Using Design, Build and Test Projects for Improving the Design of Fluid-Thermal Systems and HVAC Design

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Abstract

The goals of the newly-awarded project by NSF are to adapt and implement proven concepts from previous NSF projects in order to integrate hands-on experiments in traditional thermal science lecture courses and to reorient traditional teaching laboratory courses with design, build, and test (DBT) activities. In particular, the following principles and methods are adapted: a hands-on experience integrated to abstract concepts discussed in lectures, a clear linkage to industrial applications, and Design Build and Test (DBT) projects. Specifically, two DBT course modules are developed: the heat exchanger and scaled building air-conditioning system. The project reforms the current thermal science stem curriculum with changes to three required lecture courses in such a way that the contents of the stand-alone ME lab course is integrated with the lectures through the execution of DBT activities. This adaptation enhances students' learning of thermal science subjects by providing students an enhanced, open-ended design problem experience in the mid-stage of the curriculum rather than near the end when the senior design project is required. It supports improved comprehension of the thermal-fluid contents through practical application and immediate, relevant implementation, rather than a fragmented learning process. DBT activities enhance students' critical thinking skills with the decision-making and close-loop accomplishment experience. Through a planed evaluation process, the project leads to three outcomes to demonstrate that the DBT approach better equips students with an ability to apply mathematics, science, and engineering to thermal-fluid systems design, that the students can have a platform to practice teamwork, professional and ethical responsibility, and that the reformed curriculum contributes to an increase in student's interests in thermal/fluid subjects, better retention rate, and more attraction to prospective students. Finally, the developed process ensures a favorable cooperative learning environment with a strong sense of accomplishment for the underrepresented student population. This presentation focuses on the progress of the project in the following areas: (1) Planned activities, (2) student design team's efforts, and (3) pre-project evaluation serving as a benchmark for project implementation evaluation.

Introduction

The principal investigators are committed to adapting and implementing proven concepts from three previous CCLI projects, from the University of Wisconsin-Milwaukee (Award No. 0127075) and the Colorado State University (Award No. 9950619) and University of Idaho (Award No. 9952308). The three projects are closely related and focus on the *integration* of hands-on experiments in traditional lecture courses, and the reorientation of traditional teaching laboratory courses to be structured for *design, build, and test* (DBT) student activities. Through the adaptation of these two goals, the principal investigators seek to reform the current thermal sciences curriculum by affecting changes to three required courses in the Mechanical Engineering curriculum: *Heat Transfer* (engineering science component), *Design of Thermal and Fluid Systems* (design component), *ME Lab* (thermal science laboratory course), and one required courses in the HVAC Professional Certificate: *Air Conditioning Design*.

The objectives of this reform are three-fold: (1) to increase student achievement in the traditional lecture course in thermal sciences and to gain better comprehension of the course content, and (2) to increase engineering design experience in the overall curriculum, and (3) to develop critical thinking skills, and promote more *synectic* thinking, i.e. the ability to relate seemingly disconnected topics and use them together to solve open-ended problems. Integrating hands-on experimental components into the traditional lecture course will create a more cooperative learning environment, and will provide learning opportunities for *sensate* learners (those the learn better by seeing and doing rather than through abstract thinking and conceptualizing). In addition, the laboratory assignments with their associated data analysis will provide an alternative to the standard end-of-the-chapter problems with their single-point solutions. Reorienting the traditional laboratory course from the execution of well defined encapsulated laboratory experiments to a DBT format will address the need for more open-ended design problem experience in the overall curriculum, and more specifically support improved comprehension of the thermal-fluid content through practical application. Furthermore, requiring that the designs be tested incorporates experimental planning and data analysis as well.

Problem and Needs

Despite various levels of efforts, the U.S. educated, engineering graduates with the Bachelor's degree continue to decline during the last decade, while the demands from industries and non-industrial employers remain steady. In the last decade, several factors have been identified for this trend, such as the "unfriendly" nature of delivery of engineering curricula, which does not tolerate a broader variety of learning styles. Of greater concern, engineering education methodology is not as attractive to woman as it is to men. Engineering education has become too mathematical, too abstract, and is not employing recent pedagogical trends, such as problem based learning, and cooperative learning, in large scale. The impact of this has been noted in industry, which has clearly had a major impact on the development of new accreditation criteria for undergraduate engineering programs. Starting in 2000, ABET's (Accreditation Board for Engineering and Technology) *Criteria for Accrediting Engineering Programs* has stressed the need for engineering programs to initiate cooperative learning environments with teamwork and communication skill development, as well as the development of practical hands-on skills and engineering design experiences[1]. To respond to this, many schools are reforming their curriculums to put design into all four years of the curriculum and to orient their programs to focus on system design. Additionally, ABET, industry, and faculty have identified the need to utilize more open-ended problems to promote critical thinking skills and the ability to adapt to real-world problems (which are ill-defined, incomplete, and lack a single correct solution). Integration of experimental data analysis into the traditional lecture course will provide an alternative to the standard end-of-the-chapter problems with their single-point solutions. These problems offer little more than an exercise in math and teach little in understanding the underlying physical phenomena. Lastly, the NSF itself as well as notable researchers have identified that the only way there will be enough engineering graduates to fulfill the future needs is the "stalk the second tier" of potential engineering students, that is, to recruit and develop teaching strategies to address the educational needs of woman, minorities, and students whose learning styles don't fit the traditional pedagogy of engineering schools[2].

Within the Mechanical and Materials Engineering (MME) Department, informal research is showing that close to 50% of our students are *sensate* learners, who are "good with their hands", and who enjoy as well as expect hands-on experience as part of their education. This is probably due to the fact that almost all of our students are first or second generation American, with a sizable minority coming from high schools outside the US. Additionally, the local school systems have embraced project based learning methodologies. The majority of students at FIU are female and Hispanic, and currently FIU is in the top three producers of Hispanic engineers in the US. FIU is in the unique opportunity to graduate numbers of female engineers that will exceed the national average. To address these issues, curriculum reform with pedagogical change is necessary.

Another issue facing FIU, being located in a generally poor to lower income community (Miami has been rated the poorest city in the US, for the last two consecutive years), is that large numbers of our students work outside of school and essentially all of our students commute from all points in Dade and Broward counties. This makes it difficult for our students to collaborate effectively on design projects, particularly during the fabrication stages. Students need equipped teaching laboratories that are open and staffed so they can work on their projects during class time. Clearly, more equipped and accessible facilities are needed for student use.

Mechanical Engineering has been particularly hard hit by economic constraints with respect to its teaching laboratories. The cost of commercially available teaching equipment exceeds the capital available. With the shift to a software-driven society, the administration, as well as government agencies, find it hard to justify the expenditures for laboratory equipment with prices near that of research grade equipment. Unfortunately, the lower cost equipment ($5K to $20K) is very specific in scope and is not well suited to open ended problems. As has been observed by various scholars and international students, the level of hands-on training for Mechanical Engineering students in U.S. is less than those in the higher education institutions in the developing countries[3]. Another reality is that the lower cost equipment is now finding its way into high schools, which recently, are getting a bigger slice of the funding in the State of Florida. Clearly, teaching laboratories have to change their focus and adapt to the new economic situation.

Design, Built, and Test (DBT) Projects

To address the problems and needs identified in the last section, the principal investigators propose a specific plan of curriculum reform. This plan is based on the adaptation of successful curriculum enhancements performed by other NSF awardees of CCLI grants. The plan focuses on reorientation of *EML 4906L Mechanical Engineering Laboratory* from a traditional encapsulated experimental experience into a DBT experience for the students

DBT Laboratory Experience

The plan is based on the work done at the University of Idaho (NSF Award No. 9952308) whereby the principal investigator created a user-friendly wind tunnel facility facilitating DBT student projects. This project successfully designed, fabricated and debugged an experimental apparatus, which served as a learning tool for over 15 student DBT projects spanning several classes. Additionally, this project incorporated training and development components and an outreach component for high school students. The objectives and outcomes of the project at University of Idaho are completely in-line with the needs and goals at FIU[2]. The PI(s) intend to adapt this project for use in a the thermal-fluid sciences by the development of a laboratory facility to support DBT student projects focused on heat exchanger design and HVAC (heating, ventilation, and air conditioning) duct system design.

Cross Flow Heat Exchanger DBT. The PI(s) will update a current piece of teaching equipment in the laboratory (PA Hilton Cross Flow Heat Exchanger Apparatus). The device is well suited for the DBT adaptation as it has a removable test section, in which the students can place their heat exchanger (HE) sections. The apparatus is equipped with a blower system to draw room air through the HE section as various air speeds. Pressure drop can be measured as well as air speed through the section. The advantage of using room air is simplicity, however, the negative aspect of the apparatus is that it is not configured for a second fluid loop. The PI(s) intend to add a temperature controlled hot water system to the apparatus and additional instrumentation to facilitate DBT projects. The fluid loop can be accomplished through either a recirculating temperature controlled bath, or a tank-less water heater and pump assembly. Both systems are commercially available. The water will be heated to 80-85 °C and cooled by the air drawn through the HE sections built by the students. Additional instrumentation is necessary so that the water flow rate and temperature into and out of the HE section is monitored. This can be accomplished with commercially available thermocouples and flow meters. A small assortment of instrumentation components will be needed to convert the signals from the sensors to usable output. This will be accomplished by several means, and a detailed trade study needs to be accomplished prior to final selection. While digital computer based acquisition is preferred, in many cases, these systems are not user-friendly to students, and they are not always amenable to rapid change out of projects. Manual bench systems such as dedicated digital readouts, and ten channel thermocouple units provide flexibility and adaptability as well. In any event, instrumentation needs to be "turnkey" for DBT projects, allowing for rapid change-out of student projects, sustainable operation without the need for software licenses, and with negligible learning curves. Figure 1 illustrates a schematic of the common test facility with a student-built prototype.

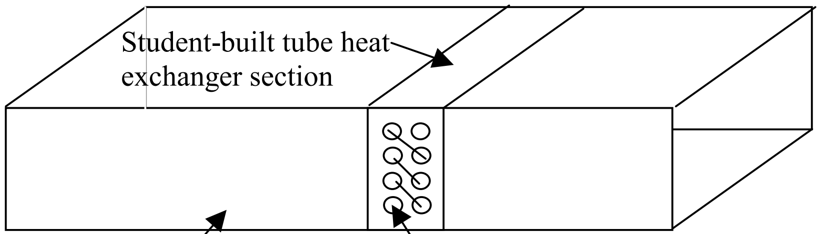


Figure 1 Schematic of the cross-flow heat exchanger testing facility (DBT Module #1)

The most important part of the DBT approach is to facilitate the ability of the students to actually model and build prototype systems for the test phase. The cross-flow heat exchanger is essentially a duct through which one fluid (e.g. cold air) flows. Across the duct are placed an array of tubes carrying the second fluid in the system (e.g. hot water), which are oriented perpendicular to the flow of the first fluid, i.e. the tubes are in said to be cross-flow. The engineering problem is maximizing the performance of the system, which is done through several parameters, the relationship of which is not trivial, nor fully understood. The configuration is well suited to student projects as it only required students to configure a group of tubes across the test section, connecting the tubes together to form a closed fluid path. However, the permutations of this simple configuration are numerous allowing for students to exercise creativity as well as engineering intuition. More advanced designs can be accomplished by adding thin fins to the tubes creating an assembly similar to those used in air conditioning systems and automotive radiators.

To facilitate student fabrication, some constraints need to be imposed: the tubing will be commercially available copper tube, the test section will be formed using transparent acrylics (e.g. Plexiglas or Lexan), and silicon tubing will be used to connect the tubes together. Alternatively, more motivated students can use available copper fittings and solder their systems together. Two part epoxies will be used for fastening and holding components together. Students will need access to basic shop tools and equipment in the teaching laboratory in close proximity to the testing apparatus. As well as to have a small inventory of raw materials. Additionally, precut pieces of materials should be made available (particularly the walls of the test section). Commercially available components are available as well (Heatcraft, Inc.) In any event, the laboratory will need to be equipped with a drill press and a band saw (table top is sufficient, home shop quality) soldering equipment and raw materials.

Student design will be facilitated by commercially available software specifically for designing heat exchangers of this configuration (one example is EVAP-COND developed by NIST). The software is designed for the industrial community so the learning curves are minimal. Students can use the software to make preliminary estimates of system performance and to rapidly do iterative design activities to improve their designs. Iterative design is a key component to developing intuitive engineering knowledge, and serves to strengthen the understanding of fundamental principles. Yet it is one of the least used learning activities in engineering education, mainly because of the pressure to cover a lot of materials superficially rather than to cover one thing in depth and to completion. The DBT activity provides the students with an opportunity to focus on a single problem from concept to reality.

After the design is finalized based on engineering analysis, a prototype is made. A team of two to three students can be formed to build and test their design. The energy balance is calculated from the test results, which include inlet and outlet temperatures and flow rate (determined from the velocity measurements) of two fluids.

Scaled Conditioned-Air Duct System in Building DBT. The PI(s) will develop a common facility that allows students to build and test their design of a scaled air distribution duct system in a building model. The common facility consists of an air supply from a compressed air line available in the lab, and a 6x6x6 ft freezer box that cools the compressed air to the desired temperature (see Fig. 2). A mixing box (not shown) is also constructed to allow fine-tuning of supply temperature and flow rate of conditioned air. Students are required to build a scaled air distribution (duct) system to supply conditioned air to a model building. The types of building for the projects will be limited to a simple high ceiling warehouse, or one story office building with one cooling zone. An existing collaboration with FIU School of Architecture will allow for scale models to be fabricated easily. The material for both the building and ducts is Plexiglas, which permits easy flow visualization. Also, the model building can be easily assembled and dissembled.

A team of three to five students is formed first to conduct cooling load calculation based on the assigned R-values and a 10 ^{o}C temperature difference between the indoor and outdoor. The load is then scaled to fit the model building. Students make their open-ended decisions on the layout, and sizing of the duct system, and select a supply temperature and flow rate. After a few iterations, they will finalize their design-and-build decision and build their system. The duct system will be installed in the model building and connected to the supply air. Thermocouples and velocimeters will be installed to monitor the temperatures and flow. A dyed smoke test can also be used to test the uniformity of air distribution. The test results include pressure drop, temperatures, flow rate, energy usage and energy balance (cooling load validation). Initially, the humidity will not be monitored; however, students are encouraged to discuss the potential effects of non-uniformity of air/wall temperature on moisture accumulation in building materials.

The *maintenance cost* of the DBT facilities after the project finishes will be absorbed through the departmental lab management fund allocated annually.

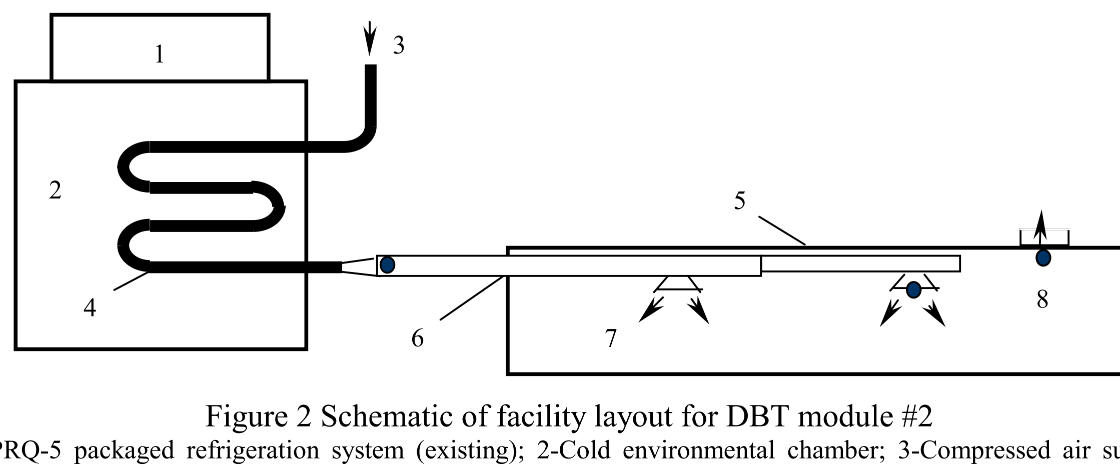


Figure 2 Schematic of facility layout for DBT module #2

1-PRQ-5 packaged refrigeration system (existing); 2-Cold environmental chamber; 3-Compressed air supply (existing); 4-Tube heat exchanger; 5-Building model; 6-Duct system designed and built by students; 7-Diffusers; 8-Typical locations where temperature, pressure and flow sensors will be placed.

Course Integration with DBT Experience

The two DBT lab modules will become available during the offering of the following courses in a semester:

EML 4140 Heat Transfer (3 credit hours) Students are required to register additional one credit hour for *EML 4906L Mechanical Engineering Laboratory* concurrently with EML 4140. The meeting hours for EML 4906 will be flexible. Students are given an orientation for DBT at the beginning of the semester, and the planning and execution of DBT experience will be synchronized with the lectures of *Heat Transfer*.

EML 4706 Design of Thermal and Fluid Systems (3 credit hours) DBT#2 will be an integrated part of this course. The instructor of the course will work closely with the lab technician on scheduling the lab hours so that the DBT activities will follow a similar structure to EML 4140, as shown in Table 2. Emphasis is placed on flow rate, pumping power and energy balance requirements. The thermal comfort and moisture requirements need not be addressed.

EML 4603 Air Conditioning Design (3 credit hours) DBT #2 will be an integrated part of this course. For those students who already taken EML 4706 before taking EML 4603, their project requirement will be adjusted to reflect a new challenge. Such adjustments include a different building model, or multi-zone air distribution. The basic common facility developed will be able to handle such individual project requirements with little modification. The students, on the other hand, will be able to have a variety of options to complete their DBT project. Table 3 outlines the relation between the lecture subjects and DBT experience.

Progress to Date

The NSF project is divided to two tasks that are carried out over a two-year period. The first task is to design and build the lab system. The second task is to apply the DBT modules to the curriculum.

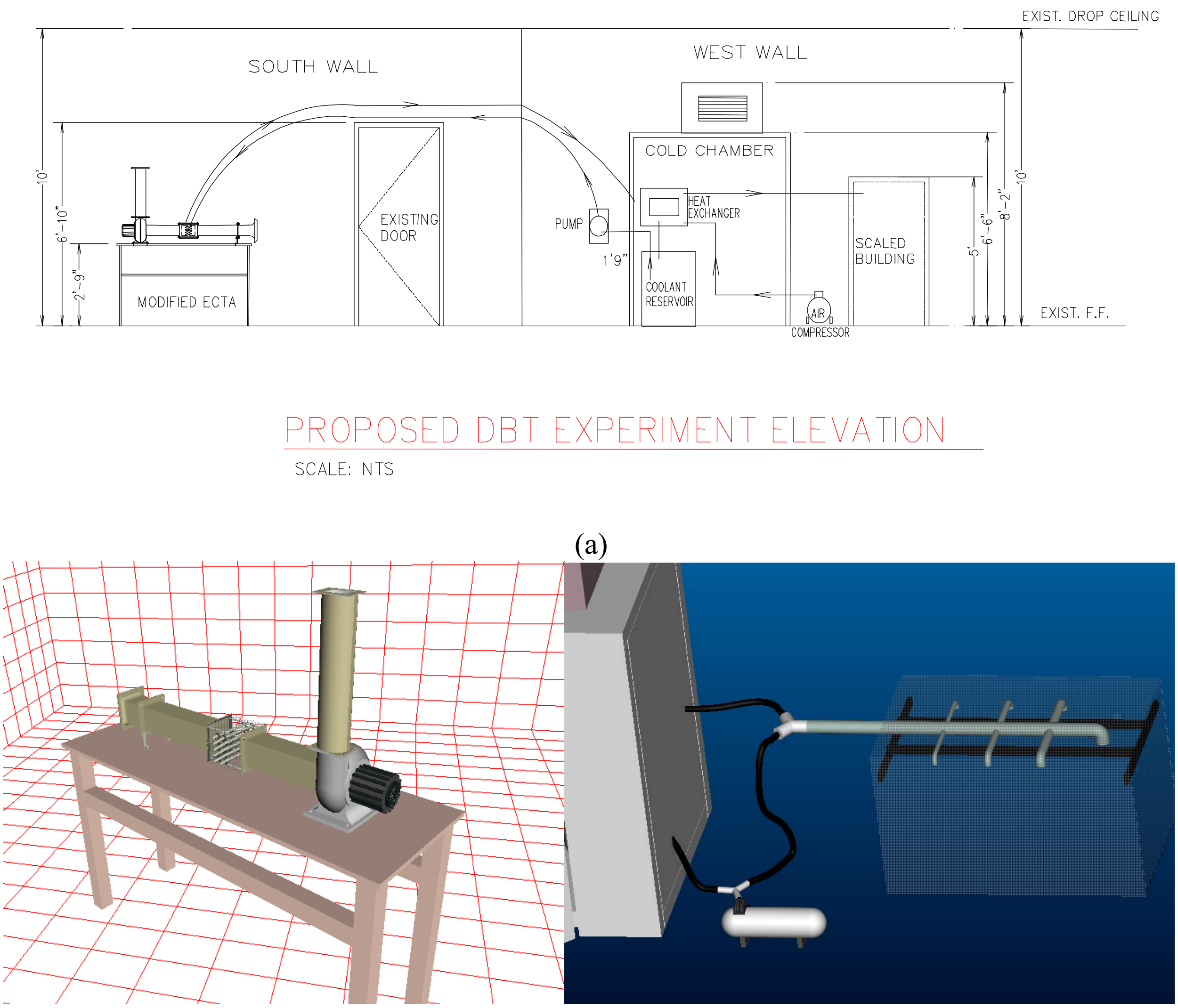
A team of four ME senior students was assigned the task to design the entire laboratory system during the Fall semester, 2004. Figure 4 shows the schematic of the completed design. The involvement of the senior students in the NSF project from the beginning will not only enable the faculty to have direct inputs from the students on the project implementation, but also give those students a unique opportunity to design a system that serves future students design needs, a process of "designing for design". Based on the design the materials and equipment have been or are going to be purchased to start the construction phase of the project.

The senior design process involves the following steps:

- Concept synthesis including literature review, concept generation, concept reduction;
- Detailed design including the following components design: Cold chamber, duct system testing facility, cross flow heat exchanger and DBT experiments floor layout
- Bill of materials
- Engineering analysis including both mechanical engineering analysis and failure mode analysis

Pre-project Student Surveys

In order to evaluate the outcome of the DBT project, we conducted an initial student survey to gauge the students' attitude towards the concept of DBT projects and effect on the ME education. The survey was conducted near the end of the Fall semester, 2004, and consisted of a total 24 questions, in which the majority of the questions are directly related to various aspects of DBT concept. Table 1 lists the survey questions. Students from four classes in the area of Thermal/Fluid areas were asked to response to the questions by selecting various answers. Questions 1 to 7 calls for specific answers. For Question 7, the following choices were given:



(b) (c)

Figure 4 Presentation of by student team design for their senior design project: (a) Entire system; (b) Cross Flow Heat Exchanger (CFHE) and (c) Duct System Testing Facility (DSTF)

A. Overwhelmingly engineering science oriented.
B. Mostly engineering science oriented.
C. Balanced between engineering science and design.
D. Mostly design oriented.
E. Overwhelmingly design oriented.

Table 1 Mechanical and Materials Engineering Student Survey - Design, Analysis and Test Components

1	What is your gender?
2	What is your ethic background?
3	How many MME Laboratory Courses have you taken?
4	Have you taken EML 3126 Transport Phenomena?
4	Have you taken EML 4140 Heat Transfer?
5	Have you taken EML 4706 Design of Fluid/Thermal Systems?
6	Have you taken any or plan to take any HVAC courses?
7	Rate the balance of subject matter in the MME curriculum (check the one that you agree with the most).
8	Fluid Mechanics is a more complex subject than Structural Mechanics?
9	Heat Transfer and Thermodynamics are more complex subjects than Structural Mechanics?
10	Students prefer Structural Mechanics over Heat Transfer/Thermodynamics because it is more physical and the phenomena can be envisioned easier?
11	As a student, hands-on learning experiences help me learn complex material and concepts.
12	I prefer learning through hands-on application more than from strictly from textbook and lecture?
13	The MME curriculum does a very good job of integrating design and engineering analysis skills?
14	The MME curriculum does a very good job of developing design skills, methods and practices?
15	I feel that the MME curriculum is a collection of totally independent courses with little opportunity to integrate the knowledge learned in previous courses.
16	Instructors regularly test my knowledge of engineering science through practical, real-world design problems and projects.
17	Laboratory courses should be integrated tightly with core lecture courses (e.g. Transport Lab with Transport Phenomena lecture).
18	MME Laboratory courses are well integrated with lecture material in core courses.
19	Laboratory experiments and demonstrations should be integrated with the core course lectures.
20	My instructors in my core lecture courses regularly use learning aids and demonstrations to support the lecture material.
21	I am given the opportunity to design and test engineering systems?
22	When I am submit design oriented assignments, I have the opportunity to get feedback through design review so I can make improvements.
23	When I submit design oriented projects, I am given the opportunity to evaluate the design through simulation and/or prototyping testing.
24	Open-ended design projects allow me to be more creative in my solutions.
25	Open-ended design projects force me to investigate and explore engineering science material in an independent manner.
26	I get more motivated to learn and practice my engineering skills through project work as opposed to formal examinations.
27	The MME curriculum does a good job of integrating the material in two or three core courses when I do major projects.
28	I enjoy team projects and feel they are effective for developing my engineering skills.
29	Team projects allow lazy and poor students to get the same grade without doing the same level of achievement.
30	I don't like to work on team projects, because it is inconvenient (i.e. impacts my schedule).
31	I don't like to work on team projects, because there are always students who do less work than me and this leads to confrontation.
32	Cheating is a big problem in the MME department.
33	I have first hand knowledge of people who have cheated on exams, homework, and/or projects.
34	With increased use of computer assignments, it will be easier for students to cheat on assignments.
35	Cheating bothers me because students are getting the same grades as me without doing the work.
36	When cheating occurs in non-team assignments, the students who cheat don't appear to gaining much (i.e. in general, they still get poor grades)

For the rest of questions, students were asked to choose from different degrees of agreement:

A. Strongly agree
B. Agree
C. Neutral
D. Disagree
E. Strongly disagree.

Questions 1 to 31 are directly related to the scope of the NSF project, while Questions 32 to 36 were designed to test the students' attitude towards the ethical issues related to the project orientated learning.

The survey was given to students enrolled in the following four classes offered by the department; EML 3126 (Transport Phenomena), EML 3126-L (Transport Phenomena Lab), EML 4706 (Design of Thermal Fluid Systems), and EML 4608-C (Mechanical Systems in Environmental Control). It is intended to be part of a pre-project evaluation and to serve as a benchmark for project implementation evaluation.

The results were analyzed in three groups. The first group was on the overall results obtained after organizing the 74 completed surveys from all four courses. The second one took the results obtained from EML 3126, which was mostly made up of students in their freshman or sophomore year of the program, and compares them to the results from EML 4706, which was made up of students in their junior and senior year. The final group simply reported the results of the final two courses EML 3126-L and EML 4608-C individually. For this paper, only the results selected from the first group are presented for the sake of briefness.

Figure 5 shows a breakdown of the number of students who completed the survey from each course and their composition. It can be seen that the majority of the sample was made up of students from EML 3126-L, followed by EML3126, then EML 4706, and finally EML 4608-C. The majority of the students surveyed were male, and the majority of the students where of Hispanic origin, which was followed in descending order by White and Other, African American and finally Asian.

When asked how many Mechanical and Materials related Lab courses the students have taken the majority of them (52.7%) seem to have taken at least three Labs. 87.8% of the students surveyed have taken EML 3126. The majority of the students surveyed have not taken EML 4140 (Heat Transfer, 73 %), EML 4706 (Design of Thermal Fluid Systems, 71.6%), nor have they taken any HVAC courses (54 %), although a significant 43.2% has taken one of the HVAC related courses.

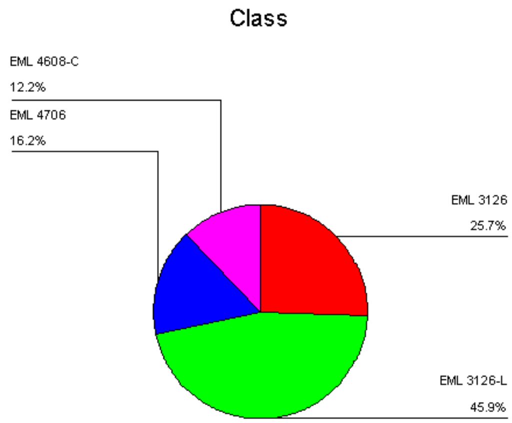
When asked to rate the balance of the subject matter offered in the Mechanical and Materials Engineering curriculum (Question 7) the majority of the students surveyed feel that the subject matter is mostly science and engineering oriented. Only 24.3% felt that it was balanced between the engineering science and design. Figure 6 shows the breakdown of their responses.

Question 8 asked if the students fell that Fluid Mechanics is a more complex subject than Structural Mechanics the majority of the students surveyed agreed that it was with 66.3% agreed or strongly agreed and 29.7% neutral. Only 2.7% disagreed. On the other hand, when asked if Heat Transfer and Thermodynamics was a more complex subject than Structural Mechanics

(Questions 9) the significant percentage (40.5%) of the students surveyed felt neutral, and only 46% agreed or strongly agreed.

Class

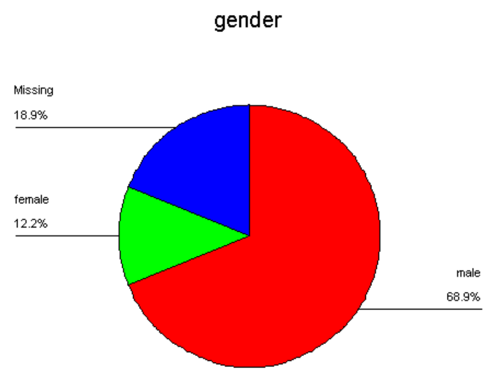
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	EML 3126	19	25.7	25.7	25.7
	EML 3126-L	34	45.9	45.9	71.6
	EML 4706	12	16.2	16.2	87.8
	EML 4608-C	9	12.2	12.2	100.0
	Total	74	100.0	100.0	



(a)

gender

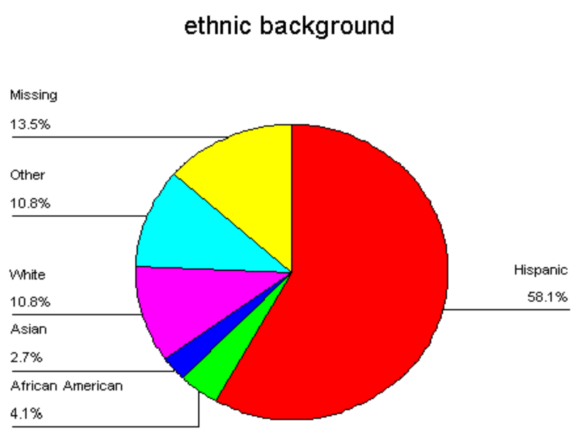
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	51	68.9	85.0	85.0
	female	9	12.2	15.0	100.0
	Total	60	81.1	100.0	
Missing	System	14	18.9		
Total		74	100.0		



(b)

ethnic background

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hispanic	43	58.1	67.2	67.2
	African American	3	4.1	4.7	71.9
	Asian	2	2.7	3.1	75.0
	White	8	10.8	12.5	87.5
	Other	8	10.8	12.5	100.0
	Total	64	86.5	100.0	
Missing	System	10	13.5		
Total		74	100.0		



(c)

Figure 5 Survey class composition

The most important questions related to the DBT concepts are Questions 11 to 31. We select a few significant findings to demonstrate that the DBT concepts are in line of students' needs. The majority of the students surveyed strongly believe that hands-on learning experiences help them learn complex material concepts, and strongly prefer learning through hands-on application rather than strictly through textbooks and lectures. The response breakdowns for Questions 11 to 12 are shown in Figure 7.

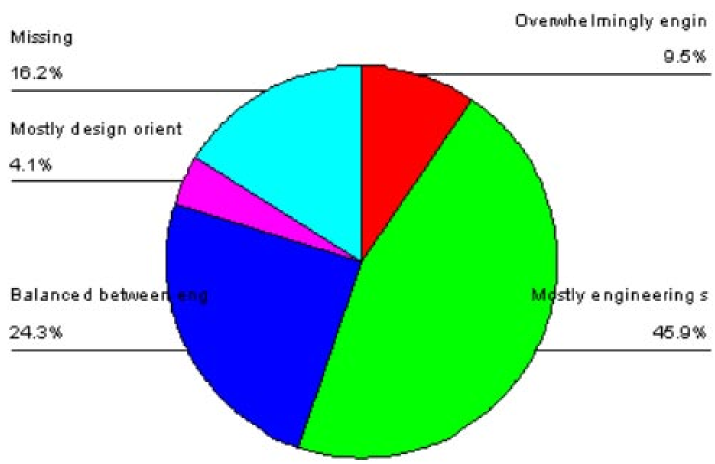
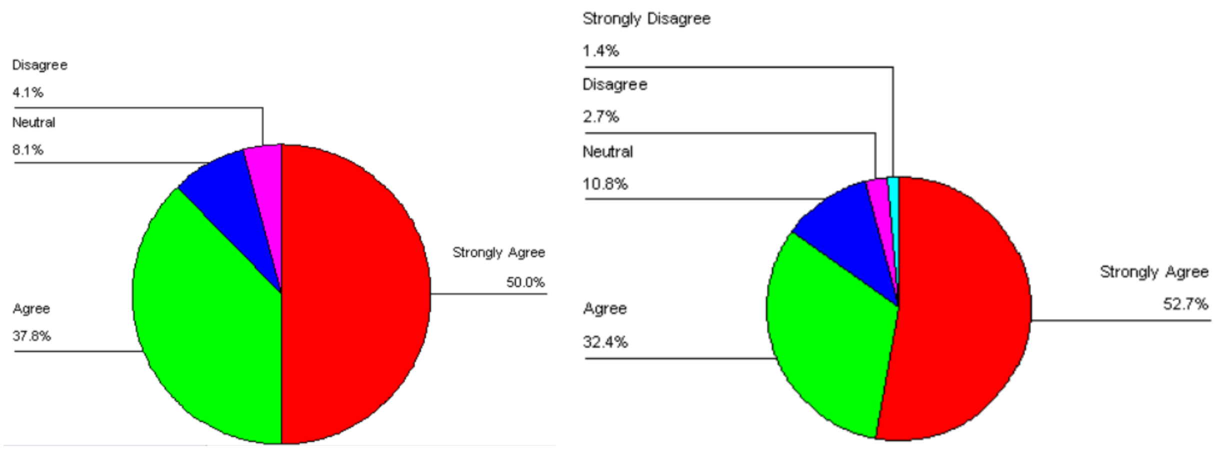


Figure 6 Response to Question 7



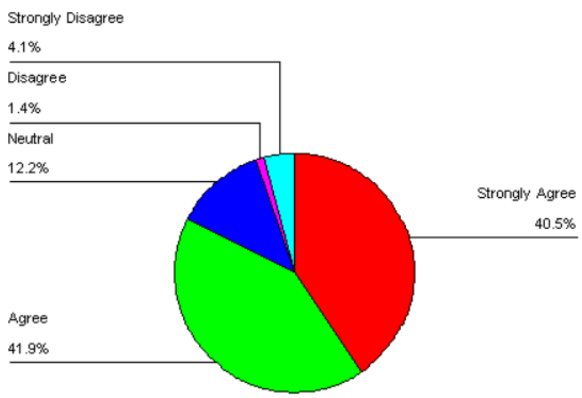
(a) Question 11 (b) Question 12

Figure 7 Responses to Questions 11 and 12

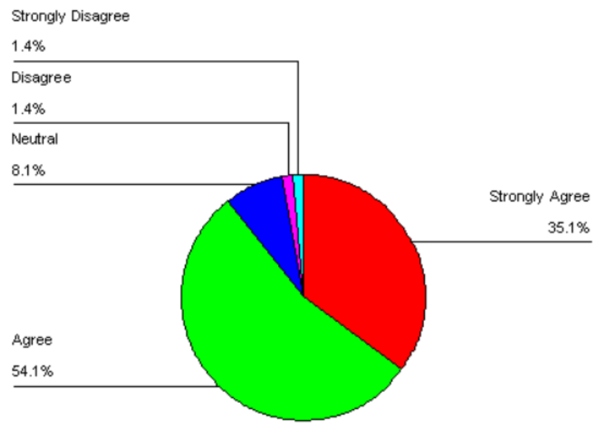
In Question 15 students were asked if they felt that the MME curriculum is a collection of totally independent courses with little opportunity to integrate the knowledge learned in previous courses. The survey showed that this statement is generally true considering 44.6% agree or strongly agreed and 34.8% disagreed or strongly disagreed. A good size of 20.5% felt neutral.

Most of the students surveyed either agree or strongly agree that laboratory courses (Figure 8a) or laboratory experiments and demonstrations (Figure 8b) should be integrated tightly with core lecture courses.

Students did not feel strongly that the current ME curriculum did the good job in those aspects. The responses to Questions 18 and 20 show approximate equal division between neutral and agreed. Further analysis yields that most neutral responses come from the low-level students such as those in EML 3601, while agreed students were seniors in design classes.



(a) Question 17



(b) Question 19

Figure 8 Response to that (a) laboratory courses should be integrated tightly with core lecture courses (e.g. Transport Lab with Transport Phenomena lecture) –Question 17, and (b) Laboratory experiments and demonstrations should be integrated with the core course lectures– Question 19.

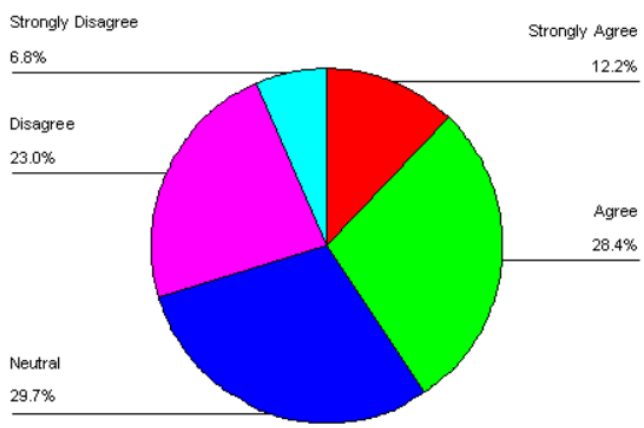
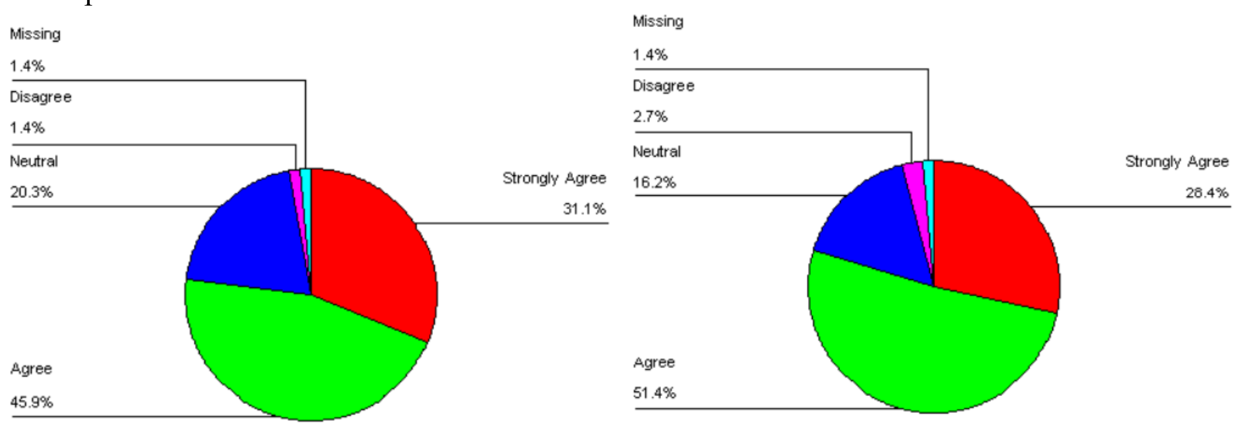


Figure 9 Response to Question 23: When I submit design oriented projects, I am given the opportunity to evaluate the design through simulation and/or prototyping testing.

Most of the students surveyed agreed when asked if they were given the opportunity to design and test engineering systems (Question 21). The majority of the students surveyed also agree that they have the opportunity to get feedback through design reviews after they submit design oriented assignments so that they can make improvements (Question 22). However, the percentage of the students feeling neutral increases when asked if they are given the opportunity to evaluate their designs through simulation and/or prototype testing, as shown in Figure 9. This may also result from the disparity of the junior-level and senior-level students and is an indication that the junior students, although taking some lab courses, did not have a close-loop experience for project improvement.

The majority of the students surveyed agree that open-ended design projects allow them to be more creative in their solutions. They also agree that open-ended projects force them to investigate and explore engineering science material in an independent manner. Figure 10 shows the response results.

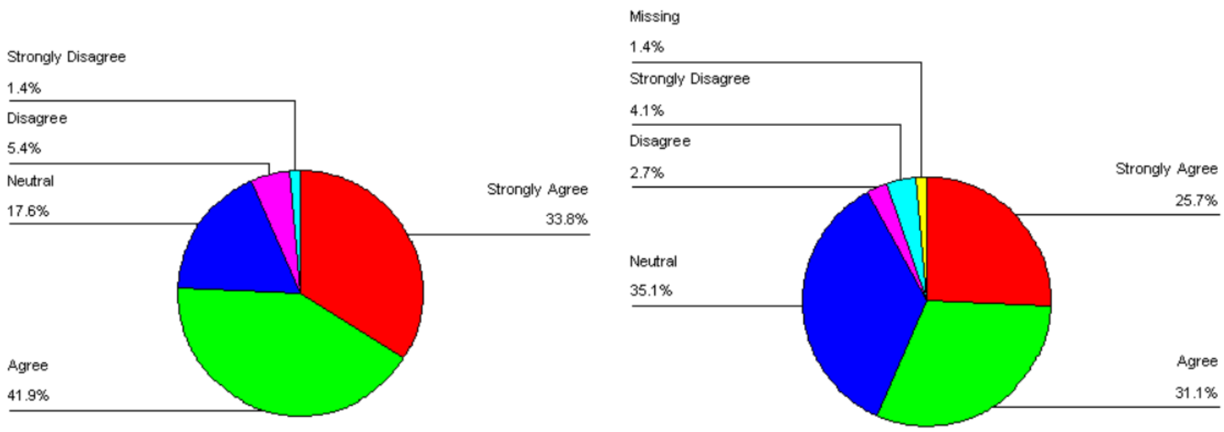


(a) Question 24 (b) Question 25

Figure 10 Responses to Questions 24 and 25

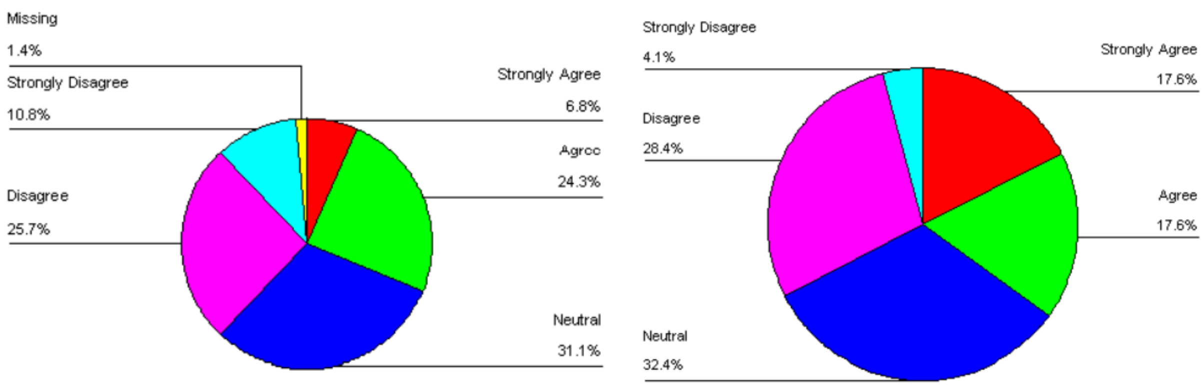
When asked if they get more motivated to learn and practice engineering skills through project work as opposed to formal examinations most students surveyed agree (Figure 11a- Question 26). The majority of the students surveyed either felt neutral or agreed that they enjoy team projects and feel they are effective for developing engineering skills (Figure 11b- Question 28).

The students were divided with a significant percentage of neutral when asked if they disliked team projects because they were inconvenient (Question 30). Similar trend holds when asked if they dislike team projects because there are always students who do less work than them and this leads to confrontation (Question 31. See Figure 12). This again reflects the division in opinions between the junior class, which has less experience in team projects, and senior class, which has more complete training in project-orientated learning.



(a) Question 26 (b) Question 28

Figure 11 Responses to Questions 26 and 28



(a) Question 30 (b) Question 31

Figure 12 Responses to Questions 30 and 31

Summary

This paper outlines the newly-awarded project by NSF with its goals to adapt and implement proven concepts from previous NSF projects and integrate hands-on experiments in traditional thermal science lecture courses in order to reorient traditional teaching laboratory courses with design, build, and test (DBT) activities. Through two DBT course modules to be developed: the heat exchanger and scaled building air-conditioning system, the project reforms the current thermal science stem curriculum with changes to three required lecture courses in such a way that the contents of the stand-alone ME lab course is integrated with the lectures through the execution of DBT activities. We claim that this adaptation enhances students' learning of thermal science subjects by providing students an enhanced, open-ended design problem experience in the mid-stage of the curriculum rather than near the end when the senior design project is required. It supports improved comprehension of the thermal-fluid contents through practical application and immediate, relevant implementation, rather than a fragmented learning process. DBT activities enhance students' critical thinking skills with the decision-making and close-loop accomplishment experience.

The primary outcomes of this project are:

(1) To demonstrate that the DBT approach will better equip students with an ability to apply knowledge of mathematics, science, and engineering to thermal/fluid systems design;
(2) To demonstrate that the students will have a platform available for them to practice teamwork, professional and ethical responsibility, and
(3) To demonstrate that the reformed curriculum will increase ME students interests in the thermal/fluid subjects, which will potentially increase ME student enrolment.

A preliminary survey from both junior and senior mechanical engineering students shows that the Design, Build and Test concepts are in line with mechanical engineering students' needs. Students feel strongly about achieving their education goals through a more integrated and relevant-to-engineering approach. The project will continue towards the completion of the lab system and implementation of DBT modules in the selected classes. More evaluations will be conducted to assess the quality of the project.

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