BRAINSTORMING EXERCISES AS AN ACTIVE LEARNING COMPONENT OF THERMAL SYSTEMS COURSES

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Abstract

Several active learning exercises have been developed and tested for the Thermal/Fluid Systems Design and Thermodynamics courses. It was found that active learning exercises could be used to do more than just engage the students. The exercises can be tailored to promote the development of specific engineering skills and can be used to replace lecture coverage of certain topics. Overall the exercises were found more favorable to students than traditional lectures, promoted teamwork skills, and sponsored creative thinking. Student interest in energy related topics was also encouraged. In this paper several active learning exercises used in the Thermal/Fluid Systems Design and Thermodynamics courses will be presented. Example problem descriptions and exercise references are provided along with student and instructor observations. Lessons which the instructor has learned regarding exercise formation and use will be presented to aid others in formulating similar activities.

1. Introduction

During the Fall 2004 semester the author taught the Thermal/Fluid Systems Design course offered at Minnesota State University, Mankato. The course was composed of nine senior level undergraduate students. At the beginning of the semester it became obvious that several of the students had a limited view of what qualified as a thermal/fluid system. Since the course content did not strictly conform to their expectation of the topic a lack of interest was evident during some discussions. To help combat this, the students were asked to select a thermal/fluid system which they were interested in. They were to locate an article or journal paper discussing the system and present it at the next class. The intention was to better determine their interests and impressions of thermal/fluid systems so that these aspects could be actively engaged. Student topics ranged from the drying of grain to high pressure washers.

The thermal systems course was organized around four major design projects; three smaller ones which focused on an individual component of the thermal design process (i.e. process design, optimization, and cost analysis) and a larger cumulative design incorporating at least two of the three design components. Initially it was hoped that the student topics could be integrated as topics for these design projects. Unfortunately, formulating a suitable problem with sufficient background information proved to be too time consuming once the semester had already begun. An alternative method of incorporating more student interests in the course was therefore sought.

During this same semester the author was participating in the Faculty Teaching Certificate Program offered through the Center for Excellence in Teaching and Learning, at Minnesota State University. Various methods of incorporating active learning in the classroom had previously been discussed during this program. To explore how active learning could be better utilized in engineering it was decided to use the student topics as a basis for the creation of several in-class exercises. These activities were to be structured to provide more time for active learning during class time while promoting student interest in the field.

A general definition for active learning is that it is "any instructional method that engages students in the learning process." [1]. Numerous engineering educators have promoted the inclusion of active techniques to improve student retention and understanding [2,3]. However, care should be taken in the use of the term "active" which is used in the literature to imply either that the student is actively doing something, as opposed to passively sitting, or that the student learns best by doing rather than reflecting [4]. While the first definition seems more applicable it will be shown that both definitions are relevant to these exercises. A simple brainstorming format was initially chosen for the activities. Brainstorming involves students working together to create multiple ideas for a problem. It is part of every open-ended design process and tests the students' creativity and insightfulness. There is great flexibility in how such problems are structured, depending on the class topic and the instructor's intention. While there is no one right way to present such an activity there are apparently several "less than right" ways. It was also discovered that besides addressing learning objectives these activities could be structured to address instructor, or course objectives, as well.

This paper will present several of the brainstorming and active learning exercises used in the Thermal/Fluid Systems Design course as well as the introductory Thermodynamics course. Each of the exercises was designed to take the majority, if not all, of the class period. The results of student evaluations will be discussed as well as instructor observations during the exercises. Several interesting results emerged, as well as ways to improve the exercises. Overall the exercises were found more favorable to students than traditional lectures, promoted teamwork skills, and sponsored creative thinking. Student interest in energy related topics was also encouraged. However, if the problem was not introduced and structured properly some students formed negative opinions and sought to redefine the objective to eliminate work. General guidelines that have been determined will be presented at the end of the paper to aid others in formulating similar activities.

2. Description and Discussion of Individual Exercises

For all exercises short surveys were given to the students one class period following the activity. The survey questions used scales of either 1-4 or 1-5 with 1 always being the positive side. The choice to use the 1-4 scale for certain questions was intended to force students to choose between the positive and negative sides.

Thermal Systems Exercise #1: Engine cooling and rider comfort control for a motorcycle

Problem Description: *Develop a general concept for engine cooling on a motorcycle. Identify what the key variables would be and how they would relate (i.e. flowrate, size, coolant* *properties, etc.). Once you have an idea of how to cool the engine see if there is a way to make use of the waste heat. Ideally this would be some method of providing extra heating for the rider which will improve comfort. The manner in which the heat is transferred from the system and to the rider is up to you. Identify the key design variables and constraints.*

The initial exercise was designed as a typical brainstorming exercise. The problem statement did not provide numerical specifics and the solution was intended to be very open-ended. This exercise was performed after reviewing heat exchanger calculations and design in lecture. The learning objectives were to stimulate creative thought and promote the analysis skills of problem setup and identification of design variables. The course objective was to promote student interest by incorporating one of the topics the students identified as an area of interest, in this case the cooling system of a motorcycle engine. For the exercise, a general concept was desired and the students were instructed to identify the key design variables. It was stressed that there was no right or wrong answer to the problem. To make it more interesting the problem was presented as a work project where their supervisor wanted an evaluation of the concept for future development. The class was divided into three groups, each with three individuals. They were given access to the classroom dry erase boards and computers. Students were instructed that at the end of class each group was to present their ideas. Schematics of existing motorcycle cooling systems were provided as background information[5].

Exercise Evaluation:

Student comments on the surveys indicated that the students were not happy with the lack of concreteness to the problem. From an instructional point of view this could be seen as a positive aspect. The students are being enticed to develop their creative abilities. However, it is likely that their resistance to the problem stems from the fact that they do not see learning to be creative as a valid educational objective for the course.

> *Brainstorming projects are good, except they are kind of like we just make stuff up, no real theory behind it.*

> *Include a more realistic problem.*

Therefore, the first lesson for the instructor was that the students should be made aware of the learning objectives of the assignment and how they relate to the overall course objectives. Course objectives are routinely included in syllabi, however; the linkage between specific assignments and these objectives may not be clear to the student. If they do not see a reason for the exercise the students will not receive the full effect of the activity.

A second concern was the problem topic itself. While it was intended to appeal to student interests it would appear that this was not achieved. This comment is supported by the neutral response to the second question ("How interesting was the problem?"), shown in Table 1.

> *I really like the brainstorming exercise, but it was made slightly difficult because of the lack of background knowledge. If it were something I was interested or had prior knowledge about it would have been a little more stimulating.*

It is obvious that a topic was chosen which appealed to only a narrow segment of the class, perhaps only one person. The second lesson was, therefore, to include more background information on the topic and to make more of an effort to explain why this is a challenging and interesting problem. Unfortunately, with exercises of this type only limited time is available to impart background information and it may not be possible to inspire all students with the topic.

As seen in Table 1 the general student responses were only slightly positive. However, the sample size was quite small (nine students). Of particular interest were the responses to the third and fourth questions. The students were much more positive about the exercise promoting teamwork skills than they were about engineering skills (note: there was a scale change between the two questions). This was interesting because in follow-up discussions with the students it appeared that they did not consider teamwork an engineering skill (or perhaps only a minor part).

Table 1: Survey questions for thermal systems exercise #1 (1 is positive for all scales)

How useful was the problem in understanding course material? (1-4)	2.33
How interesting was the problem? (1-4)	2.33
Did the problem promote development of engineering skills? (1-4)	2.00
Did the problem promote teamwork skills? (1-5)	1.56

In observing the groups while they worked it was interesting to note that each one took a different approach. The first group spent the majority of their time sketching on paper different concepts for the design. The second group spent most of their time looking up information on how motorcycle engines worked and conceptualizing the function. The last group spent the majority of their time looking for a current design on the Internet that they could modify. When the solutions were presented this last group revealed their lack of interest in the problem. As phrased the students were asked to provide an evaluation of the concept. This group stated their evaluation was the project was not worthy of further consideration. Instead they concentrated on improving the engine cooling aspect without examining the use of waste heat. Unfortunately, their presentation was largely a description of a current design they found online during the class. Since the exercise was conducted on an un-graded basis the students obviously felt little inclination to take it more seriously.

Several lessons were learned from this first attempt, however; they can be summed up as follows. While the problem can be open-ended the assignment instructions should not be. Greater care could have been taken in specifying learning objectives, presenting the topic, and enforcing the expectations.

Thermal Systems Exercise #2: Inlet Air Cooling to Improve Gas Turbine Power Output

Problem Description: *Develop a general concept for turbine inlet air cooling. You may use any individual or combination of processes described in the handout. Derive relations or methods to calculate the new inlet air temperature, humidity, and the resulting specific volume.*

Assume two possible cases, one where the ambient air is 100 F and 40% relative humidity and one where the ambient temperature is 20 F and 70% relative humidity. Model a simple Brayton cycle in Cyclepad. You will use this to determine the performance of your system. Using this numerical model, compute a baseline power output and new outputs for the two possible ambient cases.

Taking cues from the first exercise the second was formatted slightly different. Again, the topic was one that a student had identified as an area of interest, inlet air cooling for gas turbines. However, this time it was also a topic that would be used for the next major design assignment. This exercise was therefore intended to incorporate student interests and allow a better introduction of the topic prior to the full assignment. To allow for a lack of background knowledge a review of inlet air cooling was provided to the students in the prior class[6]. They were asked to read it before the next meeting. Instead of making the problem an open ended brainstorming exercise the students were given a specific task (calculate performance) with limited options (select a cooling method). As an additional feature a classroom numerical tool, CyclePad, was utilized to allow numerical modeling to be performed quickly[7]. This program had previously been introduced and the students were already familiar with it (Figure 1). Again, the students were split into groups of three and given access to computers and dry erase boards. At the end of the exercise each group was to present their method and performance values for comparison to see which had devised the best solution.

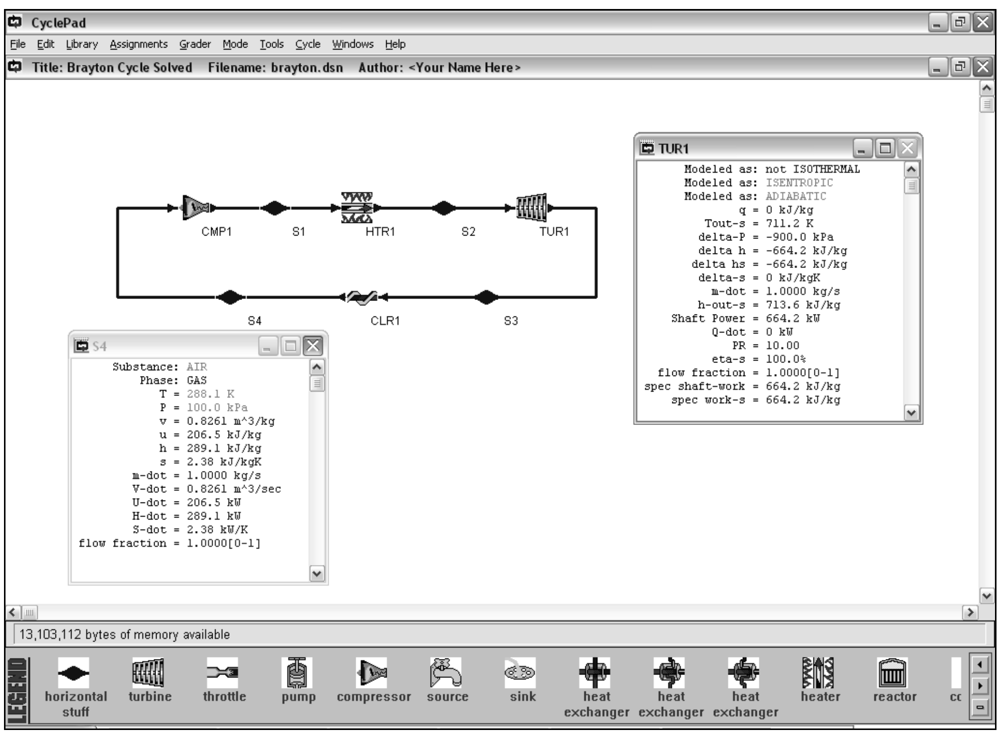

Figure 1: Graphical display for the CyclePad model of a Brayton cycle gas turbine (Exercise 2).

Exercise Evaluation:

It was quickly evident that the majority of students had not read the assigned material. In fact, one student commented again:

> *Interesting, nice if (we) could have the brainstorm problem a class ahead of time to become more familiar.*

However, the students did see the problem as much more relevant to the course topic.

> *I like the brainstorm because it helps us to think how we need to for designing thermo/fluid systems.*

As seen in Table 2, interest in this problem improved slightly. Due to the nature of the problem less interaction between members was involved and the teamwork assessment was not as positive. However, with the added use of Cyclepad and the specific objective (performance numbers) the students thought the problem promoted more use of engineering skills.

Table 2: Survey questions for thermal systems exercise #2 (1 is positive for all scales)

How useful was the problem in understanding course material? (1-4)	2.22
How interesting was the problem? (1-4)	2.00
Did the problem promote development of engineering skills? (1-4)	1.67
Did the problem promote teamwork skills? (1-5)	2.11

Again the students appeared to have a problem with the clarity of what was expected. In addition, there was unexpected difficulty with nomenclature. Specifically, the difference between a gas turbine cycle and a steam turbine process confused many students. An interesting, although unintentional, learning experience came from using the Cyclepad program. There was confusion between the groups on how to evaluate the change in performance due to the manner in which the system was being modeled. Inlet cooling improves gas turbine performance because it allows an increase in the air mass flowrate into the compressor. When modeling this in Cyclepad both the inlet air conditions and the mass flowrate can be specified. Additionally, values can be specified at different data nodes which have different priorities over each other. It was necessary for the students to specify the correct values at the correct locations in order to accurately model the change due to inlet cooling. The topic was actually carried over into the next class so that we could discuss the modeling method used in the program and how the problem should be formulated for correct solution. This turned out to be an excellent example of why the "black box" should not be trusted.

The main instructor lesson taken away from this exercise was to take the role of a facilitator by moving around the class and interacting with the students. By moving from group to group it was possible to monitor their progress and to help correct problems quickly. However, it was important to actually talk to each group. For instance, asking them about a value in Cyclepad. The students appeared more open to discussion and asked more questions of the instructor when this occurred.

<u>Thermal Systems Exercise #3: Reliability of a Nuclear Power Plant</u>

Problem Description: *A simulation of a simple nuclear power plant is provided (http://www.ida.liu.se/~her/npp/demo.html). You can control several things (four valves, three pumps, and the level of the control rods) by clicking with your mouse. The program simulates several possible plant accidents which require action on your part to save the plant and prevent a loss of coolant accident (LOCA). One possible reliability allocation (block diagram) for this plant is shown below (where each block has an associated reliability). Determine how to protect the plant for each scenario and provide design suggestions that will improve reliability.*

The third exercise explored a new use for the activities. The topic of design for reliability had been discussed during a previous lecture but there was insufficient time to work several problems or include the topic in a design assignment. The brainstorming exercise seemed to offer a way to give the students some quick, high content, exposure to the topic. In order to overcome the previous knowledge hurdle a topic was chosen for which they were more familiar with. Prior to this exercise a guest speaker from the local nuclear power plant had visited to speak to the class. Part of his discussion had focused on the nuclear power plant's design for reliability and accident prevention. To take advantage of this exposure a simple online simulation (Figure 2) of a nuclear power plant was used to provide an accident scenario[8]. This exercise was more abstract in that no numerical values were desired but different alternatives had to be devised and evaluated for the problem solution. One change that was made concerned group formation, for this exercise the students were asked to form a group that included someone they had not worked with previously.

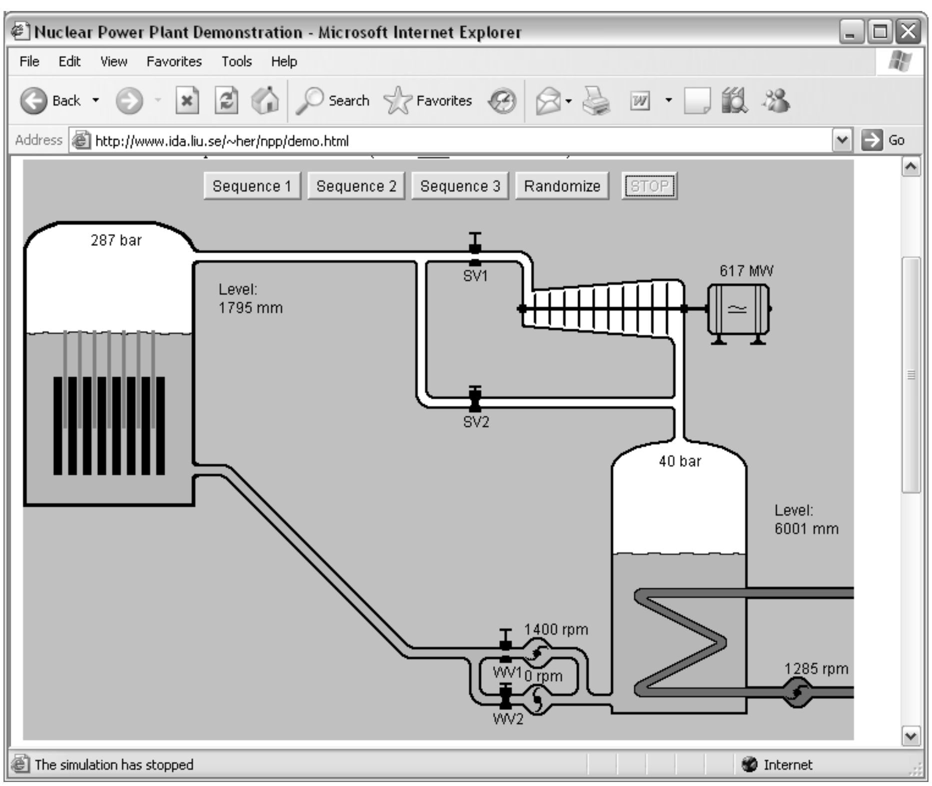

Figure 2: Online screen for the nuclear power plant accident simulation (Exercise 3).

Exercise Evaluation:

The big change in student response for this exercise was in the interest category. The relation to the previous guest speaker and the use of the online simulation greatly increased student interest in the problem. This combined with the shuffling of group members seemed to create much more animated groups. However, distinct differences could still be seen in the group approaches. For instance, one group analyzed the purpose of the components first before attempting the scenarios while a second group tried random actions to find a solution then reasoned the cause and effects. The element of problem solving (saving the plant) seemed to add a lot of interest to the exercise. While the addition of multimedia could have contributed as well, student reactions during the exercise appeared to be keyed to the problem more than the tool. At the end of class the different suggestions to improve reliability were presented and an active discussion resulted.

Table 3: Survey questions for thermal systems exercise #3 (1 is positive for all scales)

How useful was the problem in understanding course material? (1-4)	2.00
How interesting was the problem? (1-4)	1.89
Did the problem promote development of engineering skills? (1-4)	2.33
Did the problem promote teamwork skills? (1-5)	2.11

In reviewing the student responses it should be noted that the lessons learned in previous exercises, particularly with regard to defining exercise objectives, had not been fully processed or implemented. This could explain the neutral response to the engineering skills question, however; from the previous lecture the students were aware that designing for reliability was an important engineering skill. Apparently a disconnection still existed.

There were two instructor lessons from this exercise. The first was that in-class activities such as these could be used for more than just to break up the passivity of the classroom. They can also be used as an alternative to lectures in the coverage of course material. The second lesson dealt with group formation. While the survey results in Table 3 do not indicate the students felt there was an improvement in teamwork skills the instructor observations contradict this. Forcing the groups to shuffle members appeared to promote more interaction among the students and is recommended.

Thermal Systems Exercise #4: Genetic Algorithms for Optimization

Problem Description: *Read problem 8.8 in your textbook*[9]*. For this problem you are designing a solar collector and storage tank. Before you begin the optimization ensure that you can reproduce the objective and constraint equations given. To represent the two design variables we will represent the volume by a 4-bit binary number (volume = decimal value / 10) and the area by a 5-bit binary number (allowing only integer values). Combining these we have a design vector (or genome) which is 9-bits long. A simplified version of the genetic algorithm is presented below (shown below). Work through this procedure repeatedly until an answer converges, the problem diverges completely, or time is exhausted.*

You may use Excel to generate a random integer between a and b using the following function:

*= ROUND ((RAND( ) * (b – a) + a) , -1)*

1. *Repeatedly flip a coin to generate eight nine-bit numbers. Write these on the board and label them with parent numbers.*
2. *Convert each design vector into its two components and calculate the resulting objective function.*
3. *Compute a "fitness" for each parent by dividing their objective value by the sum of all objective values.*
4. *Different forms of parent selection exist. For this problem, select all parents with fitness values less than 0.5. If there are not enough, start duplicating the parents with the highest fitness values. You want a total of 10 when you are done.*
5. *Randomly choose two parents. Calculate a random number between 1 and 9. This will be your crossover point. Take the bit values from Parent 1 up to this point. Take the bit values from Parent 2 after this point. This is your first child. Now repeat this with the Parent order reversed. Repeat this step five times to generate 10 new designs for the next generation.*
6. *Randomly choose one of the children. Calculate a random number between 1 and 9. Flip that bit value. This represents mutation.*
7. *Return to step 2 and repeat the process.*

Following on the success of the third exercise the last one was designed to introduce a new topic that is not normally covered in thermal systems courses; genetic algorithms for optimization. Due to time constraints it is difficult to introduce this method along with the more common forms of numerical optimization. This exercise was designed to expose the students to how a genetic algorithm works with the most efficient use of class time. The students were given a short lecture, approximately 10 minutes, before beginning the exercise. The purpose of this was to simply introduce the topic and remind the students of the basic biological functioning of genetics. At the basic level this is actually simpler than it sounds since students will come to class with a certain pre-existing knowledge. The problem they were asked to solve was a simple two variable optimization from their textbook. Step by step instructions (seen above) were provided for them to perform a simple genetic algorithm. In order to save time and confusion the basic genetic algorithm was modified slightly, specifically in the parent selection step. The instructions were designed to allow tasks to be split up among group members to encourage active teamwork.

Exercise Evaluation:

This exercise received the highest score for interest of all four exercises. Despite the somewhat theoretical concept being introduced students rated the development of engineering skills equal, or better, than previous exercises. Time constraints were a serious problem, however. Ironically, the majority of time was spent understanding and confirming the formulation of the optimization problem, not using the genetic algorithm. Activity and teamwork were very high for this exercise. A competition actually developed between the groups to see who could generate their new generation of solution vectors first and which group had the best solution. In addition, this was the first, and only, time the students made use of the dry erase boards.

Table 4: Survey questions for thermal systems exercise #4 (1 is positive for all scales)

How useful was the problem in understanding course material? (1-4)	2.11
How interesting was the problem? (1-4)	1.67
Did the problem promote development of engineering skills? (1-4)	2.00
Did the problem promote teamwork skills? (1-5)	2.00

The fault with this exercise was time. There was insufficient time to achieve a full solution. Student impact would undoubtedly have been higher if an optimized solution could be obtained. While this is a very time consuming process when done by hand there was a definite advantage to the team effort. In addition, mistakes were made in the exercise formulation which extended the time required. Choosing a problem with only one variable and having the students review the problem before class would have saved approximately one third of the time expended.

Thermodynamics Exercise: Design of a "Perpetual Motion" Engine

Problem Description:

- *Consider this building, think of as many exergy sources as you can. Eliminate the ones already put to a useful purpose (such as electricity from an outlet). Share your ideas with a neighboring group.*
- *Evaluate the potential of each source for powering your "perpetual motion" machine and choose one to work with. Devise a method of converting your exergy source into useful work (i.e. create an engine concept). Explain the operating principles of the device to a neighboring group (different than last time).*
- *For your design, conduct "back of the envelope" calculations to determine the general size of the device and its power output magnitude. Evaluate any design obstacles and identify a possible application for your device. Share your overall concept (source, engine principle, and application) with another group (different from the last two times).*

The thermodynamics class was a much larger class (54 students enrolled). This can pose problems with active learning exercises[10]. However, since exercises 3 and 4 had worked so well to introduce new topics in the Thermal/Fluid Systems course an exercise was created for the Thermodynamics course around the topic of exergy. The portions of Thermodynamics dealing with the 2nd law consistently give students more conceptual problems. In addition, exergy topics often are not covered as in-depth as they perhaps should be. The use of an active learning exercise presented the possibility of increased comprehension and material coverage following Thanksgiving break, a time when students traditionally have trouble concentrating and are already overwhelmed with tasks. The exercise was designed along the open-ended brainstorming path but with more explicit instructions than exercise 1. In addition, due to the large class size more emphasis was placed on the pair-share method. The pair-share method promotes greater involvement by students by asking them to share their ideas with classmates and then listen in return. Due to time constraints and class size it is impossible to have every student or group present their ideas to the whole class. The exercise instructions sought to overcome this by including several group pair-shares followed by a limited number of groups presenting ideas to the entire class at the end of the exercise. Due to the repeated pair-share activities additional time was used and this placed a constraint on what could be done overall. To keep the students on track time limits were given until the start of each pair-share period.

Exercise Evaluation:

The class was instructed to self-organize into groups of three to four. Initially there were problems with individuals who were unwilling to join a group and undertake the assignment. Instructor encouragement was necessary, however; it was evident that some of these individuals did not actively participate even after joining a group. Student comments seemed to reflect a range of opinions on the exercise as a tool for introducing exergy. While many were positive some found the problem too abstract.

> *I think it's a great way to introduce and learn about a new topic.*
>
> *It was a very interesting exercise, which required us to think in ways that we normally wouldn't.*
>
> *I thought it was an interesting topic and I enjoyed the exercise.*
>
> *A little too abstract for my taste.*
>
> *It was an interesting problem, but I think being that we didn't have much time on Chpt. 6, it might have helped to work more problems instead. If we would have had more time, then the exercise would have been great to do.*

The last comment appears to reflect a common conceptual problem with the introduction to thermodynamics course. There is a transition from lower levels of learning to the higher level analysis and synthesis of problems during this course. Students prefer to study only problem solutions, not solution methods. In fact, the aspect of "back of the envelope" calculations in the last assignment step was specifically added to this exercise to help address this by reinforcing problem solving flexibility.

While the interest level reported was fairly neutral (Table 5), students did rate the development of engineering skills and teamwork positively. For this course two additional questions were asked dealing with understanding of exergy and development of problem solving skills. Students were not sure if the exercise helped their understanding of exergy but had a fairly positive

Table 5: Survey questions for thermodynamics exercise (1 is positive for all scales)

How useful was the problem in understanding course material? (1-4)	2.09
How interesting was the problem? (1-4)	2.14
Did the problem promote development of engineering skills? (1-4)	1.83
Did the problem promote teamwork skills? (1-5)	1.86
Did the exercise help your understanding of exergy? (1-5)	2.14
Did the exercise encourage your problem solving skills? (1-5)	1.86

response to the improvement of problem solving skills. Another indication of student interest in this problem is shown by the fact that several students continued to contact the instructor with new ideas or questions weeks after the exercise.

3. Comparison to Traditional Lecture

Students were also surveyed with a simple yes or no question as to whether they preferred these exercises over traditional lectures. As seen in Figures 3 and 4 there was a consistent majority of students who preferred the brainstorming exercises. Due to the small sample size quantitative results for the Thermal Systems class are difficult to obtain. However, it is interesting to note that for all exercises the Thermal Systems students had a more favorable opinion than the Thermodynamics students. There was also an increase in the number of respondents who did not answer this question in the Thermodynamics course. In retrospect these results are not that unexpected. Students at the Thermodynamics level have most likely not been involved in many active learning exercises. Any instructor who has heard the question "What problems should I study for the test?" will understand the students' initial trepidation. This method of learning goes against what they have, unfortunately, defined as the norm.

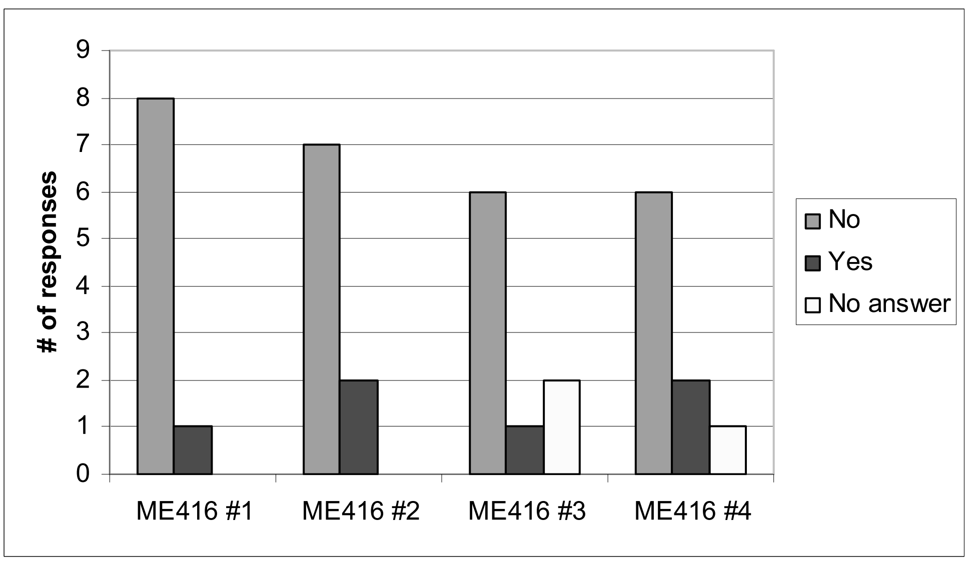

Figure 3: "Would class time be better spent with a traditional lecture?" results for the Design of Thermal Systems course.

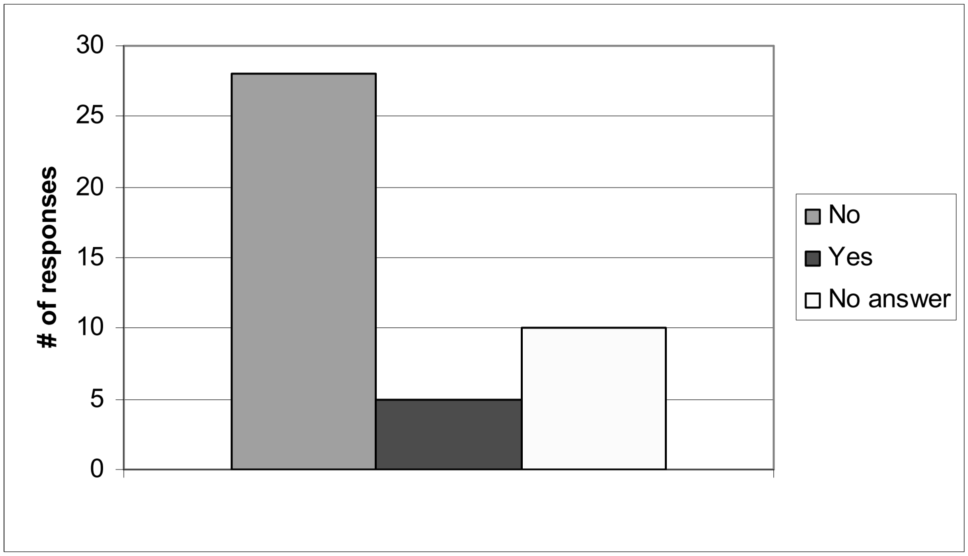

Figure 4: "Would class time be better spent with a traditional lecture?" results for the Thermodynamics course.

4. Conclusions

In this paper several active learning exercises used in the Thermal/Fluid Systems Design and Thermodynamics courses have been presented. Example problem descriptions and background references have been provided along with student and instructor observations. Several specific lessons for the instructor attempting to use these types of activities have been presented. The most important of these will now be summarized.

Active learning is a useful teaching method. While the obvious intention of such methods is to break the passivity of traditional lectures and to involve the students to a greater extent in their own learning, these exercises have shown several other possibilities. It must be remembered that active learning implies more than just being active. The exercise must be structured with specific learning objectives in mind. For instance, active learning exercises can be used to promote specific engineering skills, such as brainstorming solutions, teamwork, and approximation. Exercises can also be developed which teach a specific topic, sometimes more efficiently than a traditional lecture. One objection raised to active learning is that it takes time away from other aspects of the course. As this shows active learning exercises can be structured so that they take the place of certain lecture components thereby preserving the content to class time ratio.

When formulating specific exercises several things must be kept in mind. Open ended problem does not imply open ended instructions. Specific outcomes for the exercise should be identified. In addition, students should be told how the exercise relates to the learning objectives of the course. It is easier for students to see the objective of a lecture but it is often much harder for them to see the full potential of an active learning exercise. In terms of group dynamics, the instructor should take the role of facilitator. Large classes can make use of pair-share techniques and groups should be mixed up if repeated activities are used. Time management is of great concern. The scope of the exercise should be carefully managed to match the instructor's time expectation and student's attention span. For longer activities time limits should be specified to keep students on track.

Each of the exercises described involves the student in the learning process and takes the place of typical lecture material. Each of the exercises also has the student "doing" something to understand the material. Subsequently, these exercises satisfy both definitions given in the Introduction for active learning. The careful observer will notice though, that the exercises carry certain elements of reflective thought as well. The largest impact to learning may happen after class, when the student is reflecting on the activity. When was the last time you heard a student reminisce about a lecture on exergy?

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