The Impact of Faculty-Mentored Versus Web-Guided Engineering Design Experience on Freshman Skills

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Abstract

This study explores the impact of freshman engineering design experiences on student engineering design-related perceptions and performance. The impact of two teaching methods, faculty-mentoring versus web-guidance, used in the teaching of engineering design were also explored. Four skills associated with engineering design were assessed: open-ended problem solving, information search, mechanical building, and teamwork. Web-use related skill of information search was also assessed. Assessment methods included: pre- and post-activity student skill self-report surveys, observations of student teamwork and presentations, student interviews, and performance scoring of team design notebooks using a scoring rubric developed for design-related activities. Post-activity student skill self-reports revealed statistically significant gains in problem solving and mechanical building skills for Mentored and Web-guided groups when compared with pre-activity responses. Performance assessment of the Web-guided group using a team-based engineering design work scoring system showed higher scores for the use of technical concepts in the design process than the Mentored group. Based on teamwork observations and performance assessments of design notebooks, it was concluded that Web-guided students' higher scores in this skill were due to the fact that the web-based electronic design portfolio template, or Design Process Templates, helped students complete pertinent steps in the design process. This data also revealed that students in the Web-guided group were hampered by differences in HTML programming skills within the group. This difference limited some students' ability to act as a team in using the Web-based Design Process Templates for much of their design work. This issue was a particular problem for women who reported lower pre-activity HTML programming skills than men. Furthermore, instructor versus student conceptions of the design process hampered some students' use of the Design Process Templates.

Introduction

This study explores the impact of freshman engineering design experiences on student engineering design-related perceptions and performance. Freshman performance in engineering design was measured for several skills: problem solving, mechanical building, and teamwork skills. Recent studies have argued that exposing students to engineering design activities during their freshman year will provide the sort of multi-dimensional, challenging experience that provides a base for many important skills students need for success in engineering [11,33, 35, 2, 47]. The problem for engineering faculty is how to present this complex activity so that novice students are enriched rather than frustrated by the experience. Due to the real complexity of the engineering design process, instructors are often frustrated in their efforts to create material suitable for freshmen [24, 11, 12].

The use of multimedia instructional materials has grown at a phenomenal rate in recent years. Not surprisingly, that trend has been greatest in the teaching of undergraduates in technical disciplines, undergraduate engineering education among them. While multimedia has become widely used, studies that rigorously define either the multimedia form or the education assessment experiment are, according to Clark and others, surprisingly rare. Nor is the pedagogical rationale for employing educational technology instructional tools rather than traditional methods clear [7, 19, 39, 41, 38].

This work draws on the work of Simon, Dym and others who suggest that, in order for novice students to benefit most from any form of engineering design activity, one must first recognize that the design process is, in fact, made up of a set of interrelated skills. The most difficult of these to master are problem solving, parameter estimation, and information search within a domain. Some have suggested that students are often frustrated in their initial attempts to design since they have not been given any training in such skills [42, 12]. In this work, particular attention has been given to the experimental treatment and assessment of student learning outcomes for these skills.

This study also employs a mentor pedagogical model in which a mentor closely guides, rather than leads, students through a complex activity, such as engineering design. The merits of this model, though once the norm in engineering apprenticeship, have received greater attention in recent years in engineering education as well as other disciplines [29, 13]. It would be of great interest, then, to explore the impact of a faculty mentored engineering design team experience versus a Web-guided team experience on student skills.

Background

There are numerous models for initiating students into the nuances of the engineering design process from mini-design problems, which focus on problem solving skills, to major capstone design projects, which encompass many skills [2, 4, 9, 26, 30, 31, 33, 35, 47]. Leifer has noted that instructing students in the engineering design process provides an opportunity for introducing constructivist learning experiences into engineering student classroom activities [22]. He drew on Kolb's experiential learning model which describes learning as taking place in an iterative cycle of four basic steps: reflective observation, concrete experience, active experimentation, and abstract conceptualization. Based on this cycle, Leifer suggests that engineering design and technical concepts should be intertwined. In this way, students can best learn technical concepts through the practice of engineering design.

Simon has noted that the engineering design process is actually made up of a set of intertwined skills including open-ended problem solving, information search in an expert knowledge domain related to the design in question, and teamwork, among others. In greater depth, Dym has explored the steps of the engineering design process with particular focus on information search, expert knowledge, and the nature of expert intuition in engineering design [12]. Taking a different perspective, Bucciarelli has explored the social process of engineering experts as they collectively draw on their own design knowledge and experience in constructing a new engineering design [5]. Others have addressed the need to instruct students in the skills of engineering design through the creation of exercises in problem solving [26], mechanical building [8, 34], visualization in design [46], or teamwork [5].

There is a growing trend to take advantage of multimedia curricular materials to enhance student learning in engineering. These materials include computer-based packages that might contain simulations, graphics, text, video clips, as well as interactive exercises which explore this material [1, 8, 15, 16, 17, 23, 31, 39]. This sampling of work on educational technology and engineering education often have similar instructional goals. The overall goal of multimedia curricular material is that difficult concepts might best be taught through presentation of those concepts in a variety of forms, be they visual simulations, text, or graphics. Furthermore, it is thought that the interactive, flexible nature of the ideal user interface might furnish a learner-centered constructivist environment for self-paced and styled material comprehension.

Hsi and Agogino have noted that students haphazard, unstructured approach to web-based multimedia material in engineering seldom leads to positive learning outcomes [15]. A brief review of the literature reveals that this issue is not confined to engineering studies; the problem has also been apparent in other studies [19, 45]. Some authors have suggested that, in order for novice students to benefit from multimedia material, they require some direction when that material is unfamiliar. Such direction might include explicit instructional strategies for problem solving and information search or feedback. Nizamuddin and O'Neil explored this approach with success in their design of an intelligent tutor for algebra [32]. In their work, the authors compared student algebra exam grades when students were given explicit problem solving strategies in addition to algebra instruction. They found that students performed significantly better after completing the tutors module on algebra problem solving strategies. Deek et al. achieved similar results in their study of a computer-based computer programming tutor [10]. Jacobsen and Spiro argued that students also require guidance in their use of web material [18]. They suggested that students have no rules or criteria for information search in unfamiliar, complex domains, hence their display of haphazard search behavior. In their study of the use of Thematic Criss-Crossing Web, they found that students who were provided with web links that explicitly demonstrated critical interrelationships performed better in problem-solving essays than students who were given the same web material without the Thematic Criss-Crossing Web links. Shabo addressed the issue of students' random search of a web domain by integrating the most useful elements of the linear instructionist and non-linear constructivist pedagogical approaches [40]. In his design of a web tool for endocrinology, information was first presented in a linear instructionist manner. After completing this material, students were required to complete WebDiagrams or concept maps, in which they needed to construct a map of their understanding of the material. As students build their diagrams, students had the option of using an expert feedback tool to check their diagrams for misconceptions and correct them.

In their long-standing argument concerning the role of media in instruction, Clark and Kozma have struggled with the question of whether any medium unto itself can improve the message [7, 21]. Clark has argued that many studies have over-reported student learning outcomes when comparing student groups taught material via educational technology tools versus traditional classroom-based lectures. Since 1983, Kozma and others have endeavored to discern some general thematic categories for the use of various media in instruction [21]. In their approach to the teaching of engineering design, Regan and Sheppard have suggested that a combination of hands-on learning and interactive multimedia tools appears to best benefit student learning [39].

In the mentor-student pedagogical model, a mentor closely guides, rather than leads, students through a complex activity, such as engineering design. The merits of the mentor pedagogical model, though once the norm in engineering apprenticeship, have received greater attention in recent years in engineering education as well as other disciplines [13, 29]. It is argued that, if students are to take part in complex, self-paced constructivist learning experiences, then the ideal role for the teacher is a guide on the side.

Overview of Study

Few studies of freshman engineering education have carefully examined the impact of pedagogical model on the teaching of introductory engineering design. This study was designed to explore student learning outcomes after exposure to traditional mentored versus educational technology-guided learning environments. It also compares student learning in an experimental group of students who experienced a freshman design subject with those who did not. In the first experimental case, student design teams were guided by a faculty mentor. In the second experimental case, teams were guided by web design tools that students were encouraged to use. In each instance, students were guided through activities that allowed them to comprehend some of the essential skills of engineering design, including problem solving, information search, mechanical building, and teamwork. After this stage, students are then required to complete a team design project again under the guidance of a faculty mentor or web-guide. In order to best improve mechanical building skills, both student groups were also asked to build prototypes of their designs. The control group did not complete any experience in freshman engineering design. Table 1 summarizes the experimental treatments for the Mentored and Web-guided groups and the control group treatment.

Table 1. Treatment characteristics for control and experimental groups

Group	General Treatment	Team Structure	Team Communication	Support Material
Control	None			
Mentored	Team design and hands-on building of prototype	Peer group of 4 students with faculty mentor guidance	Face-to-face, email, paper team design notebook	Paper readings and exercises supplemented with some readings from mentor
Web-guided	Team design and hands-on building of prototype	Peer group of 4-5 students with web guidance and ability to email instructor	Face-to-face, email, web-based team design notebook	Web-based readings, exercises, and Design Process Templates

Faculty-Mentored Group Treatment

The faculty mentored seminar was developed around the theme of creating mechanical or computer-based devices that could be easily used in small village medical clinics of African nations where electrical power and technical expertise are scarce [43]. The design projects groups were organized as closely-mentored small design teams. Each team was to choose a design from an instructor-supplied list. The mechanical devices on the list were chosen due to their common physical and mechanical features. This commonality allowed the instructor to give technical lectures and paper readings on pertinent physics and mechanics concepts. Other lectures focused on teamwork, an introduction to the engineering design process, and creating design team notebooks. Lecture-related technical exercises were also to be completed by students. The technical exercises allowed students to begin to explore the concept of parameter estimation using the technical concepts presented in lecture. A library of additional material pertinent to the technical concepts, on engineering design, and material potentially of use in each design project was created by the instructor. The faculty mentor or Undergraduate Assistant (UA) of each team would suggest different works from this library based on the directions being taken by student design team inquiry. The faculty mentor and UA were charged with guiding the team through the design process from idea inception, problem formulation, parameter estimation, possible design alternatives, and the final building of a prototype.

The Mentored group took part in a team building exercise during one lecture period, the Delta Design Game [5]. The game's goal is to teach students about design team negotiation and how, as a group, to follow a set of technical guidelines in order to create a design. The game's simple concept is as follows: students are to design a building from a set of different colored cardboard triangles. Each triangle has been assigned different physical and economic properties. Finally, the students play various technical experts working as a team. The experts include an architect, civil engineer, and materials engineer. For each expert, different aspects of the design are, by the nature of that discipline, more important than others. For example, while the civil engineer might be most concerned with structural integrity, the materials engineer might focus on material capabilities. The goal of the game, then, is for team members to negotiate the design based on their technical expertise.

Web-guided Group Treatment

The Web-guided seminar was developed around the theme of introductory aeronautics principles and the design of a prototype dirigible [30, 31]. While lecture topics paralleled the teamwork, design process, and technical material covered by the Mentored group, all reading material and lecture-related exercises were placed on the Web. Rather than completing paper exercises on technical concepts and parameter estimation, the Web-guided group completed their exercises on the Web and emailed them to the instructor. Unlike the Mentored group, who needed to refer to assigned paper texts when completing parameter estimation assignments, the Web-guided group could refer to web-linked readings and examples when completing their assignments.

All materials for the team design project were to be placed on the Web, in the form of Web-based electronic design portfolio templates, herein called Design Process Templates. While many instructors, to date, have placed lecture and homework sets on the Web, it is the development of Web-based design project material that is perhaps the most innovative contribution. The design project materials provided a rigorous electronic format for completing each design project step: 1) pertinent notes from lecture, homework, library search for ideas; 2) pertinent sketches from past homework, brainstorming; 3) vehicle concepts that synthesize several sketches; 4) drawings of each vehicle component and configurations; 5) delineation of technical design criteria and critical analysis of team design (including equations used and analysis); 6) presentation of alternatives and prototype; and 7) graphical and technical presentation of final design. Each template contains web links so that student teams can quickly refer to pertinent material on alternative designs, technical concepts, parameter estimation, and graphical presentation ideas.

By placing design process materials on the Web in interactive template form, it was hoped that pertinent lecture and other materials would be, in an organized and categorized form, immediately available to teams during the team design process. Furthermore, the templates would structure access to the web material by concisely structuring each step in the design process.

The structure of the Web-based Design Process Templates, with their web links to pertinent material if a student chooses to use them, is similar in its pedagogical model to that of Shabo's web materials for teaching endocrinology [40]. In that work, mentioned earlier, Shabo hoped to combine linear instructionist and nonlinear constructivist models in the development of web material and exercises. In this way, he hoped to guide, rather than control, the direction taken by students as they explored the material and to offer them rapid assistance when needed as they completed the exercises. The Design Process Templates are both linear and non-linear: their order is linear, however, students may use the web links embedded in each template in a nonlinear constructivist manner.

During one lecture period, the Web-guided group took part in the same team-building Delta Design Game mentioned above on the Web rather than face-to-face. By playing the game on the Web, it was hoped that each team would begin to build its ability to share ideas via Web-based communication and graphics tools.

Subjects

Two-hundred and five freshman students out of a possible 1074 total freshman took part in this study at MIT 6 years ago. Students were grouped into either of two experimental groups, Mentored or Web-guided, or the control group which received no treatment. It was not possible to randomly assign students to each group, nor was it possible to control group size or characteristics since the groups were created via scheduled classes voluntarily chosen by students. The control group was made up of 153 freshman students enrolled in a required calculus subject. The control group was screened via pre-activity survey for any engineering design-related activities in which they might have taken part during their freshman year.

The pre-activity survey also screened for another variable that could potentially confound results: plans to major in engineering. Indeed, it was found that nearly all students in the experimental groups planned to major in engineering (81% and 84% for the Mentored and Web-guided groups, respectively). Hence, the control group, which originally contained only 60% of students who planned to major in engineering, was further cut to include only those students who planned to major in engineering. This created a final control group of 92 students.

The experimental group was made up of 52 freshman with 20 in the Mentored group and 34 in the Web-guided group. Table 2 summarizes the final experimental and control group characteristics by total and gender.

Table 2. Experimental and Control Group Characteristics

Group	**Men**	**Women**	**Total**
Control	59	33	92
Mentored	12	8	20
Web-guided	24	10	34

Methods

The methods used to assess student learning outcomes in this study included a set of complementary methods used with success by others in assessing engineering student learning [3, 14, 37, 38, 44]. These methods included pre- and post-activity student skill self-report surveys, teamwork observations and performance scoring, design notebook performance scoring, and post-activity student interviews. The assessment plan employed allowed for a more efficient combination of each method. In short, pre-activity survey results and preliminary teamwork observations are analyzed as soon as possible after project activities have begun. Doing so allows one to tailor further additional observations (and observation checklists) and post-activity interview questions in order to monitor potential issues that impact student learning [24] .

Shute and Regian suggest that the assessment of student learning outcomes after exposure to web learning environments provides an opportunity for collection of unique data [41] . They note that the use of computer-based educational tools can allow for collection of complete data on students' study behavior and learning styles and the impact of these variables on learning outcomes. The use of computers for data collection can also assist in the creation of complete and efficient databases of student work for analysis. Reeves warns, however, that dependence on the computer for data collection can allow one to disregard the value of traditional assessment methods [37] . The data collection opportunity provided by student work via computer was employed in this work through collection of data on student hits, web use patterns.

Engineering Design Behavior and Performance Scoring

In order to most efficiently collect data and score student behavior and performance, an observation and performance scoring system was developed specifically for student engineering design work. The system was developed and tested as part of the ECSEL project whose primary goal was the inclusion of design activities as part of undergraduate engineering education [24] . Observation checklists and portfolio scoring are often used methods in education assessment, however, such methods have seldom been applied in engineering design [3, 38] . Table 3 lists skills associated with engineering design and some of the pertinent behaviors associated with each skill. The skills include problem solving, mechanical building, and teamwork. For the Web-guided group, Web-use skills and behaviors were also included. By translating skills seldom measured by traditional quantitative exams or final engineering design reports in this way, both observations and design notebooks can be analyzed and scored. It must be noted, however, that observation data collection was not limited to checklist behaviors and performance scoring. Students were scored as teams rather than as individuals since all work was completed as a group. Observations and design notebooks were scored based on the behavior checklist in Table 3. Each behavior was scored using a 3-point scale where 1=displayed inadequate proficiency, 2=displayed adequate proficiency, and 3=displayed superior proficiency.

Pre- and Post-Activity Student Skill Self-Report Surveys

Like the observation and performance scoring system, the pre-tested student skill self-report survey questions were based on a description of behaviors associated with engineering design and Web-use skills. Students were asked to respond to behavior statements which might describe their own behaviors using a 5-point scale where l=strongly disagree and 5=strongly agree. The brief survey also included questions on gender, plans to major in engineering, and other engineering design activities in which the student took part during their freshman year.

Students were also asked about prior subjects completed in which all class materials were on the Web. Students in the Web-guided group were also asked if they had prior general and HTML programming experience.

The survey was distributed to the experimental group both prior to and after the treatment activities. Because of administrative problems, the survey was distributed to the control group only at the time that the experimental group took their post-activity survey. Since control group survey responses were not statistically different from the experimental group's pre-activity responses, and since the survey instrument controlled for students with confounding design experience, it was concluded that this plan was satisfactory for control and experimental group comparisons.

Table 3. Engineering Design Skills and Performance Characteristics

Design Skill	Performance Characteristics
Open-ended problem solving	• Use technical concepts correctly in parameter estimation • Consideration of alternative designs guided by technical feasibility • Information search for design ideas structured by consideration of technical parameters
Mechanical building	• Display acquaintance with rudimentary mechanical parts and devices • Able to translate 2-D drawing into 3-D prototype
Teamwork	• One or more students act as project leader or manager • Students share work equally as team design project progresses • Team members able to discern between major and minor team problems and address them appropriately • Team members able to bring problem to supervisor if needed

Teamwork Observations and Scoring

Both an observation checklist and open-ended observation were used in monitoring teamwork. While the checklist structured the collection of essential data on engineering related skill performance as described above, open-ended observations provided an opportunity to collect data on other issues that might impact student learning. Teamwork was also scored based on observations of teamwork behavior described above.

Since the 6 student teams in the Mentored group needed to meet often with their faculty mentor or undergraduate assistant, most teamwork sessions took place in scheduled bi-weekly meetings in one classroom. This arrangement allowed for observation of all 6 teams in the early and mid-stages of their design activity. As the teams neared the prototype stage, each group worked in a lab or other workshop. From that point, observations were limited to 3 of the 6 teams.

Each of the 6 student teams of the Web-guided group scheduled their own group meetings. When those meetings overlapped, it was not possible to observe all face-to-face meetings. Since teams often worked on the Web, it was possible to collect data on student emails, time spent on particular Web pages, and web links chosen.

Post-Activity Student Interviews

Post-activity student interviews were semi-structured. The goal of the interviews was to further explore student survey, Web-use, teamwork observation, and design notebook scoring results. Six students from each experimental group were interviewed for a total of 12 interviews. Where possible, one student from each student team was included. Interviews were also mixed by gender so that 8 men and 4 women were interviewed.

Results

Pre-activity student skill survey

Table 4 shows mean student responses to the pre-activity engineering design skill survey for the control and experimental groups. Students were asked to agree or disagree using a 5-point scale (where 1= strongly disagree and 5= strongly agree) to a series of statements that might describe their own perceptions of skills related to engineering design. As mentioned earlier, the control and experimental groups were screened for prior engineering design experience during their freshman year and plans to major in engineering. By doing so, one could ensure that the two groups were homogeneous in the most pertinent variables that might confound results. In fact, results of a one-tailed t-test revealed that there were no significant differences between the experimental and control group means for all skills listed in Table 4 (df= 142, $p>0.005$).

Table 4 shows that student pre-activity perceptions of open-ended problem solving and mechanical building skills are moderate (average response is 3.5 on a 5 point scale). Teamwork responses are somewhat higher averaging 3.9 on a *5* point scale. All pre-activity survey statements were designed to reflect positive behavior except one. The teamwork statement, “If team was having problems working together, I would try to work and ignore them,” was the only statement to which students disagreed (average 2.3 on *5* point scale). This was an expected response since most students felt that they would address a team problem rather than ignore it.

There are two very interesting aspects of student self-reports of skills that allow them to be a highly useful assessment tools. First, students generally do report honestly on skill levels [3].

Second, self-reports highlight the relationship between perceived skill strengths and motivation to take part in particular learning experiences. For example, freshmen who felt that they are strong in skills related to engineering work voluntarily chose to take part in

Table 4. Comparison of control and experimental group mean responses to pre-activity engineering design skill self-report survey (1)

GROUP **Engineering Design Skill**	**CONTROL GROUP Mean pre-activity response N=92**	**EXPERIMENTAL GROUP Mean pre-activity response N=52**
Problem Solving		
• Comfort with open-ended problem solving	3.3	3.8
• Methodical in setting up and solving complex technical problems	3.6	3.4
Mechanical Building		
• Love to build things	3.4	3.4
• Can design and build a device if given a box of mechanical parts	3.2	2.8
Abstract/ Concrete Design Connections		
• Can see how abstract concepts can be used in design	3.4	3.4
• Can grasp technical concepts without many concrete examples	2.9	3.3
Creativity		
Creative thinker	4.1	3.9
Teamwork		
• Effective team member	4.0	4.1
• Capable team leader	4.0	3.8
• If team having problems working together, would try to work and ignore the problems	2.3	2.3
• If team having major problems working together, would discuss with instructor	3.4	3.3
Web use		
• Comfortable using the Web for information search	4.3	3.9
• Comfortable taking a class where all materials were located on the Web	3.2	3.5

(1) One-tail t-test shows equivalence of control and experimental group means for all skills (df =142, $p < 0.005$).

learning experiences which would require the use of those skills; in this way, students might further hone those skills. Students who do not choose such classes generally perceive that their strongest skills are not in engineering-related areas.

Though the complete data are not included in this paper, the pre-activity survey was also given to control group students who did not plan to major in engineering (N=61). It is worth mentioning, however, that for open-ended problem solving and mechanical building skills, one-tail, t-test results revealed that the mean student responses were significantly lower than responses of students who did plan to major in engineering ($df = 151$, $p<0.005$). The differences were particularly strong when comparing responses to open-ended problem solving and mechanical building skill questions for control group women who did (N=33) and did not (N=41) plan to major in engineering ($df=72$, $p<0.005$).

Table 4 also shows that students feel moderately comfortable and familiar with Web-related activities (average 3.7 on a *5* point scale). This experience, however, is particularly important for the Web-guided group only since pre-activity familiarity is essential for project success.

Due to the importance of Web familiarity for the Web-guided group, the data for this group was examined more closely. Table 5 shows pre-activity Web-related mean responses by gender and total for the Web-guided group only. The table shows that there is no difference in Web-familiarity for web use or search, but that there may be a small difference for HTML programming for men and women.[1]

Table 5. Pre-activity Web-related skills by gender for Web-guided group.

Web skill	Men Mean response N=24	Women Mean response N=10	All Mean response N=34
Comfort using the Web for information search	4.0	4.3	4.1
Comfort level if all class materials on the Web	3.6	3.5	3.6
Comfort with HTML programming	3.2	2.3	2.9

[1] Calculation of statistical significance was unwarranted due to small size of experimental group.

Post-activity student skill survey

Table 6 shows mean student responses to the post-activity engineering design skill survey for Mentored and Web-guided groups.

Problem solving. Table 6 results show that students' perception of skill improvement in open-ended problem solving was greater for the Mentored groups than for the Web-guided group, though the mean response for both groups was 4.2. The table also shows that the Mentored group perceived greater improvement in their ability to methodically set up complex technical problems, though, again, the mean response for the Mentored group is only slightly higher than for the Web-guided group (4.0 and 3.8, respectively). Both groups perceived significant improvement in their ability to use abstract technical concepts in design (3.9 and 4.0 for Mentored and Web-guided groups, respectively).

Mechanical Building. For both groups, students perceived significant improvement in both the ability to set up a design problem if given a random set of mechanical objects and devices (4.0 for both groups). This improvement is related to students' greater enjoyment of building such devices (4.0 and 3.8 for the Mentored and Web-guided groups, respectively). It is useful to note at this point that, while both student groups were involved in hands-on learning through the actual building of mechanical prototypes, the learning experience for open-ended problem solving, parameter estimation, and use of abstract concepts in design took place via two different media. While the Mentored group were exposed to the latter skills via their face-to-face mentor-student teamwork, the Web-guided group were exposed to those skills via face-to-face student peer group and Web exercises.

Teamwork. Table 6 shows no significant improvement for team member effectiveness (4.4 and 4.1 for Mentored and Web-guided, respectively) or team leadership capability (4.2 and 3.9 for Mentored and Web-guided, respectively) for either group. This is perhaps due to the fact that pre-activity responses were already high, hence these skills could not be improved by the present learning experience.

Table 6. Comparison of mean post-activity student skill survey for the Mentored and Web-guided groups and results of paired t-test for comparison of pre- and post-activity mean responses (1)

GROUP Engineering Design Skill	MENTORED GROUP Mean post-activity response N=18	WEB-GUIDED GROUP Mean post-activity response N=34
Problem Solving		
• Comfort with open-ended problem solving	4.2*	4.2
• Methodical in setting up and solving complex technical problems	4.0*	3.8
Mechanical Building		
• Love to build things	4.0*	3.8*
• Can design and build a device if given a box of mechanical parts	4.0*	4.0*
Abstract/ Concrete Design Connections		
• Can see how abstract concepts can be used in design	3.9*	4.0***
• Can grasp technical concepts without many concrete examples	3.8**	3.2
Creativity		
• Creative thinker	4.0**	4.4***
Teamwork		
• Effective team member	4.4	4.1
• Capable team leader	4.2	3.9
• If team having problems working together, would try to work and ignore the problems	2.9	2.6*
• If team having major problems working together, would discuss with instructor	3.9	2.8***
Web use		
• Comfortable using the Web for information search	4.3**	4.4
• Comfortable taking a class where all materials were located on the Web	3.8	2.9
• Comfort with HTML programming	NA	3.4**

(1) Mean student responses are marked with asterisks where pre- and post-activity mean responses were statistically unequal. One-tail, paired t-test probabilities are marked next to mean responses as follows: *$p<0.005$, **$p<0.01$, ***$p<0.025$.

The ability to handle teamwork problems that hinder progress improved significantly for the Web-guided group, but not for the Mentored group (2.6 and 2.9 for Web-guided and Mentored groups, respectively). When comparing these results with pre-activity responses, the Web-guided group were more likely to ignore minor team problems and continue to work (1.9 pre-activity versus 2.6 post-activity) and more likely to address team problems themselves, rather than refer them to the instructor (3.3 pre-activity versus 2.8 post-activity). In light of the fact that the closely mentored group showed no change, the change in the non-mentored Web-guided group is especially interesting. As the next section on teamwork observations will discuss, the non-mentored Web-guided team needed to make decisions concerning teamwork problems themselves rather than referring them immediately to an always present mentor or teaching assistant.

Web-related Skills. Table 6 shows, as expected, no change in the Mentored groups perception of web-related skills, but significant changes in the Web-guided group's perception of skill improvement (2.8 for comfort if all class materials on the Web). Students' comfort level if all class materials were to be found on the Web actually decreased significantly when compared with the pre-activity response (3.6 for pre-activity and 2.8 for post-activity). As teamwork observations to be discussed below will illustrate, this response reveals students' discomfort with using 'linear' Design Process Templates for a non-linear design process.

Teamwork Observations and Design Notebook Performance Scoring

Teamwork Observations and Design Notebook Performance Scoring allow one to explore issues raised by the pre- and post-activity student skill survey results.

Mentored Group Teamwork and Design Notebook. Observations of student team mentor activity revealed that faculty mentor teaching style was a crucial factor in the creation of teamwork patterns. The impact of teaching style on student learning in engineering has been studied [26, 28]. For 2 teams in their early design stages, the faculty mentor teaching style was one of strong leadership. In these groups, when the faculty mentor was present, students spoke little in the early design process stages while the faculty mentor talked about ideas for the project. The faculty mentor suggested readings and questions for students to explore. In later meetings, faculty and students would discuss the readings with the faculty mentor and the mentor would point out important issues related to the student team's design. The students appeared unable to make progress on their project when the faculty mentor was not present at their design meetings. Nevertheless, even with a teaching style characterized by strong leadership, the faculty mentor was able to discuss concepts of parameter estimation, and carefully work through pertinent examples while students watched. In the last stages of the design process, however, particularly when the prototype design needed to be built, student team members took command of their design. At this last stage, students were able to work, discuss ideas, make adjustments to their design without assistance from their faculty mentor or teaching assistant.

For the other 4 teams, the faculty mentor style was one of guide rather than leader. In these 4 cases, the faculty mentor acted as an informed peer in helping students to explore and shape ideas. Students would offer ideas and the faculty member would question different aspects of those ideas. Two faculty members often brought the discussion of ideas back to the technical criteria, technical feasibility, and parameter estimation if student discussion became too vague. When the faculty member offered suggestions of pertinent readings, those suggestions were based on questions formulated by the students, not the faculty member. Nevertheless, while discussion between mentor and students was highly active, the faculty mentor or undergraduate assistant still closely guided it. When the design process reached the prototype stage, the 4 teams took command of their design and were able to complete the work, and make adjustments, with little assistance from their mentor.

All student teams used only the information supplied to them by their faculty mentors to complete the project even though a project room, filled with pertinent materials, was provided. Since students were encouraged, but not required to seek additional information, they did not do so. In interviews for SP753, freshmen noted that, though there was a project room full of information, they did not know how to figure out what information might be relevant to their project so they focused on material suggested to them by their faculty mentor.

Interestingly, all student teams received high scores on teamwork. Table 7 shows mean team performance scores for Mentored group teamwork. There were no issues of unequal sharing of work among team members (team received a score of 80% out of all possible teamwork points). There were no instances of problems that were not immediately addressed by the faculty mentor or teaching assistant. The team received a low score (73%) on this behavior since faculty, not team members, were the initiators of discussions of teamwork problems. Team leadership was given no score since team leaders were the faculty mentors or teaching assistants.

The Mentored group team notebooks showed a wide variety of effort. This is to be expected since each faculty mentor stressed use of the team design notebook to record teamwork to varying degrees. Also, each group assigned one student to be the keeper of the notebook. He or she would be responsible for recording the results of all team meetings. To varying degrees, each notebook contained initial ideas, excerpts from readings, initial calculations, alternatives if the initial idea showed limitations, and then final ideas, calculations and drawings. Overall performance scoring of the Mentored group design notebooks is shown in Table 7. Scores for open-ended problem solving skills are moderate: 1) use technical concepts correctly in parameter estimation (85% of total possible points for this skill), consideration of alternative designs guided by technical feasibility (73%), and information search for design ideas structured by some consideration of technical parameters (67%).

Web-guided Group Teamwork and Design Notebook. As mentioned, students were expected to individually complete lecture-related exercises and readings, and carry out much of their preliminary and final team design work on the Web so that they could best share it with team members. Data on students' use of the web material as they completed their individual Web-based lecture-related exercises (critical thinking, parameter estimation, use of technical concepts in calculations) was perhaps the most interesting data collected for the Web-guided group. For those exercises, the instructor embedded pertinent web links that the student could refer to in completing each of the three exercises. Other available web readings were available, but not linked, as well. Data on student use patterns showed that 100% students spent some time on all of the web-linked material while working on the exercises. About 15% also briefly explored other available material when completing the parameter estimation and use of technical concepts calculations. About 40% referred to other available material when completing the critical thinking exercise. Since one can never be exactly sure how a student is spending his or her time when logged on, patterns of use do show that, while logged on, students appeared to work on the exercise, refer to one or more web link, then continue work on the exercise. Instructor grading of the student exercises showed high grades for all students who completed the exercises.

Observations of the 6 Web-guided student teams showed a general pattern of team behavior in relation to Web-guided Web tool use. Unlike student use patterns for completion of lecture-related exercises, student teams, in general, worked off-line and completed design steps in individually or team-determined order, then mounted their work into the series of Design Process Templates in the order requested by the instructor.

When students worked as a team on-line, they only logged into one or two student accounts, hence it was difficult to obtain a range of individual student use patterns. For only one template, parameter estimation, did students use the template as expected by the instructor. When completing that template, student team members would refer to hyperlinks on technical concepts and examples of parameter estimation from their lecture exercises. For all other templates, students rarely referred to web-based materials.

Students also rarely used the team email or discussion system. Rather, team emails concerned meeting scheduling; emails to the instructor asked for clarification of different design parameters.

Table 7. Mean Scores for Mentored and Web-guided Teams Based on Design Notebook and Team Observation Performance Scoring Results (1)

Group Performance Characteristics	MENTORED GROUP Mean Team Score	WEB-GUIDED TEAM Mean Team Score
Open Ended Problem Solving		
• Use technical concepts correctly in parameter estimation	85%	100%
• Consideration of alternative designs guided by technical feasibility	73%	83%
• Information Search for design ideas structured by some consideration of technical parameters	67%	78%
Mechanical Building		
• Display some degree of acquaintance with rudimentary mechanical parts and devices	80%	78%
• Able to translate 2-D drawing into 3-D prototype	100%	100%
Teamwork		
• Equal participation by team members as design project progresses	80%	44%
• One or more student able to act as team leader	NA	67%
• Team able to discern between major and minor team problems and addresses issues that hinder progress	73%	89%
• Team able to bring problems to attention of instructor/ supervisor if needed	60%	50%

(1) Score percents represent number of points scored for each performance characteristic out of total number of points possible for perfect performance.

When working off-line, student teams showed a typical, somewhat non-verbal, pattern of team member interaction. Student team members would often have worked alone on one or two design ideas, looked alone for information on the web, and carried out some calculations. He or she would then bring these ideas to the team meeting. Depending on how much work others had already completed on potential designs, and depending on the strength of the personality of various team members, one of the designs would be chosen. If the team did work on-line during team meetings, it was generally to use the Design Process Templates to check some parameter estimations.

When each team reached the stage where they were required, by scheduled deadline, to mount their design ideas on the Web, many realized that this would require substantial mastery of HTML programming. Many teams found themselves working all night to scan in designs, to mount calculations into the Design Process Templates, and to complete the correct formats for the Preliminary and Final Design Reports. Since, often, only one team member was experienced in HTML programming, he or she would either do most of this work alone, or teach others how to program.

Web-guided teams experienced significant team member interaction problems. For the most part, these problems were related to shirking of work or a team member not coming to team meetings. When such problems arose, the team would continue to work. If the problem was one student coming up with all design ideas without working with other team members, at least one team asked the instructor to intervene (to no avail). Because teams needed to address major and minor teamwork issues on their own with little assistance, the teamwork observation scores differed from the Mentored group scores. Table 7 shows that mean team scores for the Web-guided group. The scores were: 1) equal participation as team design project progresses (44% out of total possible points); 2) one or more students able to act as leader (if chosen to do so) (67%); 3) team able to discern between major or minor team problems and will address issues that hinder progress (89%); 4) team able to bring problems to attention of instructor or supervisor if needed (50%). While the Mentored teams participated more equally in teamwork than the Web-guided teams, the Web-guided teams were better able to recognize, on their own, minor team problems that one could ignore.

Since students worked off-line and then mounted their work into the Design Process Templates, the Web-based design notebooks did not represent all of any student team's work. Design notebooks could only be scored, however, on the material contained in the Web-based notebooks. Table 7 shows Web-guided group team mean scores for open-ended problem solving. These scores were: I) use technical concepts correctly in parameter estimation (100%); 2) consideration of alternative designs guided by technical feasibility (83%); 3) information search for design ideas structured by some consideration of technical parameters (78%). These scores are all higher than those received by the mentored group (85%, 73%, 67%, respectively, for the 3 skills listed). One might conclude that, because of the rigor required by the Design Process Templates in completing parameter estimation steps and because of the limitations placed on information search, Web-guided students were able to show higher performance levels for these skills.

When students began to build their dirigible designs, students appeared more enthusiastic and engaged in their team design work. Only at that point in their teamwork did student team members interact with strong verbal discussion of design parameters. Students intensely involved in arguments concerning their designs and how to improve them replaced the oddly silent student teams trying to mount their designs into the Design Process Templates.

Student Post-Activity Interviews

Interviews of students from the Web-guided and Mentored groups reveal that rigor comes at a price. While students in the Mentored group were highly enthusiastic about their design experience and looked forward to having as much fun in future engineering design activities, their design notebook performance scores show that they performed less well in the set of measured attributes than the Web-guided group. In contrast, while the Web-guided students had high scores for their design notebook work, most were less than enthusiastic about the design experience. The Design Process Templates appeared to be the crucial factor in determining Web-guided group satisfaction.

In the interviews, Web-guided students mentioned that only 2 or 3 of the 34 students had any strong capability in HTML programming, hence, completing the Design Process Templates took a tremendous amount of time. Students mentioned that while there was some satisfaction in mastering the HTML programming skills, they thought that the requirement was excessive. One student argued that a formal design notebook, Web-based or otherwise, was counter to the goal of a design notebook. He thought a design notebook was something in which one "fooled around" with ideas: "I liked to try this and that idea, explore it. It was too difficult to put all the real stuff in my design notebook on the Web."

Other Web-guided students mentioned equipment accessibility as another barrier to satisfaction with a class with all subject materials on the Web. All students mentioned that many on-campus housing units do not have computers connected to Web browsers (at the time of this study); there was only text reading capability. It was often difficult or inconvenient to return to the central campus to obtain pertinent materials: few computer terminals were available in the dorm or it was too late to return to central campus when the student discovered he or she had forgotten to obtain the material. Some students mentioned that some lecture readings were somewhat unreadable because the format was too small. Some also felt that the instructors explanations of some technical material was insufficient since students could find it all on the Web.

Student skill self-report surveys are useful because they not only measure skill levels, but they also are excellent measures of motivation [3]. While the Mentored group's design notebook mean scores were lower than those for the Web-guided group, their post-activity skill surveys showed that they perceived that they had learned more than the Web-guided group.

Discussion and Conclusions

Discussion of results should begin with the basic questions educators have posed when considering how to design an introductory engineering design experience: Should there be rigor or should there be fun in freshman design experiences? Should there be careful calculations of parameter estimates or should there be engaging whimsy? Clearly a review of the literature on engineering design education for freshmen or seniors shows that there are both types of experiences being attempted. Many hope that there will be both experiences in a freshman design activity. The present study shows that finding the right mix of rigor and fun is a difficult one, particularly for freshman. Too much rigor and students are demotivated; too little rigor and freshmen will simply have to learn those lessons next year. First and foremost, in light of the significant impacts in many skill areas for the experimental group compared to the control group, the results of this study strongly argue for some form of freshman design experience. The results also suggest that a mentored open-ended design activity, if more care is taken in teaching parameter estimation and information search skills, might offer an ideal, though costly, solution.

Certainly the above questions do not begin to address the issue of how multimedia materials might be integrated into a freshman experience, but they do provide a few hints. As Shabo and others have argued, one must consider not only the design of the various units that might be contained in a multimedia educational tool, such as the Design Process Templates described in this study, but also how that tool will be accessed [40]. Will access be highly structured and linear so that it severely hinders students with non-linear learning styles, or will it be a fairly random set of linked ideas, readings, photos, and exercises that students become lost in? The present study showed that the line between linear and non-linear access and web structure is a difficult one. One might also ask another question: is a human mentor as good as a web guide for teaching engineering design? Due to the linear format for the design of the web tool in this study, a human mentor is still better than a web guide. To state the obvious once again: engineering design is a highly complex activity. It cannot be linear via Design Process Templates, it does not have clear steps even in its convoluted circular nature. But that does not preclude its use in engineering design work. The results of this study suggest that the Web-guided students did greatly benefit from the use of the web exercises and design notebook work in parameter estimation and information search. These two skills are crucial in the engineering design process. Their performance scores indicate that the web linked exercises and Design Process Templates did, in a sense, force students to rigorously complete these steps. Whether completion was too rote, or whether students will be able to recall and use those skill in future activities, is certainly an unanswered question. In contrast, the Mentored students were somewhat lax in their completion of these steps. While their discussions of these concepts with the faculty mentor showed that students understood these skills, their design notebook performance scores were still lower than the Web-guided group.

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