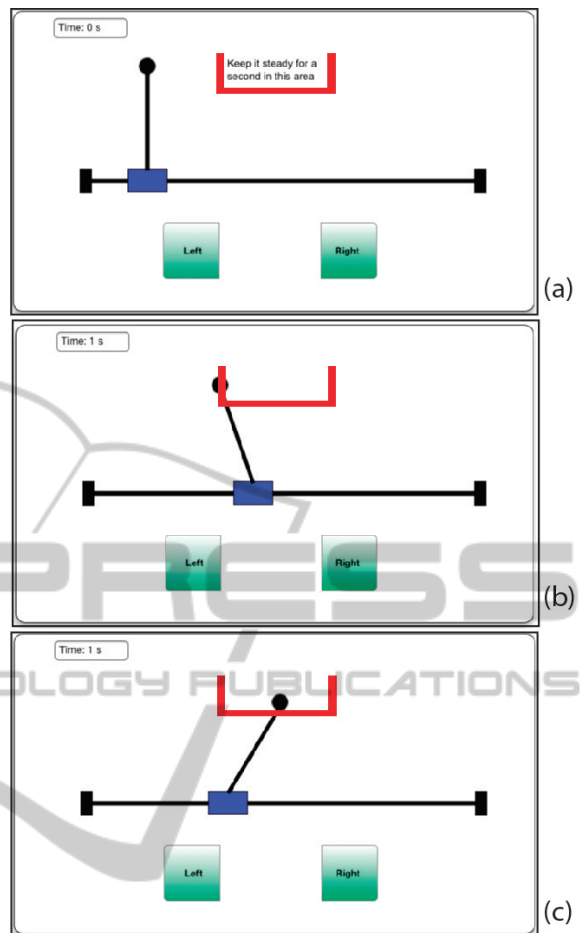


Figure 6: Real-time simulation of segway control.

the user must control the blue pivot point below the mass; this is done by using two green input buttons at the bottom of the screen to move the pivot point left and right. As is the case for the crane simulation, the behavior of the system is physically correct; the mass tends to fall when the blue pivot point moves away from the position directly below the mass.

Figure 7(a) shows the starting point for this simulation, with the weight positioned stably above the pivot point. In Figure 7(b), the pivot point has been moved below the red target zone, and the weight, tipped to the left, appears to be falling away from the target zone. In Figure 7(c), the weight is in the target area but falling to the right.

Simulations such as this are crucial for interactive textbooks in the science and engineering domains. They offer realistic representations of complex concepts, and they provide students with a form of hands-on learning. By allowing students to vary the parameters that drive the simulation, tools like this allow students to explore systems in a way that text explanations cannot reproduce. Further, when complemen-

tary simulations are paired, as here, students may gain deeper insight into the concepts that are being illustrated. We feel that interactive simulations such as this should be used as often as possible in textbooks for science and engineering students. We believe that authors and publishers should treat this as a priority as they develop textbooks for use on electronic devices.

3.5 Interactive Planning Tools

In addition to designing devices, engineering students learn to use a formal process of defining problems, developing designs, and evaluating design concepts. To guide students through these steps, design courses teach students to prepare a number of planning tools. These tools are specialized flowcharts and tables, with variations in layout that accommodate the designers' needs at different stages of the design process. We ask students to prepare planning tools in order first to insure that design decisions are made in an orderly process, and second in order to create records of their design decisions for later reference. We developed these interactive charts to give the students a simple but fast way to learn how the tools work before they begin work on their own charts.

The first of these interactive planning tools is the Morphological Chart, or "Morph Chart," shown in Figure 7. In a Morphological Chart a designer displays a set of possible design solutions, organized by subfunctions. In this way, the Morph Chart presents all of the possible combinations of ideas for a design project, and designers can develop system design concepts by integrating subsystem components from the Morph Chart.

In the interactive Morph Chart of Figure 8, a simplified list of system subfunctions is shown in the row headings on the left, and diagrams of possible solutions are aligned in the matrix of the chart. In this interactive chart, students can brainstorm possible system designs by directly selecting solutions from the matrix; a possible system configuration is then assembled at the bottom of the display. The concept system display changes each time the user selects or changes a solution; Figures 8(a) through 8(c) show that the display highlights the selections as the user builds a system concept. Using a tool such as this, a user can create a large number of different design concepts.

While interactive simulations are useful for teaching technical concepts, interactive charts are useful for teaching the planning and record-keeping components of engineering projects. Design tools such as the Morphological Chart are fundamental to the mechanical design process as we teach it at Georgia Tech. We believe that they guide students into making

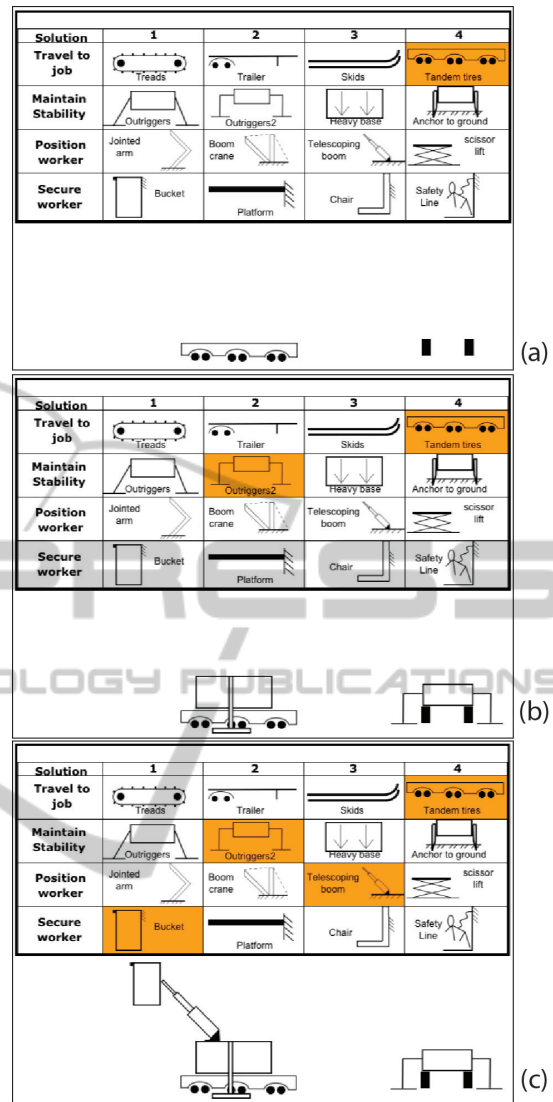


Figure 7: Interactive Morph Chart.

good decisions. By making these tools interactive, we have made them more interesting to learn and more convenient to use.

4 ASSESSMENT

To assess the how well the iBook text engaged the students, we developed a survey to determine whether the students found the book to be useful and to determine which interactive tools, if any, were of greatest interest to them. The survey asked students first to assess, on a scale of 1 to 5, the usefulness of the iBook, and second to assess, on a scale of 1 to 5, the usefulness of the interactive features in general. For both questions, a response of 1 meant "Very Useful," and

a response of 5 meant "Not Useful"; a response of 3 meant "No Opinion." In a third question, we asked the students to rank the utility of four of the interactive elements on a scale of 1 to 4, with 1 being the most useful and 4 being the least useful.

Over the course of two terms, we distributed iPads with the iBook textbook, to four studio sections with a total of 80 students enrolled. Of these, 45 students returned completed survey forms to us. Of these, 82%, (37 of 45 students) responded positively, finding the book to be useful or very useful. Three of 45 students (6%) responded negatively, finding the book to be not useful or not very useful. Five of the 45 students, or 11%, gave a neutral response of no opinion.

When asked to evaluate whether the interactive elements were useful, 68% of the respondents (31 of 45 students) rated these to be useful or very useful while 3 students (6%) rated them as not useful or not very useful. Eleven of the 45 students (11%) gave a neutral response of no opinion. These survey results are displayed in Table 1.

Table 1: Evaluation of Textbook and Interactives, Most Useful to Least Useful.

	1	2	3	4	5
Textbook	14	23	5	0	3
Interactives	11	20	11	2	1

To establish the relative utility of the interactive components of the book, we asked students to rank the embedded videos, interactive 3-D drawings, interactive simulations and interactive charts. Here, students ranked the interactive charts as most useful and embedded videos as least useful, with 3-D drawings and interactive simulations tied in the middle. The complete response set is shown in Table 2. The distinctions are small in our survey results, however, and it may be that the different types of displays appeal to different groups of students in a large class.

Table 2: Student Ranking of Interactives Best to Worst.

	1	2	3	4
Videos	9	7	12	13
3-D Drawings	6	13	12	10
Simulations	9	12	12	8
Charts	16	7	5	13

The print version of the textbook, of course, provides no interactive elements to which these results can be compared. The print text offers design tools in static form, and students using the print textbook did find value in these displays; 173 students responded to our survey question regarding the usefulness of the textbook, and 80% of respondents assessed these as

"Useful" or "Very Useful," while no users gave negative responses. These responses are similar to those obtained for the interactive textbook, and this calls for further investigation into the way that examples are prepared and displayed in print and interactive forms.

5 DISCUSSION AND FUTURE DIRECTIONS

Our survey results demonstrate that students respond positively to electronic textbooks, and we believe that the interactive elements are important to this response. To make our interactive elements compelling, we have made them rich with information related to our class topics. While we have not yet related textbook use to student learning, our results suggest that this textbook has had an impact on the problem of student engagement.

The current interactive textbook can be viewed as a proof of concept version, and it is reasonable to seek ways to augment it. Generally, we seek new ways for students to interact with our displays. One path of development is to enable students to edit and export the interactive tools for use in other programs. Students might open and modify a 3-D drawing as part of an assignment, for example. Or, our Morphological Chart might be integrated with a drawing tool that would allow students to create, integrate, and evaluate design concepts from within the book's pages.

In the same fashion, the current tools for editing and organizing reports do not yet provide options for students to test their own ideas for writing and editing. To make such writing and editing tools more richly interactive it will be necessary to integrate them with an Automated Essay Scoring system that provides real time feedback on the students' written work.

6 CONCLUSIONS

Our results indicate that students responded positively to this interactive textbook, and to the particular interactive displays that were included in it. These responses are significant because they show that the creating interactive textbooks enables instructors to respond to the problem of student engagement independently and relatively easily. With tools that are easily available, instructors in science and engineering courses can develop textbooks that have a positive impact on their students' engagement.

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