SENIOR-FRESHMAN COLLABORATION IN A CAPSTONE DESIGN COURSE

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Abstract
An innovative capstone design course entitled “Design of Fluid Thermal Systems,” involves groups of seniors working on various semester-long design projects. Once projects are awarded, freshmen enrolled in the “Introduction to Mechanical Engineering” course are assigned to work with the senior design teams. The senior teams function like small consulting companies that employ co-operative education students; e.g., the freshmen.

One of the objectives of building this collaboration is a desire to increase the retention rate of the freshmen by involving them with the seniors in some interesting design work. Additionally, the seniors benefit by gaining team leadership experience, and by developing the ability to communicate their ideas to a non-technical audience as their design work progresses.

This project began in Fall 2001, and at the conclusion of that semester, an assessment instrument was administered to the seniors to ascertain their opinion of the experience. After reviewing the comments made by the seniors, improvements were made to this project, and these improvements were implemented in Fall 2002. At the end of the Fall 2002 semester an assessment was made and the following conclusions were drawn:

- The seniors and the freshmen all believed that the interaction was a rewarding experience.
- The seniors felt that their freshmen co-ops made useful contributions to the overall design effort. The freshmen also believed this was so.
- The seniors learned to appreciate the management problems encountered while managing co-workers with limited technical expertise.
- The seniors and the freshmen both recommended that the program be continued in the future.

Background
“Design of Fluid Thermal Systems” is a senior-level, capstone design course at the University of Memphis. Students in this course are divided into groups of 3, 4 or 5 members who work together as a team on a design project. Selected projects are presented to the design teams who must bid competitively on three of the projects. The design team with the lowest bid is awarded that particular project to work on for the entire semester. (See the text listed in the Bibliography for information on the bidding process.) Design teams are treated like companies and as such, each group chooses a company name and designs a company logo. Titles of projects for the Fall 2002 semester are provided in Table 1. Some groups developed web sites for their companies. More detailed project descriptions are provided in the Appendix of this paper.

Groups elect a Project Director who meets with the course instructor on a weekly basis. The Project Director works with the group members to identify a list of tasks required in order to finish the project by the end of the semester. The list of tasks includes, for example, sizing and selecting

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a pipe to convey a specific fluid; sizing and selecting a pump; selecting a heat exchanger; predicting system performance; and writing a report about the design of the system.

When the tasks are identified, a completion date is selected for each one. By the end of the fifth week of the semester, for instance, a pipe material and size will be selected. The tasks and target completion dates are summarized in the form of a task planning sheet, an example of which is in Table 2. Also included on the task planner is the name/initials of the individual responsible for completing the task.

Each group member keeps and maintains a notebook or diary of all tasks completed for the project. The diary contains any and all details of the work done by that particular member on the project. This would include something as short as a phone call, or as detailed as calculations to predict when a pump will cavitate.

Table 1. *Project titles and company logos.*

Title	# of Engrs	Student Designed Logos
Design of a Shaved Ice Maker	3	SPEAKA Exceeding All Expectations
Avoidance of Hydraulic Shock in an Oil System	4	LEKBERGANIAN INDUSTRIES
Cooling System for a Series of Heat Sources	5	INTERNATIONAL ENGINEERS
Design of an Experiment to Illustrate the First Law of Thermodynamics	3	CLAD Engineering
Solar Hot Dog Cooker	4	

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Table 2. *List of tasks to be completed for the First Law Experimental Device.*

	Week Number									
Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Develop power & fluid flow equations for system	■									
Determine which existing components can be used	■									
Begin layout of components		■	■							
Find vendors for purchase of components			■							
Determine instrumentation needed			■	■						
Purchase equipment & instrumentation			■	■						
Construct bench for mounting equipment			■	■						
Complete configuration & final assembly					■	■				
Obtain data on the device							■	■	■	
Refine experimental procedure									■	
Write instructions for use									■	
Present & submit reports									■	■

The Project Director meets with the course instructor on a weekly basis, and brings his/her group members' notebooks. The instructor checks to ensure that the group or company is working on schedule. If so, the "company" earns a satisfactory performance evaluation for the week. If not, the company's performance is deemed unsatisfactory and repeated unsatisfactory evaluations will affect the group's final grade. A student who continually fails to perform satisfactorily is "fired" from the company by the instructor.

Project Rationale

A two course sequence of freshmen level courses was recently overhauled with the express intent of increasing retention in addition to delivering a fairly standard set of "Introduction to Engineering" topics. One of the ideas tried in Fall 2001 was to get the freshmen involved with the seniors. Seniors can provide valuable insights to the freshmen and provide them with a perspective about the University that faculty cannot provide. The seemingly ideal way to do this was to have the senior design teams take on freshmen as part of their companies. Thus, the design "companies" were assigned "co-op" students.

Certainly freshmen are not expected to be able to size pumps or to make engineering-based decisions on materials to use for food handling. There are, however, things that the freshmen can do to work credibly with the seniors.

For example, one company in Fall 2002 was assigned the project of designing a solar hot dog cooker. Hot dogs would be placed on a conveying system (also solar operated) that would move them through a concentrating collector. The hot dogs were to be cooked by the sun at a maximum rate of one every 15 seconds. The students were to select the shape of the concentrating collector and design a method for moving the hot dogs. In addition, the students were to consider economic, environmental, health, and safety issues, as well as determine the cost (initial plus operating) of the entire system. The properties of hot dogs were needed in order to complete this project. The

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freshmen were assigned the task of measuring the physical properties of hot dogs, and tasked with finding a source for the thermal properties. Moreover, the freshmen and seniors worked together to make measurements of temperature versus time for cold hot dogs immersed in hot water. One design decision involved whether the hot dogs were to be frozen or merely refrigerated initially. The seniors and freshmen discussed this together, weighing the pros and cons of each initial condition.

In another project, one company was assigned the project of designing a system to shave ice. The ice was available in 1 x 1 x 1 ft cubes, and the shaving was to be done automatically. The students were to consider economic, environmental, health and safety issues according to FDA guidelines, and to determine the cost (initial plus operating) of the entire system. The seniors, in addition, had to write an ASTM standard for measuring the “quality” of shaved ice. (Quality in this sense does not refer to the traditional thermodynamic quantity. Instead, the seniors had to define a quality—good versus poor—of shaved ice, and the freshmen worked with them in this endeavor.)

Typically, there were 2 freshmen assigned to each senior; that is, each company had at least 6 freshmen co-op students to work with. The seniors (technically experienced persons) had to communicate their ideas to the freshmen (non-technical audience) as the design work progressed. Freshmen were invited to attend planning meetings with the seniors, and so were able to observe the interaction that exists in technical meetings. In many cases, freshmen were present during much of the planning and design phases of the projects.

Near the end of the semester, the freshmen were required to submit written reports describing their experience and to give oral reports to their classmates regarding the work that they had completed as co-ops. Freshmen were asked to describe the project they worked on, and explain how they contributed to its overall completion.

Assessment Process

At the conclusion of Fall 2001, seniors were given an assessment instrument and asked for their opinions on this collaboration. Results revealed that the most significant problem was in scheduling. The seniors and freshmen were all too frequently unable to coordinate their schedules and to have meetings that everyone in a group could attend. In response to the Fall 2001 findings, in Fall 2002, the senior course and the freshmen course were synchronously scheduled, and Thursdays were set aside as team meeting days.

Another area needing improvement, as pointed out in Fall 2001, was in the organization of the collaboration effort. Seniors felt that it was poorly organized. The reason it was poorly organized can be attributed to many factors, one of which was the scheduling problem. Another is that the freshmen often had little idea about what was expected of them, and the seniors had little idea about how to have the freshmen work with them. Moreover, this was an attempt at a new idea, and there is always a trial-and-error period in such endeavors. The assessment process is used to great advantage here in learning what the problems are from a different perspective, and in making modifications that will hopefully improve the program.

Seniors and freshmen were both given assessment instruments at the conclusion of Fall 2002, and the results are provided in this paper.

Assessment Results—Senior Survey

At the end of the Fall 2002 semester, the seniors were given an assessment instruments in the form of a quantitative/qualitatively-based survey which measured results in the following areas:

- program objectives as related to ABET's "A-K"
- coverage of competency topics as compared to course objectives
- course management
- appropriateness/relevancy of pre-requisites
- progression of technical communication skills

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- interaction/experiences with freshman students

The focus of the assessment is on their opinions regarding their interaction with freshmen. Figure 1 displays graphically the seniors' responses. As indicated in the legend, a purple color means "Strongly Agree," a red color indicates "Agree," yellow means "Neutral," green signifies "Disagree," while cyan indicates "Strongly Disagree." The colors in the legend are arranged purple to cyan—top to bottom. In the chart, purple to cyan is arranged left to right. The statements were worded such that a preponderance of purple and red at the left edge is considered highly favorable.

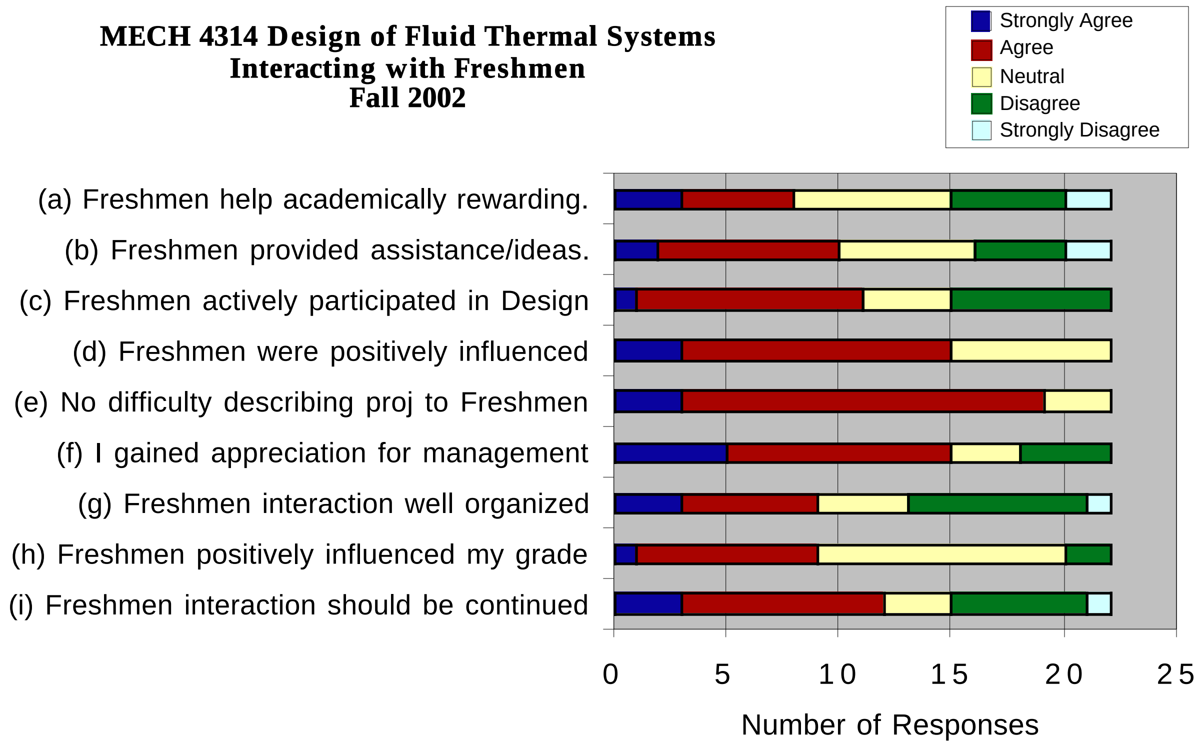

Figure 1. *Results of senior responses to questions about senior/freshmen interaction.*

(a) Interacting with the freshmen was an academically rewarding experience.
The response to **Item a** indicates that interacting with freshmen was not particularly rewarding for 7 out of 22 seniors, although 8 of 17 thought it was. Seven students neither agreed nor disagreed with this statement. Seniors in general did not feel that their grades were improved by the presence of freshmen on their design teams. (See Item h.)

(b) The freshmen were able to provide our group with assistance/ideas.
Despite the response to **Item a**, **Item b** shows that 10 of 22 seniors believed that freshmen were able to provide some assistance to the overall design effort. Every group was able to have the freshmen work productively with them in some capacity.

(c) The freshmen were able to participate actively in the design process.
Item c shows that 11 of 22 seniors strongly agreed or agreed that the freshmen actively participated in the design process, but 7 of 22 did not. It is acknowledged that freshmen participation in the actual design phase is rather limited, due to their inexperience with engineering fundamentals. The goal of having the freshmen gain an appreciation for engineering design, however, is believed to have been met.

(d) I believe I was able to positively influence the freshmen to want to stay in engineering.

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One of the objectives of building this collaboration was a desire to increase the retention rate of the freshmen by involving them with the seniors in design work. **Item d** shows that 15 of 22 seniors perceived that they had a positive influence on making freshmen want to stay in engineering. Seven seniors had no opinion, and no seniors disagreed or strongly disagreed with this statement. This is one of the stronger outcomes of the collaboration.

(e) I had no difficulty in describing our project to the freshmen.
Item e indicates that 19 of 22 seniors had little difficulty in describing their projects to the freshmen. Developing the student's ability to communicate technical ideas to a non-technical audience is one of the seldom mentioned objectives in this course.

(f) By working with freshmen, I gained some appreciation for the effort involved in managing engineers.
Item f shows that 15 of 22 seniors gained some appreciation for the effort involved in managing engineers, while 4 did not.

(g) I thought that this entire exercise of involving freshmen in senior design projects was well organized.
In Fall of 2001, the seniors felt that this venture was not well organized. After making several changes for Fall 2002, we see from Figure 1 that 9 of 22 seniors felt that this project was well organized, but 9 of 22 felt it was not. The students were thus evenly divided on this issue, although there is improvement over last year.

(h) Interacting with the freshmen has had a positive effect on my grade in this course.
Item h shows that 9 of 22 seniors felt that interacting with the freshmen did have a positive effect on the grades received by the seniors. Only two disagreed, and 11 were neutral.

(i) The practice of using freshmen to interact with the senior design groups should be continued.
Item i asks the seniors about continuing the practice of involving freshmen in senior design projects, and the majority of the responses (12 of 22) are positive. Only 7 of 22 thought it should be discontinued.

Comments. The seniors were also asked for recommendations for improvement in the course. Comments regarding freshmen interaction were as follows:

> *I think [the freshmen] need a bigger role to play to help maintain their interest. Let them do a design and then once they're seniors, they will have gained lots of experience.*
>
> *Helpful with computer time.*
>
> *Useless.*
>
> *Harsher penalties for freshmen who don't attend meetings and don't do their jobs.*
>
> *Freshmen did not get involved until late in the project, provided little help.*
>
> *Bad, we should at least [have] sophomores for the freshmen are ill prepared for this.*
>
> *Too many per group.*

As shown, comments range from "Useless" to "Helpful." There appears to be no consensus, and thus no meaningful conclusions can be drawn.

In summary, the seniors appeared to view their experiences with the freshmen-senior collaboration experiment in a mildly positive light. The most positive response elicited by the survey indicates that the 15 of the 22 seniors believe the experience gave them some appreciation for the challenges faced by managers of technical projects. Close behind, 12 of 22 seniors believe the collaboration to have been a worthwhile experience and that it should not be scrapped.

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Assessment Results—Freshman Survey
The freshmen were also given assessment instruments in the form of a quantitative/qualitatively-based survey which measured their reaction to the freshmen-senior interaction/experiences.

The focus here is on their opinions regarding their interaction with seniors. Figure 2 displays graphically the freshmen responses. As indicated in the legend, a purple color means "Strongly Agree," a red color indicates "Agree," yellow means "Neutral," green signifies "Disagree," while cyan indicates "Strongly Disagree." The colors in the legend are arranged purple to cyan—top to bottom. In the chart, purple to cyan is arranged left to right. The statements were worded such that a preponderance of purple and red at the left edge is considered highly favorable.

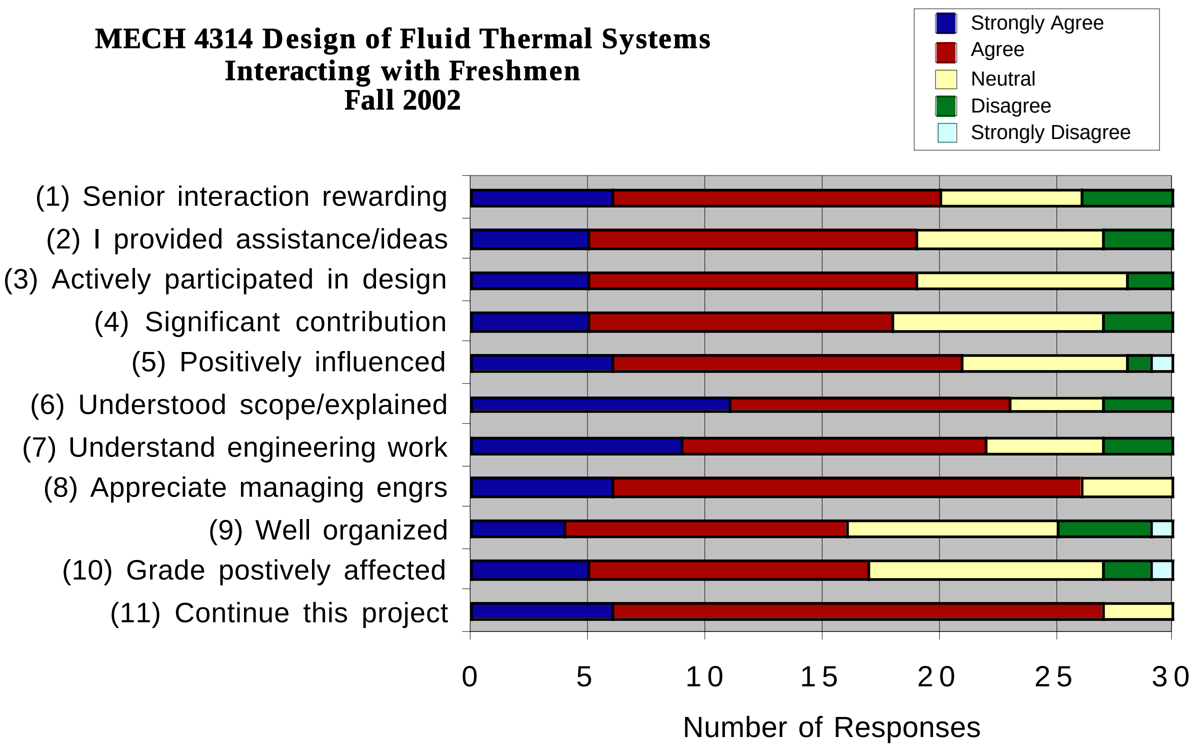

Figure 2. *Results of freshmen responses to questions about senior/freshmen interaction.*

(1) Interacting with the seniors was an academically rewarding experience.
The response to **Item a** indicates that interacting with seniors was perceived as rewarding for 20 out of 30 freshmen, although 4 of 30 thought it was not. Six students neither agreed nor disagreed with this statement.

(2) The freshmen were able to provide the senior group with assistance/ideas.
Item b shows that 19 of 30 freshmen believed that they were able to provide some assistance to the overall design effort.

(3) The freshmen were able to participate actively in the design process.
Item c shows that 19 of 30 freshmen strongly agreed or agreed that they actively participated in the design process, and only 2 of 30 did not. As mentioned earlier, freshmen participation in the actual design phase is rather limited, but this was not perceived as so by the freshmen as indicated by their response. The freshmen believe they have indeed gained an appreciation for engineering design.

(4) I believe that I made a significant contribution to the overall design project.

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18 of 30 freshmen agreed with this statement, while 9 expressed no opinion, and only 3 disagreed. The freshmen apparently felt that their participation in this collaboration was worthwhile.

(5) The seniors were able to positively influence me to want to stay in engineering.
One of the objectives of involving freshmen with seniors was to increase the retention rate of the freshmen, or at the very least, to have seniors favorably impress them. **Item 5** shows that 21 of 30 freshmen were positively influenced; 7 expressed no opinion, and only 2 disagreed or strongly disagreed with this statement. Again, this was one of the stronger outcomes of the current experiment, and one of the primary drivers for conducting it.

(6) The seniors had no difficulty in describing the scope of their project to us freshmen.
Item 6 indicates that 23 of 30 freshmen basically had little difficulty in understanding the descriptions of the projects. Four students expressed no opinion, while 3 disagreed. Developing the student's ability to communicate technical ideas to a non-technical audience is one of the seldom mentioned objectives in this course.

(7) My participation in this design project helped me to understand what an engineer would do to complete a project in the workforce.
Item 7 shows that 22 of 30 freshmen gained an idea of what engineers do when working on a project in industry. Five students had no opinion and 3 students disagreed.

(8) By working on the project, I gained some appreciation for the effort involved in managing engineers.
Referring to the comments made by the seniors, we see that in **Item f,** 15 of 22 seniors gained some appreciation for the effort involved in managing engineers, while 4 did not. With regard to the comments made by the freshmen, we see that in **Item 8,** 26 of 30 students gained this same appreciation, while 4 expressed no opinion. This item appears to provide the most positive outcome of the entire freshmen/senior collaboration.

(9) I thought that this entire exercise of involving freshmen in senior design projects was well organized.
We see from Figure 2 that 16 of 30 freshmen felt that this project was well organized, but 5 of 30 felt it was not, and 8 students neither agreed nor disagreed. The freshmen were more positive on this issue than were the seniors.

(10) Interacting with the seniors has had a positive effect on my grade in this course.
Item 10 shows that 17 of 30 freshmen felt that interacting with the seniors did have a positive effect on the grades received by the freshmen. Only two disagreed, and 10 were neutral.

(11) The practice of using freshmen to interact with the senior design groups should be continued.
Item 11 asks the freshmen about continuing the practice of involving freshmen in senior design projects, and the majority of the responses (27 of 30) are positive. Three students expressed no opinion. More freshmen than seniors (12 of 22) think this collaboration should be continued.

Comments. The freshmen were also asked for the recommendations for improvement in the course, and they were far more talkative than the seniors. Comments from freshmen regarding the senior/freshmen interaction were as follows:

> *I felt that from the start my group didn't really work together. I would have had a better opportunity to learn being in the other cooling systems group. Also the seniors kept emphasizing the project we were supposed to make, I felt they could have done more explaining of the system.*

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Talk more about the systems and make sure everyone is working together.

The organization on "The Presentation" on Power Point was poorly executed. I ended up doing all the work for my freshman group.

[Name of senior] group were very polite and very helpful when it came to do the presentation. Two thumbs up. Thanks.

I didn't receive help with non participating team members on the freshman group from senior team leader when I asked for help. Seniors should be more active with freshmen groups.

Should not classify groups such as seniors, freshmen, etc., [identify students] by their course.

Some groups did not give the freshmen much to do.

I think this program should be done with sophomores.

I didn't learn any details from our seniors. I just knew what their project was and that was about it.

Make responsibilities of freshmen more defined, so they can't use "I didn't know" as an excuse for not showing up, participating, and doing their fair share.

Sometimes I felt that the total involvement of freshmen in the group was not need[ed]. I felt that I was just coming to class and listening to a prof. lecture.

Summary And Conclusions

Two semesters of experience has now been gained with an innovative collaboration between 1st-semester-Freshmen and Seniors working on a capstone design experience. The Seniors are organized into teams that function as a small company that: 1) submits a bid for a project, 2) is awarded the project if their team is the low-bidder, 3) executes a project, 4) creates appropriate electronic and hard copy documentation of their efforts including actual (simulated) costs and 5) makes a formal oral presentation of their efforts at a symposium attended by their peers, by professors and by practicing engineers.

The Freshman-Senior collaboration is modeled on the engineering co-op tradition. A group of Freshman are assigned to each team and are expected to support the design effort in meaningful ways appropriate for their current level of technical expertise, (very low), and their motivation (expected to be high). Although some collaborations are so successful that the collaboration extends all the way to the end of the semester, the period of formal collaboration extends from bid award through completion of the preliminary design phase. At the conclusion of that phase, each team of Freshmen makes an oral presentation of their efforts to their peers. It is expected that these presentations will be of novice professional quality; every Freshman must have a "speaking part" and the teams must use modern tools such as an LCD/computer projection system. Details of the projects and student experiences during the collaboration are documented in the preceding sections of this paper.

Multiple objectives motivated creation of this collaboration. From a pedagogical point of view, introducing Freshman to the Design Process in the classroom and having them contribute to a substantial design project sets the stage for fostering creativity, and uses the entire span of their undergraduate experience to build their expertise in engineering design.

From another perspective, it is recognized that a consequence of the focus on mathematics and the sciences typical of a modern engineering education tends to limit a student's exposure to the profession they have chosen to pursue; many lose enthusiasm and some depart the program before they reach "the good stuff." Our hypothesis is that early exposure to meaningful and substantial design experiences will increase the retention rate of students in engineering programs.

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For many Seniors, this is a first experience in "management" that can provide valuable insight and experience as they prepare to enter professional practice. Success, or lack of success, in achieving these objectives has been evaluated by administering an assessment instrument, at the end of each semester, to all of the students involved in the collaboration. A summary of the results of these assessments has been presented in the preceding sections of this paper.

Overall, the experience has had a positive impact on both the Freshmen and the Seniors. Assessment of the first collaboration identified scheduling as the biggest obstacle to a better outcome. This problem was almost entirely overcome for the second attempt by rearrangement of the day/time that both courses were offered. The second biggest obstacle can be described as the need for more detailed organization and planning for the experience.

Assessment of the second experience indicates that while improvements have been realized in this area, there is still room for improvement and this will be a primary focus of the next attempt at the collaboration experience. The majority of both groups agreed that the collaboration was a rewarding experience. Seniors and Freshmen alike believe that the Freshmen made meaningful contributions to the projects. The second assessment revealed that the strongest response elicited from the Seniors was recognition of the value of their "management" experience.

Faculty evaluation of the teaching experience, the assessment information and anecdotal data has led to the conclusion that the second collaboration experience was more successful than the first. The three global objectives of Freshman introduction to design, Freshman retention in the program, and Senior management experience are all being achieved to some degree (although not measured at this point) and it is believed that the education acquired by all of the students has been enhanced by adding this experience to their curriculum.

A third Freshman-Senior collaboration is planned for the 2003 Fall semester. It appears that there was significant variation from team to team in the quality of the experience. Clear causative factors for less than desirable performance can be attributed to neither the seniors nor the freshmen. Therefore, the focus of faculty preparation for that experience will be to more clearly and precisely define the roles and expectations of all participant in the collaboration experience.

Provided continuous improvement is realized and the program therefore continues, it will be very interesting to assess the outcomes of the fourth collaboration at which time the Seniors will be the very same students who participated in the first collaboration as Freshmen.

Bibliography

Some project titles, budget/bidding sheet, project management and other details were taken from *Design of Fluid Thermal Systems* by William S. Janna, Brooks/Cole Publishers, Monterey, CA, 1998.

Janna, W. S., John I. Hochstein, Michael Racer, Anna Phillips, Hsiang H. Lin, "Freshman-Senior Collaboration in a Capstone Design Course," presented at the *2002 ASEE Summer Annual Meeting* during June 2002 in Montreal, Quebec, and published in the *2002 Annual Conference Proceedings*, on CD.

See also: http://www.people.memphis.edu/~herffcoll/mech4314.html

Biographical Information

JOHN I. HOCHSTEIN—John I. Hochstein joined the faculty of The University of Memphis in 1991 and currently holds the position of Chair of the Department of Mechanical Engineering. In addition to engineering education, his research interests include simulation of micro gravity processes and computational modeling of fluid flows with free surfaces. He is a co-author of a textbook, *Fundamentals of Fluid Mechanics*.

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Appendix: Project Descriptions

Automatic Solar Hot Dog Cooker

Solar cookers that will cook hot dogs have been on the market for some time. These devices consist of a solar reflector that reflects and concentrates energy from the sun. The concentrated energy is directed at a location where the user would place a hot dog. The energy cooks the meat, and within minutes the cook becomes a consumer.

In this project, it is desired to build a modified version of a solar cooker. The solar hot dog cooker is to have an automated feature. The user puts raw hot dogs in one end of the device and removes cooked hot dogs from the other. The cooking rate should be one hot dog every 15 seconds--a maximum speed. (Fifteen seconds is the estimated time needed to put condiments on a hot dog bun.) Furthermore, the apparatus that moves the meat through must also be solar operated. It can contain a battery or other energy storage device, but the device must be charged by solar energy primarily. Finally, the solar cooker must have a method for warming the hot dog buns, and this too must be automated and run using energy from the sun.

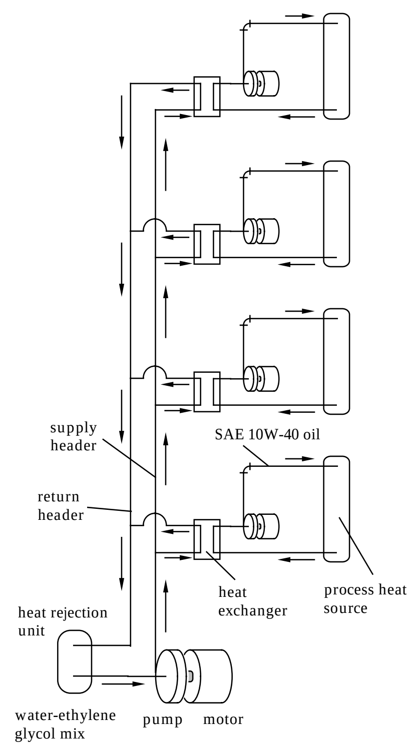
Cooling System for a Series of Heat Sources (4 engineers)

The figure shows a piping system and a number of pumps. The piping system consists of 4 injection molding machines (labeled as process heat source), through which SAE 10W-40 oil is pumped. The oil keeps the machines cool, and in so doing, is heated by 10°C. The oil flow rate through each machine is 25 gpm.

A pump moves the oil through the process heat source and then to a heat exchanger. Water is also circulated through the heat exchangers in which the water cools the oil.

Water is fed by a main pump into a pipeline labeled as the supply header. The water is piped to the heat exchangers, and is routed back to a return header. The heated water is routed to an outside heat rejection unit.

The system is designed to remove heat from the process heat source, and to discharge the heat outside.



Shaved Ice Maker (3 engineers)

In many southern cities, a "snowball" is a popular summer time treat. A snowball (sometimes called a snow cone or a slush) consists of 8 or 12 ounces of ice over which a flavored syrup is poured. The syrup is a health-destroying mixture of water, sugar, and a flavoring such as strawberry, chocolate, lemon, etc.

A manufacturer of food products wishes to market a device that produces shaved or crushed ice that is suitable for making a snowball. Typically, a 1 x 1 x 1 ft cube of ice is delivered and the machine will shave it or reduce it in some way to crushed ice.

Design of an Experiment to Illustrate the 1st Law of Thermo (5 engineers)

There are companies that manufacture and market laboratory equipment for engineering schools. Consider one such company interested in marketing an apparatus for illustrating the first law of thermodynamics by using some common industrial equipment.

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It is proposed to construct an experiment in which students can investigate the performance of an air motor, and of a gear pump. The analysis of the air motor involves the application of the First Law of Thermodynamics for an ideal gas, while for the gear pump, the First Law is applied to an incompressible fluid.

Figure 1 is a sketch of the apparatus. It consists of an air motor, a torque meter/tachometer, and a gear pump. Air from an existing compressor is routed through a pressure regulator to some pre-determined pressure p0. The air then goes through a flow meter and on to the air motor. After passing through the air motor, the air is discharged to the atmosphere.

The air motor power output is monitored by a torque meter/tachometer. The torque meter provides a readout of torque exerted by the air motor, and its rotational speed. This power is used to rotate a gear pump which pumps water from a tank, through a flow meter and a valve, and then back to the tank.

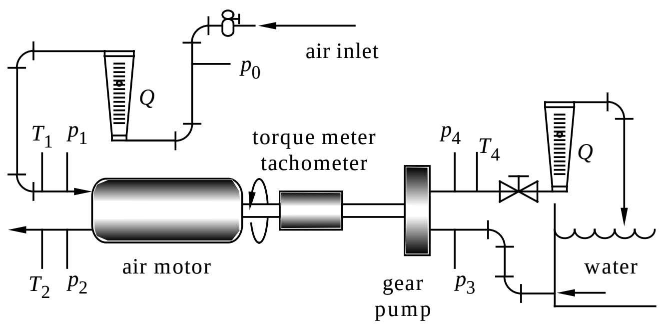

Figure 1. Sketch of the First Law of Thermodynamics Experiment.

The system is appropriately instrumented. Readings of pressure, temperature, and flow rate are obtained so that power calculations can be made.

<u>Correcting the Damaging Effects of Hydraulic Shock (4 engineers)</u>[†]

Consider a piping system used to convey hydraulic oil throughout machinery designed to make copper fittings. The machine contains what essentially could be referred to as hydraulic "jacks." These are piston-cylinder combinations into and out of which hydraulic oil is pumped. These jacks exert huge forces on the material to be formed. During operation, hydraulic oil moves through a flow line that contains pneumatic valves, which control the flow rate and flow direction of the oil.

In the course of the forming operation, the hydraulic oil moves at high pressure through a 2 or 2-1/2 nominal flow line. At the end of one of the operations, the flow of oil is reduced very quickly by a valve that is closed (either partially or fully), and a correspondingly high pressure wave is propagated upstream in the flow line. The high pressure wave travels at an extremely high velocity (i.e., the wave velocity) through the hydraulic oil. Once the wave reaches a tank or a fitting, some of the pressure is dissipated; however a wave will still move through the oil. A lower pressure wave is reflected back downstream toward the closed valve. Then after reaching the valve, the wave is again reflected upstream. These movements cause high frequency oscillations to exist in the pipeline, and they continue until they are damped out by frictional effects.

The high pressure wave moving up- or downstream in a water system is referred to as water hammer; in oil conveying systems, it is referred to as hydraulic shock. As a result of the high pressure oscillations, hydraulic shock can cause considerable damage to the piping system. Moreover, if the pipe or tube that conveys the hydraulic oil is attached to, say, a manifold, the manifold itself can also be damaged. Obviously, if the piping system cannot convey the hydraulic oil as designed, the machine will no longer work, and the investment of time and money in producing the finished product is wasted.

[†]This is an industrially sponsored project which involves working directly with a local manufacturer, and solving the hydraulic shock problem they are experiencing.

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