AC 2012-4676: FOSTERING STUDENTS' CAPABILITY OF DESIGNING EXPERIMENTS THROUGH THEME-SPECIFIC LABORATORY DESIGN PROJECTS

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Fostering Students' Capability of Designing Experiments Through Theme-specific Laboratory Design Projects

Introduction

Laboratory courses are essential and integral part of engineering curriculum. The courses provide students with good opportunities to solidify their understanding on theory of physical laws and principles learned in classroom through hands-on experimental activities in laboratory. Experiment is an effective pedagogical tool that transforms an abstract theory to a tangible measurable data or clearly visualizes the complex law onto easily understandable phenomenon. ABET requires all engineering program to show successful students' performance in conducting and designing experiments. A traditional engineering laboratory course offers a number of experiments in designated disciplines and requires students to gather and analyzes experimental data to verify the physical principles and laws. Such experiments are usually well defined in the instructional laboratory handouts with clearly defined objectives, equipment, procedure, methods of data acquisition, and tools of data analysis such as equations or computing software. Students only follow the instruction to analyze the data and obtain the experimental results to compare them to the referenced data for possible conclusions. Students usually manage to do well in this type of experimental set-up and feel satisfied if the experimental results show good agreement with the refereed results. The reason to assign experiments in this way is mainly attributed to maintain consistency of data gathering in predetermined time frame and to obtain accuracy of experimental results.

The ability of undergraduate engineering students to design and conduct their own experiments is, however, relatively low compared to the ability of conducting and analyzing regularly assigned experiments. It is considered even weaker than designing engineering systems and/or components. There may be a number of reasons for the root causes. Any novel engineering experiments require not only comprehensive understandings on scientific theory of the particular physical principles but also the art of modeling, precision measurement, data collection, and analysis. In addition, such open-end activities as developing experimental hypothesis, experimental set-up, statistical consideration, verification and interpretation of results call for high level of interactive knowledge. Unfortunately, few undergraduate students are given sufficient experiences to develop the ability to put these whole things together for themselves. It may be difficult for many undergraduate students to pick up systematic techniques about laboratory design through above-mentioned regular laboratory activities. It may also be nearly impossible for the students to develop in-depth knowledge on experimental design through completely open-end, so-called "sink or swim", laboratory design projects.

Implementation of theme-specific laboratory design project

The mechanical engineering program at Youngstown State University has been continuously upgrading its educational objectives and assessment plan since 1998 when a comprehensive assessment plan was implemented. It sets a high priority for meeting Outcome (b) - Ability to design and conduct experiments, of ABET 2000. For proper assessment of Outcome (b), the program developed assessment rubrics, as shown in Table 1, to measure students' performance.

The rubric identifies six pertinent abilities that students must develop during their studies in the mechanical engineering program. They are the abilities to identify objectives, to use appropriate tools and methods, to conduct experiments safely, to collect sufficient data and apply statistical analysis, to evaluate results for validation of objectives, and to formulate an experiment to evaluate an engineering problem. There are four levels of achievement criteria that each student must display. The program aims that every senior in the program meets or exceeds criteria 3. In order to attain the goal, the program has been requiring that each mechanical engineering laboratory course contains an open-end laboratory design project in addition to regularly scheduled traditional experiments.

One of the laboratory courses is a senior-level required course that deals with the topics in the areas such as basic and applied thermodynamics and heat transfer. The laboratory is facilitated with a number of experimental equipment which includes data acquisition instruments, conduction, forced and free convection, radiation heat transfer, refrigeration systems, internal combustion engines, flue gas analyzer, fluid power system, heat exchangers, and gas turbines for traditional experimental assignments. In addition, the course requires an open-end laboratory design project. As discussed in the Introduction, students generally did well with the traditionally assigned experiments. However, that was not the case with “sink or swim” open-end design projects. Most students were observed to be passive and/or afraid to take an initiative in conceptualizing and conducting their own experiments. Most “sink or swim” design projects are superficially developed and become less effective pedagogical tools through which the students strive to achieve their educational goals as defined in the outcome (b). Efforts and hard work put in by the faculty were less productive in achieving the outcome similar to other categories of ABET outcomes[1]. Consequently, the annual assessment showed that the outcome (b) has always been a subject for further improvement[2]. Therefore, in order to change this perennial dilemma, the open-end design assignment is modified to theme-specific laboratory design project that is carried out as shown in the course syllabus *Exhibit A*: MECH 4825L Thermodynamics & Heat transfer Laboratory.

The new way of conducting laboratory design projects is expected to help students acquire not only particular knowledge on a designated theme but also technical skills to carry out their projects to the successful conclusions. The experience and skills obtained through the project would help students develop and design experiments on other subjects. The development of such an experimental design project and subsequent assessment on the activity are examined in this paper. The theme-specific open-end design project requires semester-long activities in and out of the laboratory. A slightly altered first page of the course syllabus shown in *Exhibit A* illustrates how the new design projects are assigned and implemented. It begins with the general guidelines on laboratory design projects handed out to all students at the 2nd week of a semester. The general guidelines, as shown in *Exhibit B*, introduce the objectives of requiring experimental design projects and the anticipated outcomes after their implementation.

Maximum four students are grouped together to form a design team. One particular broad theme for research is selected as a semester project. Students in each design team are required to conduct literature search and thoroughly understand the theme materials. The team, through consultations with the faculty, then formulates an experimental model and develops an experiment that verifies their hypothesis. Students are also required to submit a written proposal and present their proposal orally. In the oral presentation session of the proposal, instructor and students discuss the viability of the experiment, schedule of activities, and the merits of the proposal. Some modifications are usually made after the instructor's written feedback on the proposal and the modified proposal are allowed to be resubmitted. Instructor keeps a copy of the proposal to check the progress of project. An interim report is required to show the actual progress of project activities. Students assemble all the hardware needed to make apparatus and instruments for the completion of their project. They develop detailed experimental procedures that allow them gather reasonable data and conduct their experiments. Students also find solutions to the problems they encounter during the process through discussions with faculty, which strengthened students' understanding of the subjects.

Table 1. Outcome (b) – Ability to design and conduct experiments

Metric & Weight (W)	Below Expectations (Score, S=1)	Progressing to Criteria (Score, S=2)	Meets Criteria (Score, S=3)	Exceeds Criteria (Score, S=4)
1. Ability to identify experimental objectives.	Student unable to identify experimental objectives explicitly discussed in class or lab.	Student only identifies some of the experimental objectives discussed in class or lab and has a sketchy understanding of these objectives.	Student identifies experimental objectives discussed in class or lab completely.	Student identifies experimental objectives beyond those discussed in class or lab and can extend implications beyond those discussed.
2. Ability to use appropriate experimental tools and methods.	Student does not have the knowledge of experimental tools and instrumentation.	Student has some knowledge of experimental tools and instrumentation.	Student has basic knowledge of experimental tools and instrumentation.	Student has advanced knowledge of experimental tools and instrumentation.
3. Ability to conduct experiments safely.	Student does not exhibit any safety knowledge or practice.	Student has some knowledge of safety and exhibits some safe behavior in performing experiments, but needs more development.	Student has knowledge of safe experimental practice and exhibits this knowledge in performing experiments safely.	Student exhibits advanced knowledge of safe practice and exhibits this advanced knowledge in performing experiments.
4. Ability to collect sufficient data and apply appropriate statistical analysis.	Student does not have any statistical ability and does not collect sufficient data.	Student has some statistical ability and collects sufficient data, but is sketchy in reaching valid statistical conclusions.	Student exhibits statistical ability and collects sufficient data. Statistical conclusions reached are valid.	Student exhibits advanced statistical ability, collects sufficient data, and reaches valid conclusions which extend beyond those normally expected.
5. Ability to evaluate experimental results to validate the achievement of objectives.	Student does not have any ability to evaluate experimental results.	Student evaluates experimental results and comes to conclusions that are only partially correct.	Student evaluates experimental results and comes to correct conclusions.	Student evaluates experimental results and comes to correct conclusions and extends the findings beyond the original scope of the work.
6. Ability to formulate an experiment to evaluate an engineering problem.	Student did not develop an experimental procedure.	Student develops a procedure with some incorrect steps.	Student develops a procedure which has correct steps.	Student develops a procedure which is correct, concise, and gives information beyond the original scope of the problem.

Finally they make and/or assemble all the hardware necessary for the experiment and conduct the experiment in accordance with the procedure that they developed. The final report focuses on detailed account of the specific experiment validating the hypothesis, which includes objectives, apparatus, the theory backing up the hypothesis, experiment procedure, data collection, dissemination and analysis of data, presentation of results in tabular and/or graphical modes, interpretation of the results, and final conclusion.

Several broad themes, mainly related to fundamental laws or physical phenomena in thermal science, are considered for the team design projects. Examples of the broad themes are thermoelectricity and temperature measurement, conductivity or other thermal properties of materials, heat transfer coefficients in forced, natural or combined convection, verifying radiation laws and/or view factors, heat exchanger, refrigeration, engines, and fluid machinery. In fall 2011, a theme of determining *convection heat transfer coefficient on a lumped mass* was selected. The project assignment sheet, as shown in *Exhibit C*, is handed out to each student of the four design teams at the 3rd week of the semester. It contains objectives, short description of theory associated with the theme, general restriction or constraints, apparatus, important parameters, a specific procedure describing the steps needed to carry out a particular design project.

Guided by the project assignment sheet, every student in each design team has studied the theme for a week and the team members met to discuss about selection of a topic and possible formulation of an experiment. Each team presented a proposal orally at the 5th week of the semester. All four teams decided to determine natural or free convective heat transfer coefficient on small solid objects. They were reminded by the instructor that one of the main criteria on the experimental model is the Biot number which restricts the sizes of the specimens. The Biot number could be initially estimated by using value of h obtained from empirical Nusselt number and the characteristic length depending on the orientation of the object and the conductivity of the specimen.

In the following week written proposals were submitted, ranging from *a solid aluminum cylinder cooled in an atmospheric air (Team 1), an aluminum square bar cooled in light engine oil (Team 2), a solid steel cylinder cooled in air (Team 3), a beef hot-dog cooled in air (Team 4)*. The first three teams used small metallic objects as lumped mass to validate the lumped capacitance method in determining a convection coefficient. To make sure that the Biot number is within the upper limit, the teams designed small specimens in the low h environment of natural convection.

Teams 1 and 2 proposed that the only variable is the temperature on the surface against time. Then the rate of internal energy change is equated to the rate of heat transferred through surface using the Newton’s law of cooling. Team 3 proposed a process similar to those of teams 1 and 2. In addition, the team stated that the temperature at the center is measured simultaneously with the surface temperature. They also pointed out that the orientation of the object is an important factor for free convection environment. Team 4 proposed using a heated hot-dog cooled in air to find the convection coefficient. The team was advised that the lumped capacitance method might not be used for their experiment due to a possible high Biot number. It was suggested that they study the phenomenon of general transient heat conduction in addition to convection heat transfer. Team 4 abandoned the lumped capacitance method and resubmitted the proposal outlining the energy conservation principle of the diffusion heat flux being equal to the convection heat flux on the surface. They proposed that the Heisler chart[3] would be used to evaluate the rate of heat conduction in the solid.

Each team designed experimental setup and prepared specimens in the weeks of 12 and 13. Thermocouples are attached and on the surface of the specimens and also at the center for teams 3 and 4 to measure transient temperatures. Since the accurate measurement of transient temperature is one of the key factors for success of the experiment, many practice sessions were conducted. All four teams reported difficulties obtaining reliable readings of temperatures on a fast time scale. After repeated attempts and practice sessions, consistent temperature readings were obtained and processed into the equations. The numerical results were compared with the values calculated from the empirical correlations for an average natural convection coefficient as shown in Table 2. The final report on the experiment was written and submitted by each team on the 15th week.

Table 2. Experimental Results

Team	Title	Experimental setup	Average h from experiment	h from empirical correlation
1	Experimentally determining convection coefficient	Horizontal aluminum cylinder cooled in air D = 1”, L = 3”	1.05 Btu/ft^2 R	1.80 Btu/ft^2 R
2	Solving for convection heat transfer	Vertical aluminum square bar in engine oil 0.75”x 0.75” x 2”	7.56 Btu/hr ft^{2}R	11.44 Btu/hr ft^{2}R
3	Validating the lumped capacitance method to determine convection coefficient	Horizontal steel cylinder in air D= 0.018 m, L= 0.096 m	12.0 W/m^{2}K	7.21 W/m^{2}K
4	Finding free convection coefficient	Vertical hot-dog in air D= 0.0184 m, L= 0.089 m	20.45 W/m^{2}K	6.20 W/m^{2}K

The projects of teams 1 and 3 are fairly identical each other. The first was determining the natural convection coefficient on a heated horizontal aluminum cylinder being cooled in an atmospheric air and the second was on a steel cylinder. Team 2 studied a heated vertical aluminum square bar being cooled in engine oil. The average convection coefficient from the experiments by Team 1 was about 42% smaller than the value obtained from the engineering correlation[4] available in literature. The free convection coefficient from the experiment by Team

2 was about 34% smaller than the value from the literature[5]. Team 3 showed their free convection coefficient was 66% larger than the value obtained from the engineering correlation[4]. All three teams concluded that they were satisfied with the results and the errors were caused by inaccurate readings of the temperature distribution. Team 3 reasoned that the rapidly dropping surface temperature caused the larger h. The experimental result of Team 4 showed a considerable difference from the value calculated from an engineering correlation by Cebeci[6]. They concluded that the accuracy was probably affected by the effect of high rate of heat diffusion.

Assessment of laboratory design project

The final reports were evaluated according to the program assessment rubric shown in Table 3. The evaluation revealed that the overall performance of the students met the assessment goal set by the program educational objectives. The table showed that the students understood the theme fairly well, identified experimental objectives, and learned how to formulate an experimental model related to the theme. The students were capable of using the appropriate tools and methods, collecting and analyzing experimental data well. The lowest points were awarded to the ability of the students to evaluate and interpret the experimental results to validate the objectives.

A similar assessment summary on the traditional open-end laboratory project assigned in Fall 2009 is shown in Table 4 for comparison. Since the topics of design projects in 2009 and 2011 are completely different, the direct comparison between them is not possible. However, the evaluation of different topics on the metrics of assessment, although subjective, indicates overall advances of students' learning and performance outcomes. The tables showed a definite improvement on the metrics 1, 3, 4 and 6. In each table, last row represents the normalized points in 1 to 4 scale which is described below:

Normalization of Survey Data:

Normalization of the points was done from 0 to 10 or 0 to 4 scale into 1 to 4 scale as shown in the two tables obtained from the student survey.

$$X_{new} = \frac{X - X_{min}}{X_{max} - X_{min}} \text{---} (1)$$

For 0 to 10 scale:

$$X_{new} = \frac{X - 0}{10 - 0} = \frac{X}{10} \text{---} (2)$$

For 0 to 5 scale:

$$X_{new} = \frac{X - 0}{5 - 0} = \frac{X}{5} \text{---} (3)$$

Where, Xnew is the normalized point of X in the scale of 0 to 1 from the scale of Xmax to Xmin (Here, 0 to 5 and 0 to 10 are two scales used in the survey tables). This was further used to convert the normalization scale into 1 to 4 by using the following equation:

$$X_{new} = \frac{Xnormalized-1}{4-1} = \frac{Xnormalized-1}{3}$$

$$X_{normalized}\text{ (1 to 4 scale)} = 3 * X_{new} + 1\text{---------------(4)}$$

For example, to convert the Metric 4-average point of 7.25 (Theme-based survey, Table 3) from 0 to 10 scale into 1 to 4 scale, Xnew = 0.725 is obtained using (1). Then, using (4), normalized point for Metric 4 is obtained as $X_{normalized}$ = 3*0.725+1 = 3.175 as shown in Table 3.

Table 3. Assessment Rubric Summary Fall 2011 for Outcome (b) Ability to design and conduct experiments with Theme-specific Laboratory Design Projects

	Ability to Identify experimental objectives Metric 1	Ability to use appropriate experimental tools and methods Metric 2	Ability to conduct experiments safely Metric 3	Ability to collect sufficient data and apply appropriate statistical analysis Metric 4	Ability to evaluate experimental results to validate the achievement of objectives Metric 5	Ability to formulate an experiment to evaluate an engineering problem Metric 6	%
Points	5	10	5	10	10	10	
Team 1	4	7	4	6	6	7	68.0
Team 2	3	7	3	7	7	7	68.0
Team 3	5	8	4	9	8	9	86.0
Team 4	3	6	3	7	6	6	62.0
Average	3.75	7.00	3.50	7.25	6.75	7.25	71.00
Normalized to 1 to 4	3.25	3.10	3.10	3.18	3.03	3.18	

Table 4. Assessment Rubric Summary Fall 2009 for Outcome (b) Ability to design and conduct experiments with traditional open-end Laboratory Design Projects

	Ability to Identify experimental objectives Metric 1	Ability to use appropriate experimental tools and methods Metric 2	Ability to conduct experiments safely Metric 3	Ability to collect sufficient data and apply appropriate statistical analysis Metric 4	Ability to evaluate experimental results to validate the achievement of objectives Metric 5	Ability to formulate an experiment to evaluate an engineering problem Metric 6	%
Points	5	10	5	10	10	10	
Team 1, Cloudiness index factor	2	6	3	7	6	6	60.0
Team 2, Heat exchanger design	2.5	7	3	7	7	7	67.0
Team 3,Thermopile pyrometer	3	7	3.5	7	6	6	65.0
Team 4, Finned heat exchanger	3.5	8	3.5	7	8	6	72.0
Average	2.75	7.00	3.25	7.00	6.75	6.25	**66.00**
Normalized to 1 to 4	2.65	3.10	2.95	3.10	3.03	2.88	

Table 5: Assessment Rubric Summary Fall 2011 for Outcome (b)

Theme-specific Laboratory Design Projects								
Metrics	**Metric 1**	**Metric 2**	**Metric 3**	**Metric 4**	**Metric 5**	**Metric 6**	**Average**	**Average %**
Points	4	4	4	4	4	4	4	100
Team 1	3.2	2.8	3.2	2.4	2.4	2.8	**2.8**	70.0
Team 2	2.4	2.8	2.4	2.8	2.8	2.8	**2.7**	66.7
Team 3	4.0	3.2	3.2	3.6	3.2	3.6	**3.5**	86.7
Team 4	2.4	2.4	2.4	2.8	2.4	2.4	**2.5**	61.7
Average Points	**3.3**	**2.8**	**2.8**	**2.9**	**2.7**	**2.9**	**2.9**	72.3
Average %	81.3	70.0	70.0	72.5	67.5	72.5	72.3	
Traditional open-end Laboratory Design Projects								
Metrics	**Metric 1**	**Metric 2**	**Metric 3**	**Metric 4**	**Metric 5**	**Metric 6**	**Average**	**Average %**
Points	4	4	4	4	4	4	4	100
Team 1	1.6	2.4	2.4	2.8	2.4	2.4	**2.3**	58.3
Team 2	2.0	2.8	2.4	2.8	2.8	2.8	**2.6**	65.0
Team 3	2.4	2.8	2.8	2.8	2.4	2.4	**2.6**	65.0
Team 4	2.8	3.2	2.8	2.8	3.2	2.4	**2.9**	71.7
Average Points	**2.2**	**2.8**	**2.6**	**2.8**	**2.7**	**2.5**	**2.6**	65.0
Average %	55.0	70.0	65.0	70.0	67.5	62.5	65.0	

Figures 1 and 2 contain solid and dashed lines representing the average points of students' performance for theme-based and traditional design experiments, respectively.

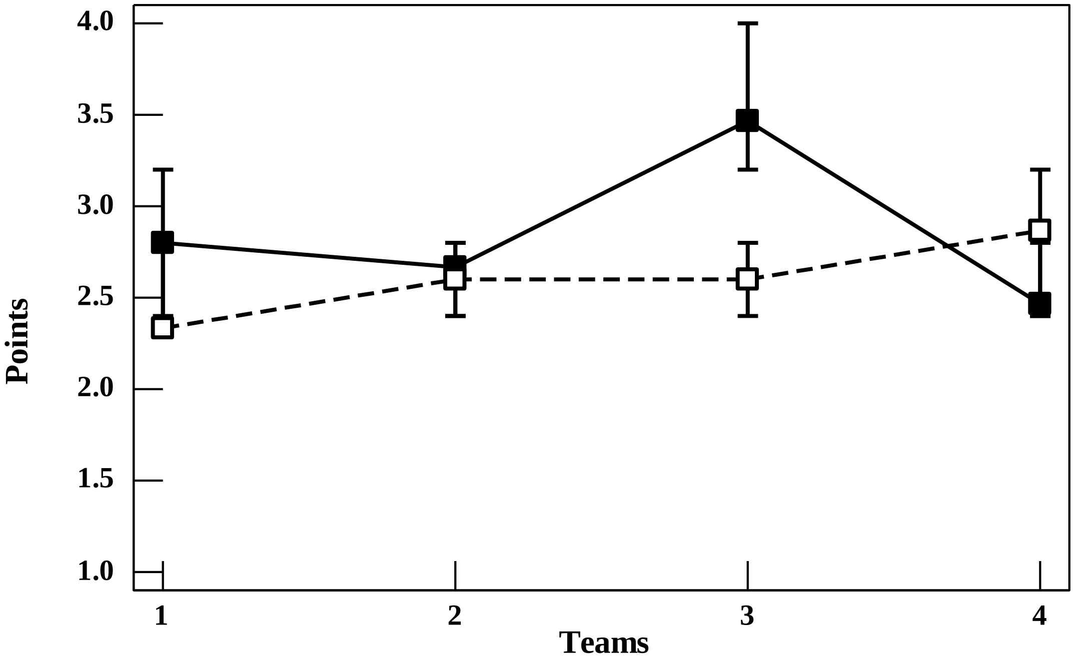

Figure 1: Points vs. Teams for (a) Theme Based (Solid squares with solid lines) and (b) Traditional Laboratory Design Projects (Open squares with dashed lines)

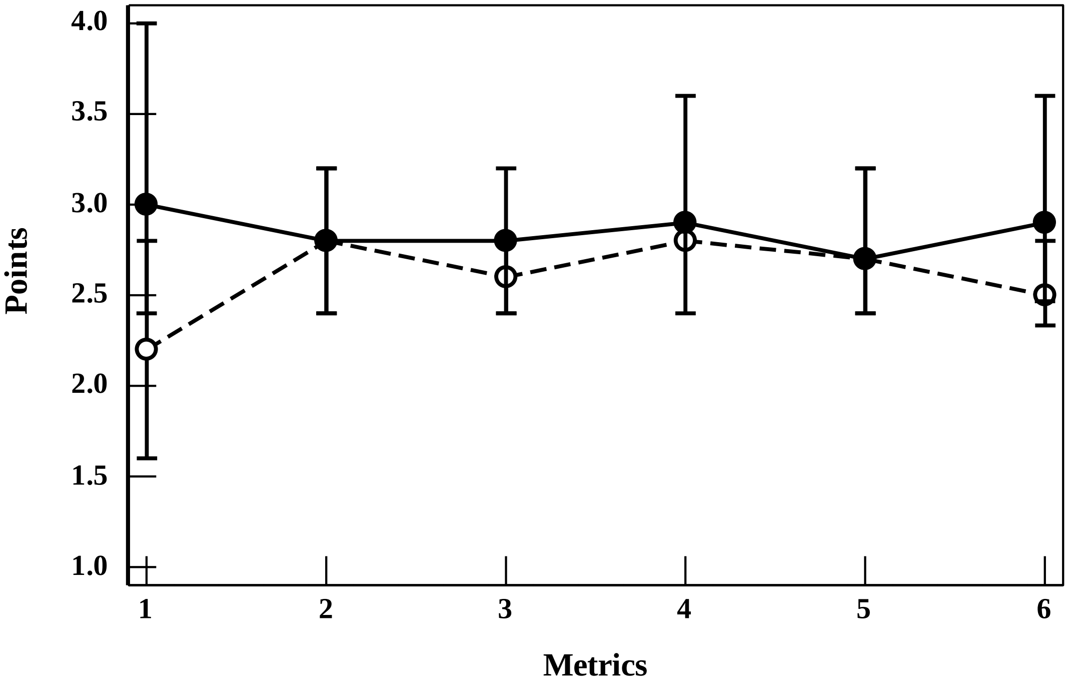

Figure 2: Points vs. Metrics for (a) Theme Based (Solid circles with solid lines) and (b) Traditional Laboratory Design Projects (Open circles with dashed lines)

In Figure 1 solid and open squares represent the average points obtained by the team for metrics 1 to 6. The vertical lines in the figure indicate upper and lower limits of points earned by each team. Similarly, two solid and dashed lines with squares and vertical lines shown in Figure 2 represent the points vs. metrics for metrics 1 to 6. Solid and open squares represent the average points of students' design performance for theme-based and traditional design experiments, respectively, with upper and lower limits in the points range indicated by vertical lines. Average points for each metric represent the average points obtained by all teams.

Concluding remarks

The new way of assigning design project seemed to produce positive results related to experimental design and students' learning. The experience strengthened the ability of students in formulating an experimental model, designing and conducting experiments, collecting and analyzing the experimental data, validating the hypothesis, and observing the entire experimental process for interpretation. The step by step assignments, continuous communication between the instructor and students through oral and written presentations of design proposal, interim report helped students acquire in-depth knowledge on the topics and the related materials.

This systematic approach guided students to carry out the project from the beginning to its successful conclusion. The theme-specific laboratory design project is expected to strengthen students' confidence on designing and conducting experimental projects on other topics.
For continuous and permanent implementation of theme-specific laboratory design projects, direct quantitative assessment should be conducted in the near future to validate the improvement of students' experimental design ability.

References:

1. "ABET Engineering Accreditation Alert", Executive Committee, EAC, March, 2011
2. "Program Annual Assessment Reports", Mechanical Engineering Program, XXX University
3. "Heat Transfer, 3rd Edition", Y. Cengel, WCB/McGraw-Hill, 2007
4. "Correlating Equations for laminar and turbulent free convection from a horizontal cylinder", S. Churchill and H. Chu, Int. J. of Heat Mass Transfer 18, 1975
5. " Correlating Equations for laminar and turbulent free convection from a vertical plate", S. Churchill and H. Chu, Int. J. of Heat Mass Transfer 18, 1975
6. "Laminar free convection heat transfer from the outer surface of a vertical slender circular cylinder", T.Cebeci, Proc. of Fifth Int. Heat Transfer Conference, 1974

Exhibit A: MECH 4825L Thermodynamics & Heat transfer Laboratory Fall 2011

Classroom: Moser Hall 1230 **Class Meets:** T/R 1400 - 1650
Instructors: John Doe, Ph.D., P.E. **E-mail:**
Reference: Thermo fluid heat text books, Engineering Experimentation, Martin Ray, McGraw Hill, 1988

Objectives of Course:
To provide mechanical engineering students with a hands-on experience in conducting and/or designing experiments on thermodynamic properties, heat transfer, heat exchangers, power and refrigeration cycles, head loss in piping systems, prime movers, combustion and energy conversion processes, and other selected thermal-fluid devices. On successful completion of this course, students are expected to

1. apply the principles of thermodynamics to analyze sample coals for thermodynamic properties and heating values by proximate and calorimetric analyses
2. utilize a variety of temperature measuring devices and instruments to obtain temperatures, understand the principles of thermoelectricity, thermocouples, and thermopiles, and be able to interpret their accuracy
3. analyze multi-bar 1-D heat conduction by thermal resistance method
4. understand clearly the concepts of temperature gradient and contact resistance
5. verify the Stephan-Boltzmann's law and net radiation exchange between surfaces
6. analyze the performance of double pipe heat exchangers
7. analyze the performance of refrigeration systems
8. analyze the performance of hydraulic systems
9. analyze the performance of internal combustion engines
10. analyze the performance of gas turbines
11. be capable of applying the principles of thermal sciences to design and analyze their own experiments
12. utilize computer software for analysis and design of thermal fluid systems or components
13. effectively present their work in written and oral form of communications

Topics Covered:

Week	Topic (3 contact hours/week)	Report / Due
1	Lab introduction	
2	Exp. 1, Part1: Proximate analysis	WG
3	Exp. 1, Part 2: Calorimetry	WG
4	Exp. 2: Temperature measurement	WG
5	Proposal for design(oral and written)	WG, Proposal
6	Exp. 3: Conduction heat transfer	WG
7	Exp. 4: Heat exchangers	WG
8	Exp. 5: Radiation heat transfer	WI
9	Exp. 6: Refrigeration system	WI
10	Exp. 7: Hydraulic system	WI
11	Exp. 8: Internal combustion engine	WI
12	Exp. 9:Gas turbine	WI
13	Design project	WG, Interim report
14	Design project	
15	Presentation	WG, Design report

Exhibit B: General Guidelines for Experimental Design Project

Intro: Laboratory design projects provide students with an opportunity to create their own experiments that verify students' own hypothesis on engineering problem or existing theory on natural phenomena. It is anticipated that it will strengthen, not only students' understanding on the theories and fundamentals of physical phenomena associated with the conducted experiments, but also on the fundamentals of experimental investigation and painstakingly repeated processes that usually accompany most experiments related to thermal fluid science and engineering. By conducting this laboratory project, you will learn and/or acquire the following skills:

1. detailed physical meaning of natural laws and equations or empirical consequences that the experiment intends to verify
2. how to hypothesize a new experiment or formulate an experiment to evaluate engineering problem
3. how to set up a particular experiment and develop a new experimental process
4. how to conduct the experiment to gather desired data, analyze them and verify the accuracy
5. how to find the system errors and minimize random errors based on preliminary analysis
6. how to validate the objective
7. how to document and present experimental work

About assignment:

1. Thoroughly investigate the theme through extensive research.
2. Select one or two significant phenomena, effects, or laws related to the selected theme that you would like to create an experiment for.
3. Hypothesize or formulate an experimental model and define the objective.
4. Construct new hardware or modify existing experimental apparatus, including instrumentation and data acquisition system.
5. Develop an experimental procedure that can validate your hypothesis.
6. Conduct experiments to obtain data based on the procedure you developed and devise a plan minimizing the random and system errors to improve the experimental results.
7. Analyze the data and verify the accuracy of the experiment
8. Interpret the results and validate the hypothesis.
9. Submit a complete written report and make an oral presentation.

Exhibit C: Assignment of Design Project

Broad theme: To obtain a convection heat transfer coefficient on a solid body

Objectives of the experiment:
To obtain a forced or natural convection coefficient by the lumped capacitance method

Design constraints:
A solid object of a lumped mass
Unknown rate of heat generation inside the body or unknown surface heat flux
No automatic data acquisition system available

Theory:

Experimentally determining the heat transfer coefficient on the surface of a three-dimensional solid is not a trivial matter due to difficulty of obtaining accurate surface temperature and transient nature of the rate of heat transfer from the object. One simple method that can be used to determine this coefficient is the lumped capacitance approximation when the solid is subjected to convection. The method assumes that temperature of the lumped mass is nearly uniform over the entire solid at any instant and the temperature changes depending upon time only. There are negligible temperature gradients within the solid, which means negligible resistance to conduction compared to the resistance to convection. When a warm body is cooled by a cold fluid stream, the rate of heat loss from the body is proportional to the difference in temperature between the surface of the body and the ambient fluid. The principle of energy balance indicates that the rate of heat loss from the surface of the solid is identical to the rate of change of the internal energy within the solid. Since there is no measurable rate of heat diffusion within the solid using the lumped capacitance method, the rate of change of the internal energy within the solid can be expressed in simple terms. Solution of this energy balance equation yields the heat transfer coefficient and the overall heat loss. The lumped capacitance method works well if the Biot number is smaller than 0.1.

Apparatus: K and T type thermocouples, potentiometers, digital thermometers, blower, stopwatch, heater or heating furnace, anemometer, design specimens

Suggested design procedure:

1. Study the theory of transient conduction and convection heat transfer and formulate an experimental model to find a convection coefficient on the surface of an object.
2. Find needed equations to be validated by an experiment.
3. Identify all experimental parameters to be determined from known or given.
4. Make a conceptual experimental setup that conforms to the given constraints.
5. Check if your conceptual setup for the experiment is realistic and simple enough to be built.
6. Build experimental devices and specimens to assemble the apparatus.
7. Set up instrumentation for data acquisition.
8. Develop an experimental procedure.
9. Conduct an experiment to obtain needed data.

10. Make a preliminary data analysis to check the results with referenced data from literature or theoretically calculated data.
11. If the discrepancy between your results and referenced data is too large or unacceptable,
12. Check the main source of the errors.
13. If the errors are mainly random, the accuracy can be improved by repeated measurements with care.
14. If the system errors dominate, modify the experiment to reduce the system errors until satisfactory results are obtained.
15. Conduct an experiment to verify appropriateness of the final experimental setup and the theory, and to demonstrate the accuracy of results for validation.
16. Review the entire process to check if the objectives of the experiment were satisfied.
17. Make a proper documentation on the final experiment.

Report:

A proposal describing concept of the design, objectives, experimental setup, and anticipated results must be orally presented by all members of your group in the 5^{h} week. A written proposal is due a week following the oral presentation. An interim progressive report must be submitted before the final experiment is conducted. A final group report must document the detailed account of the product of the project, the experiment. Submit a formal written report that must include clearly written objective, apparatus, theory, experimental procedure, data, analysis, results, and conclusions for the new experiment.