A Hypermedia Approach to Improve Teamwork in Engineering Design Education

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The primary objective of this study was to evaluate the effectiveness of using hypermedia systems to improve teamwork skills among students of engineering design. An experiment was conducted to study the effect of the method of instruction on teamwork in engineering design. Method of instruction was studied at three levels: hypermedia-based instruction, paper-based instruction, and no instruction. Data was collected on each group's performance on the problem solving task, learning, speed of performance completing the instructional presentation and the problem solving task, satisfaction with the practice of team skills and subjective satisfaction relating to the ease-of-use of the tool and overall effectiveness of the instructional presentation.

The results indicated that the hypermedia approach to team skills instruction for engineering design was at least as effective as the paper-based instruction in terms of knowledge and skills acquisition. It was more efficient in terms of the time taken to complete and the time to apply the instruction to a problem solving task. Individuals exposed to the hypermedia approach were more satisfied than those exposed to the paper-based instruction with their team's practice of decision making skills. Finally, individuals perceived the hypermedia approach to be easier to use, more effective, and more satisfying than paper-based instruction.

Introduction

Engineering design is one of the most powerful forces in producing a product that matches market needs in a manner that satisfies all the parties concerned. When designing, designers attempt to define a need and a set of technical requirements that are converted into a complete description of a product or system through a process. The resulting description should contain the information required to achieve a product or system that can solve a problem, and fulfill some human need. The product or system must also be capable of being:

- physically produced and implemented, and
- economically and financially justified.

Thus, engineering design can be defined as a detailed planning process that evolves into a goal-directed problem solving activity"] The goal of engineering design education springs from the need to combine explanation and practice, to provide education and training, and to stimulate motivation and interest. Hubka and Schregenberger '2], outline three general areas in which questions arise while designing a product or technical system. They are:

- Design process,
- Technical system, and
- Working means

Based on the above three areas, Wallace and Hales '3', suggest three pertinent questions. They are:

- What is the best design process for the particular task?
- What is the best technical system to meet the particular set of requirements?
- What are the best working means for the particular situation?

The answers to the above questions will enable students to learn "How" to design. But first, in order to learn "How" to design, students must acquire a variety of knowledge, skills, abilities, and attitudes. Thus, to train students in all these aspects, it is apparent that the need for effective design education is great. Further, without a direct design experience through projects or case studies, students cannot be expected to learn the complications of designing. Equally, without the knowledge of the "What'" and "Why'" of the various details in design, students cannot learn to be effective and efficient in the design process.

A survey by Braham[4] of various employers shows that they require students who possess particular skills. Two of the many are the ability to work well in team settings and the ability to be creative. However, a study by Katz [5] shows that many skills required by new graduates on the job, including the ability to work well in a team, are missing or are underdeveloped. Interviews of employers showed that their main concerns were the ability of the student to work on a team and the ability to communicate. Interviews of students also suggested that they are missing out on the experience of working together. A student interviewee states[5, p.172]:

"As a student you are not encouraged to do too much teamwork . . . . . You work on your own, what you learn is on your own, most of your research is on your own . . . . . Now that we've all been, like competing against one another, now we all have to be friends and form a team. And nobody's really done a lot of that."

To make the students' learning experience in engineering design and teamwork more enjoyable and productive, new technologies need to be explored and developed. Hypermedia in education offers a new opportunity for course development, and for strengthening the teaching/learning process [6]. Yet, there is very little research on which to base our design decisions when creating hypertext./ hypermedia for instructional purposes'.

Very little research has been published on applications related to engineering design or engineering design education in a hypermedia environment. Further, "relatively little research has been devoted to carefully examining such issues as how team members interact with each other; whether such interactions vary over time, with the situation, and/or with team experience; what team members learn as they work together; and what meaning can be assigned to such terms as teamwork, coordination, and cooperation"[8].

To begin to address these research needs, a hypermedia system was developed. This tool was used to introduce engineering design students to teamwork activities. The main objectives of this study were to investigate the following questions:

- Can hypermedia support group learning of engineering design and improve teamwork?
- In the context of the developed tool, can various issues in the design of hypermedia-based applications for instructional purposes be resolved through iterative development?

Method

A study was conducted with the above objectives in mind. Forty-five undergraduate industrial engineering students participated in this study. These students were enrolled in a sophomore-level engineering design course that surveys methodologies for designing engineering systems and provides the students experience in the application of these methodologies to the design of a specific engineering system. At the time the study was initiated, students had just begun working in teams on their class projects.

The study involved three groups: two experimental groups and a control group. The two experimental groups and the control group were each composed of four design teams. Three teams in each group were composed of four members each. The fourth team in each group had three members.

A hypermedia-based tool was developed using Apple Computer's HyperCard 2.2, a Macintosh-based software development environment. Animation and sound were added using Motion Works' ADDmotion II. The hypermedia-based tool was presented using an Apple Power Macintosh 6100/60 and an nVIEW Media Pro projection panel for large screen projection. A paper-based tool was also developed, using printouts of the material presented by the hypermedia-based tool. The hypermedia-based tool was presented in color, while the paper version was in black and white.

A pretest was administered to all the groups to assess their level of knowledge in the subject matter to be covered by the tool and in basic teamwork. Then, the two experimental groups received training in the use of their respective tools: hypermedia-based and paper-based. The information in the tools consisted of basic teamwork skills, and an introduction to a specific teamwork methodology (the nominal group technique 'g]) for identifying issues related to a particular problem and reaching consensus on the relative importance of these issues. The control group received no information on teamwork skills or training in the use of the nominal group technique. After the training was given to the hypermedia-based and paper-based groups, all the teams completed a team task. The task required the teams to construct a list of rank-ordered solutions to a given problem. While the hypermedia and the paper-based groups employed the NGT to complete the task, the control group, with no training, used less structured methods to complete the task.

The independent variable studied was the method of instruction. It was studied at three levels: hypermedia-based instruction, paper-based instruction, and no instruction. The following dependent variables were used to measure the effect of the independent variable. (The text in parentheses below explains the method of data collection).

- Learning (This was measured by administering a pretest and a post-test to assess the teamwork skills knowledge gained by the teams. It was also measured by assessing team performance of a task requiring the generation and ranking of issues related to a particular need. These tests were also administered to teams in the control group to assess whether either type of instruction was responsible for an improvement in teamwork).

- Speed of performance (The time taken by the teams in the experimental groups to complete the presentations made using the hypermedia- and paper-based tools was measured, as well as the time taken by all the teams to complete the issue generation and ranking task).

- Subjective user satisfaction (Data on various team skills and a variety of dimensions of subjective user satisfaction focusing on ease-of-use and perceived effectiveness of the respective tools were measured through questionnaires. These were completed after performance of the issue generation and ranking task).

Results

The following sections describe the results obtained for the measures of learning, speed of performance and subjective user satisfaction.

Learning

Learning was measured through:

- Pretest and post-test scores on a test of teamwork skills knowledge and
- Evaluation of issue generation and ranking task performance.

Pretest and Post-test scores

The scores of all individuals on the pretest and post-test of teamwork skills knowledge were tallied on a 30 point scale and an analysis of variance (ANOVA) was performed. The ANOVA showed a significant Group X When interaction @2,75 0.05 = 3.93, $p < 0.0239$). In the Group X When interaction, Group refers to the three levels of the independent variable and When indicates whether it is a pretest or a post-test score. A Tukey's grouping of the means of both the pretest and the post-test scores shows the means of the pretest for the three groups are not significantly different from each other. However, the means of the post-test for the hypermedia and paper groups are significantly greater than that of the control group. The post-test means are also significantly greater than the pretest means for all the hypermedia- and paper-based groups. The hypermedia and paper group post-test means are not significantly different from each other. Table 1 summarizes these results. Figure 1 shows the comparison of the pre- and post-test scores for the three groups.

Table 1. Tukey's grouping of pretest and post-test means

Group	Tukey's grouping of pretest means	Tukey's grouping of post-test means
Hypermedia	19.7a	24.94b
Paper	19.2a	23.37b
Control	18.11a	20. 18a

Means with different superscripts are significantly different from each other ($p < 0.05$).

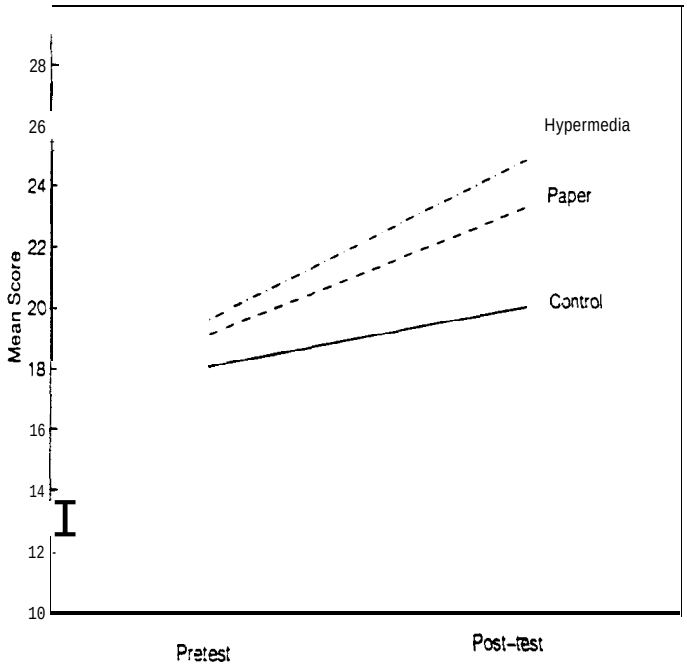

Figure 1. Comparison of means for Pre- and Post-tests

Evaluation of the task performance

The task performed by all the teams was evaluated by an instructor of the course who had no prior knowledge of the arrangement of the teams in the study. This was done to avoid any kind of bias from the experimenter conducting the study. The task was graded on two measures. They were:

- Idea generation quality and
- Idea ranking quality.

A numerical score (on a scale of O- 100) was given to each team on these two measures to facilitate analysis. A separate analysis of variance was performed on the numerical score of each of the above mentioned measures.

Idea Generation Quality

Table 2 summarizes the results of the idea generation quality ratings for the three groups. The ANOVA shows no significant difference among the three groups ($F_{2,9}\ 0.05 = 2.47$, $p < O.1392$).

Table 2. Summary of means for idea generation quality ratings

Group	Means for Idea Generation
Hypermedia	78.75[a]
Paper	71.25[a]
Control	62.50[a]

Means with the different superscripts are significantly different from each other ($p < 0.05$).

Idea Ranking Quality

Table 3 summarizes the results of the idea ranking quality ratings for the three groups. The ANOVA shows no significant difference among the three groups ($F_{2,9}\ 0.05 = 3.10$, $p < 0.0948$).

Table 3. Summary of means for idea ranking quality ratings

Group	Means for Idea Ranking
Hypermedia	80.00[a]
Paper	76.25[a]

Group	Means for Idea Ranking
Control	66.25[a]

Means with the different superscripts are significantly different from each other ($p < 0.05$).

Speed of Performance

The time taken by the teams to complete the presentations made using the paper- and hypermedia-based tools was noted and an analysis of variance was performed. The ANOVA shows a significant difference between the two groups in the time required to use their respective tools ($F_{1,6}\ 0.05 = 14.34$, $p < 0.0091$). The teams using the hypermedia-based presentation completed the presentation in less time (24.7 minutes) than the teams using the paper-based presentation (27. 1 minutes).

Similarly, the time to complete the issue generation and ranking task by all three groups was noted and an analysis of variance was performed. The ANOVA shows a significant difference among the three groups in the time required to complete the task ($F\ 2,9\ 0.05 = 71.69$, p c 0.0001). A Tukey's grouping of the means on the task completion times of all three groups shows all three means to be significant y different from each other, with the teams that were provided no instruction completing the task in the shortest time and the teams provided instruction using the paper-based tool taking the longest to complete the task. Table 4 summarizes the results of the speed of performance analyses.

Table 4. Summary of results for Speed of Performance

Group	Tukey's grouping of means for time taken to use the tool	Tukey's grouping of means for time taken to complete the issue generation and ranking task
Hypermedia	24.7 mins.[a]	18.68 mins.[d]
Paper	27.1 mins.[b]	22.81 mins.[e]
Control	N/A	15.56 mins.[c]

Means with different superscripts are significantly different from each other ($p < 0.05$).

Satisfaction with practice of team skills

Several team skills were investigated to assess team performance in this study. They were: Coordination, Communication, Cohesiveness and Decision Making. A questionnaire was developed to assess team member satisfaction with the team's practice of these skills in completing their task. The questions were

based on a Likert scale with a range of 1 through 7. The issue generation and ranking task was structured in such a way that it required the groups to employ these skills. Team member assessment of the practice of each skill was tested using more than one question.

The ANOVA for satisfaction with the team skill Coordination for the three groups shows a significant difference among the three groups ($F_{2, 42\ 0.05} = 6.69$, $p < 0.0030$). The responses to four questions were summed to assess satisfaction with the practice of this skill. A Tukey's grouping of the means of all individual responses shows that the hypermedia and paper groups were more satisfied with their performance along this dimension than the control group. However, the levels of satisfaction of the hypermedia and paper groups were not significantly different from each other. Table 5 summarizes the means for satisfaction with this team skill. Figure 2 shows the comparison of means for the three groups.

Table 5. Summary of Tukey's means for the team skill - Coordination

Group	Tukey's grouping of means
Hypermedia	6.4000 a
Paper	6.4167 a
Control	5.8333 b

Means with different superscripts are significantly different from each other ($p < 0.05$).

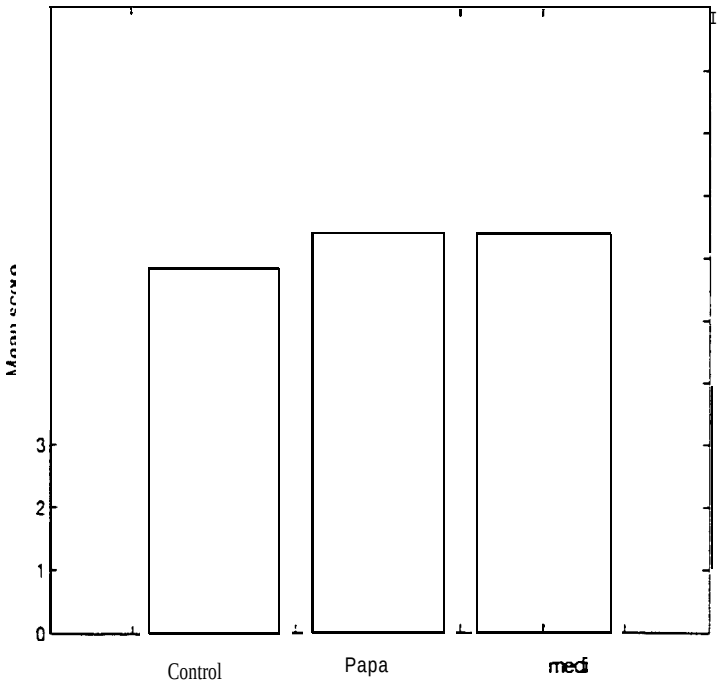

Figure 2. Comparison of means for the team skill - Coordination

The ANOVA for satisfaction with the team skill Communication for the three groups shows a significant difference among the three groups ($F_{2, 420.05} = 6.39$, $p < 0.0038$). The responses to four questions were summed to assess satisfaction with the practice of this skill. A Tukey's grouping of the means of all individual responses shows that the hypermedia group scored significantly higher on this dimension than the paper group. The hypermedia group was not significantly different from the control group. There was also no significant difference between the paper and the control groups. Table 6 summarizes the means for satisfaction with this team skill. The means of the three groups are shown in Figure 3.

Table 6. Summary of Tukey's means for the team skill - Communication

Group	Tukey's grouping of means
Hypermedia	4.5833a
Control	4.2833a, b
Paper	4.1333b

Means with different superscripts are significantly different from each other ($p < 0.05$).

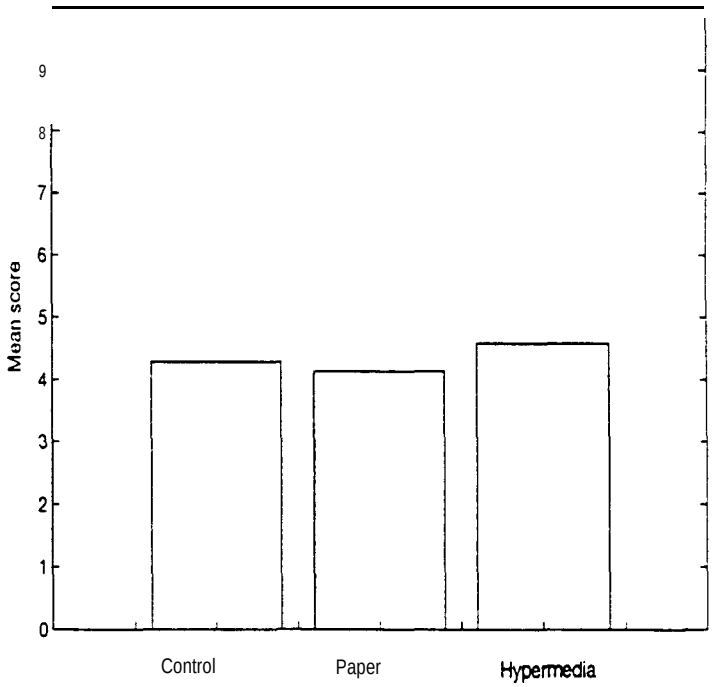

Figure 3. Comparison of means for the team skill - Communication

The ANOVA for satisfaction with the team skill Cohesiveness for the three groups shows a significant difference among the three groups ($F_{2, 420.05} = 5.13$, $p < 0.0101$). The responses to three questions were summed to assess satisfaction with the practice of this skill. A Tukey's grouping of the means of all individual

responses shows that the hypermedia and paper groups scored significantly higher than the control group. However, the scores for the hypermedia and paper groups were not significant y different from each other. Table 7 summarizes the means for this team skill. Figure 4 shows this comparison of means for the three groups.

Table 7. Summary of Tukey's means for the team skill - Cohesiveness

Group	Tukey's grouping of means
Hypermedia	5.8667a
Paper	5.7333a
Control	4.6667b

Means with different superscripts are significantly different from each other ($p < 0.05$).

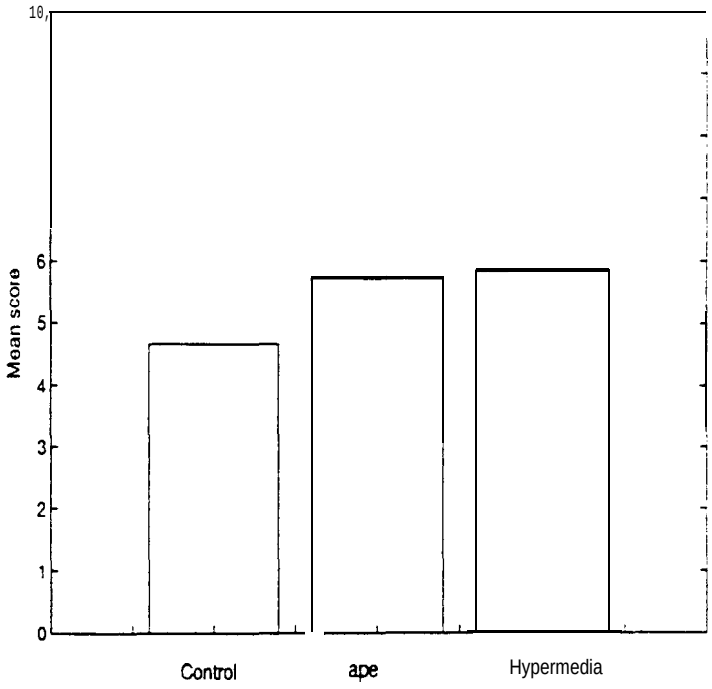

Figure 4. Comparison of means for the team skill - Cohesiveness

The ANOVA for satisfaction with the team skill Decision Making for the three groups shows a significant difference among the three groups ($F_{2, 42}$ $0.05 = 21.51$, $p < 0.0001$). The responses to two questions were summed to assess satisfaction with the practice of this skill. A Tukey's grouping of the means of all individual responses shows that all three groups are significantly different from each other, with the

hypermedia group achieving the highest score and the control group the lowest. Table 8 summarizes the means for this team skill. Figure 5 shows the comparison of means for the three groups.

Table 8. Summary of Tukey's means for the team skill - Decision Making

Group	Tukey's grouping of means
Hypermedia	6.73330[a]
Paper	6.3667[b]
Control	5.8333[c]

Means with different superscripts are significantly different from each other ($p < 0.05$).

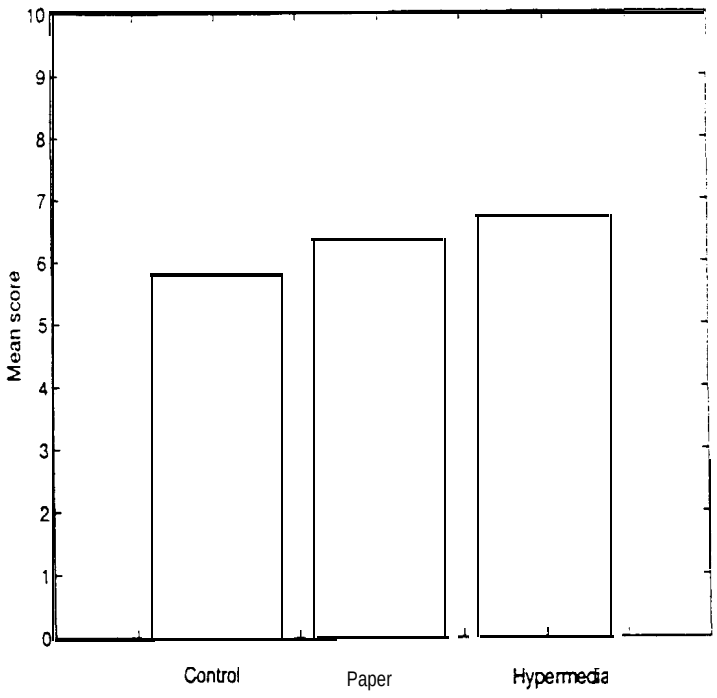

Figure 5. Comparison of means for the team skill - Decision Making

Subjective User satisfaction

Since training was provided only to two groups, the following measures: Effectiveness of the tool, Ease of use, and Satisfaction, relate only to the hypermedia and the paper groups.

The ANOVA for the measure of perceived effectiveness for the two groups shows a significant difference between the hypermedia and the paper groups ($F_{2,}$ 280.05 = 19.64, $p < 0.0001$). The mean

effectiveness rating of 6.00 (on a scale of 1 through 7 with 1 being Ineffective and 7 being Very Effective) for the hypermedia group was significantly higher than the 4.87 rating for the paper group.

There were other questions that related to the effectiveness of the tutorial presentation, applicable only to the hypermedia group. The results of these questions are reported separately. All 15 participants in the hypermedia group responded to these questions.

- On a question regarding the use of color was helpful in identifying the options they could chose, on a Likert scale of 1 through 7 (with 1 being Never and 7 being Always), the mean response was 5.94.

- On a question regarding the effectiveness of the use of large screen projection for the hypermedia presentation (with 1 being Not Effective and 7 being Very Effective), the mean response was 6.4.

- On a question regarding the effectiveness of the animation in understanding the Nominal Group Technique (with 1 being Not Effective and 7 being Very Effective), the mean response was 4.93.

- On a question regarding the effectiveness of sound in the hypermedia presentation (with 1 being Not Effective and 7 being Very Effective), the mean response was 2.06.

The ANOVA for the measure of perceived ease-of-use for the two groups shows a significant difference between the hypermedia and the paper groups ($F_{2,28\ 0.05} = 10.48$, $p < 0.0001$). The mean rating of 6.33 (on a scale of 1 through 7 with 1 being Very Difficult and 7 being Very Easy) for the hypermedia group was significantly higher than the 5.20 rating for the paper group.

The ANOVA for the measure of overall satisfaction of the tutorial presentation for the two groups shows a significant difference between the hypermedia and the paper groups ($F_{2,28\ 0.05} = 28.88$, $p < 0.0001$). The mean effectiveness rating of 6.07 (on a scale of 1 through 7 with 1 being Dissatisfied and 7 being Very Satisfied) for the hypermedia group was significantly higher than the 4.20 rating for the paper group.

Discussion

Several conclusions may be drawn from the results of this study. First, the results of the pre- and post-tests on knowledge of teamwork skills showed that instruction improved teamwork skills among students of engineering design education. There was a marked improvement in the test scores of students provided paper- or hypermedia-based instruction on teamwork skills. Students who were not provided instruction in these skills showed no significant improvement from the pre-test to the post-test.

Second, the results of the questionnaire on subjective user satisfaction indicate that students perceived hypermedia-based instruction format to be easier to use and more effective than a paper-based format presenting the same material. The hypermedia format made use of hypertext links, color, animation, sound, and group viewing on a large screen display, in addition to the text and graphics it shared with the paper presentation. Some or all of these features appear to have enhanced the users' subjective satisfaction with the hypermedia-based format, which was significantly higher than that with the paper-based format.

Teams in the hypermedia group required less time to complete their instruction than teams using the paper-based tool. Further, when the teams were asked to complete a team task following the presentation, those who used the hypermedia-based tool completed the task in less time than those who used the paper-based tool. These results may be a consequence of a navigational aid this hypermedia system offered to the teams. In completing the presentation and the task, the hypermedia-based teams could use an information map offered by the hypermedia tool to quickly switch to the segment of the presentation that contained the information currently needed by the team. The results could be simultaneously viewed by all team members on a large screen display. With the paper-based format, individual users tended to flip through the pages of the tool searching for the relevant material. After finding it, they then took time to refer other team members to this material. The control group, with no tool to consult, and no common exposure to a methodology they could apply to the team task, required the least time to complete the task. The results suggest, however, that the quality of their solutions was also poorer than that of the groups exposed to some form of instruction, whether paper- or hypermedia-based.

The results of the questionnaire assessing team members' satisfaction with their team's practice of various team skills in completing their problem solving task indicate that the individuals whose team received either hypermedia- or paper-based instruction were more satisfied with their team's practice of coordination, cohesiveness, and decision making skills than the individuals whose teams received no team skills instruction. Individuals whose teams received hypermedia-based instruction were also somewhat more satisfied with their team's practice of decision making skills than the individuals whose teams received paper-based instruction.

While statistical analysis of an instructor's ratings of the team's idea generation and ranking quality permit no firm conclusion to be based on these task performance measures, the results are certainly consistent with the subjective measure of decision making skill reported in the preceding paragraph. That is, they suggest that the quality of team decision making was higher for the teams receiving team skills instruction than for the teams not receiving it and that it was somewhat higher for the teams receiving the hypermedia-based instruction than for the teams receiving the paper-based instruction.

Finally, this hypermedia system was developed using a process of learning the users' needs, talking with experts in the subject matter, going through a process of iterative design and development, and testing the system with an instructor of the course and representative users of the system. The results indicate that this process resulted in a product that increased student knowledge of team work skills and was perceived by students to be easy to use and effective. This suggests that such a process may be generally useful for the development of hypermedia-based instruction, as well as for the development of design guidelines that may be used to inform the designers of future hypermedia tools for engineering design education.

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