Session **1566**

Development of a Project-Based and Design-Driven Thermodynamics Course

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Abstract

This paper describes a project-based learning environment for a first course in Thermodynamics. Students are challenged through a strong emphasis on design projects which expand the boundary of their thermodynamics knowledge through the integration of fluid mechanics and heat transfer fundamentals. Design projects range from determining the blower size of an automotive HVAC system, to adept selection of nozzle diameter for a jet engine at a specified speed. These design projects are used as the platform for students to solidify their knowledge of thermal fluid systems. The authors provide their personal journey in developing a project-based and design-driven thermodynamics course that show promise for the design integration throughout the Energy Systems Thread. Formal and informal assessment measures conducted on student achievement of educational outcomes are also presented.

1. INTRODUCTION

Creating a project based learning environment for engineering students has been the subject of investigation at a number of universities. In a recent study by Kettering University Core Engineering Team (CET)[1], a survey of engineering curricula at other universities was carried out. Reviewed universities included all of Kettering's Association of Independent Technological Universities (AITU) peers, Michigan universities with major engineering programs, and universities participating in the Foundation Coalition. This review[2-6] found that many universities, including Kettering, continue to offer relatively traditional core curricula. Non-traditional or innovative programs are in place at a number of universities, but relatively few of these have been implemented for all students. Most remain in an experimental stage and are offered to only a subset of the students and taught only by interested faculty. Moreover, even programs with non-traditional elements retain in one form or another the traditional engineering core topics of differential, integral, and vector calculus, differential equations, physics (mechanics and electromagnetics) and chemistry. Some of the relatively common elements of innovative core curricula that appeared in one or more of CET's proposals were: (a) a common, interdisciplinary *Introduction to Engineering* course; (b) a selection of discipline-specific *Introduction to Engineering* courses offered by the various engineering departments; and (c) integration of engineering applications into core mathematics and science courses.

One area that needs more attention is inciting project-based learning environment into the classroom. Focusing on this issue, recently this instructional approach has been integrated into the thermodynamics course at Kettering University. It is an integrated approach that challenges students to stretch the learning boundary and extends into knowledge and concepts normally dealt with in fluid mechanics and heat transfer. Projects range from determining the blower size of a car HVAC system to selection of nozzle diameter for a jet engine at a specified speed. This paper provides the authors' personal experiences in teaching project-based thermodynamics to Kettering University junior students for six quarters and documents the results showing promise that encourages design integration and project-based learning in the energy systems curriculum. Effects of this teaching method on students' learning are also documented.

2. CURRENT STATUS

At present, Kettering University offers the Energy Systems Thread (EST) that spans over three 4-credit hour courses and one laboratory course. A thread is defined as a sequence of courses with an identifiable set of objectives and outcomes, tying a number of courses to each other and is consistent with the program's educational objectives. The courses belonging to the Energy Systems Thread are thermodynamics, fluid mechanics, heat transfer, and an energy systems laboratory. The EST's educational objectives were formulated to relate closely to the educational objectives and outcomes of the ME program, which in turn are consistent with the university's mission. The relationship between the EST's educational objectives and the ME program were addressed in another paper[7] and will not be repeated here.

Thermodynamics is an integral course of the EST, and therefore the course designer must not only revisit what and how information is conveyed but also what students are learning (really getting out of the course). This task begins with writing proper educational objectives for the course. To construct a set of course educational objectives, the reader is referred to Gronlund[8] and Mager[9]. The Course Learning Objectives (CLO's) for Thermodynamics are as follows:

CLO1. Identify the thermodynamic state of any substance and demonstrate the successful retrieval of thermodynamic properties, given thermodynamic property tables.
CLO2. Identify, formulate, and solve problems in classical thermodynamics.
CLO3. Demonstrate the application of a systematic approach to problem solving.
CLO4. Apply fundamental principles to the analysis of thermodynamic power and refrigeration cycles.
CLO5. Apply fundamental principles to the design of thermodynamic systems.
CLO6. Integrate the use of computer tools in the analysis and performance of thermodynamic systems.

3. PROJECT-BASED, DESIGN-DRIVEN THERMODYNAMICS

Kettering is well known for its successful cooperative education program where each student gains valuable industrial experience while working for an industrial sponsor. The current EST, however useful, is still lacking in providing practical design experience to these students. Addressing this issue, the authors started formulating an educational plan that would integrate undergraduate instructional methodology with applied research, and supplement classroom teaching with real-world design problems. The integration of design and real-life applications into the course material brings a whole new dimension to the students' understanding of the way fluid-thermal systems behave. In addition, this pedagogical framework introduces essence of fluid mechanics and heat transfer into thermodynamics via assigned (suggested) projects.

The Accreditation Board for Engineering and Technology (ABET) directs every engineering program to a set of outcomes that all graduates must have[10]. These set of outcomes (a-k) are as follows:

(a) an ability to apply knowledge of mathematics, science, and engineering;
(b) an ability to design and conduct experiments, as well as to analyze and interpret data;
(c) an ability to design a system, component, or process to meet desired needs;
(d) an ability to function on multi-disciplinary teams;
(e) an ability to identify, formulate and solve engineering problems;
(f) an understanding of professional and ethical responsibility;
(g) an ability to communicate effectively;
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context;
(i) a recognition of the need for, and ability to engage in life-long learning;
(j) a knowledge of contemporary issues;
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Table 1 exhibits a correspondence map between the educational (learning) objectives of the project-based, design-integrated Thermodynamics course and ABET's educational outcomes.

Table 1. Learning vs. ABET educational outcomes

Thermodynamics Learning Objectives	**ABET's Outcomes (a – k)**											
		a	B	c	d	e	f	g	h	i	j	k
	CLO1	X	X	X		X						X
	CLO2	X	X	X		X		X		X		X
	CLO3			X		X		X				X
	CLO4	X	X	X		X		X			X	X
	CLO5	X	X	X	X	X	X	X	X	X	X	X
	CLO6					X		X				X

In connection with and elaboration on EC2000's outcomes, the project-based, design-integrated teaching approach fortifies the following five key ABET issues:

(1) Students must have the ability to function in multidisciplinary teams. Development of the project-based Thermodynamics course will enhance students' learning in interdisciplinary (multi-functional) team environment.

(2) Students must have the broad education necessary to understand the impact of engineering solutions in global and societal context. The project-integrated course opens students' horizons to applications of societal and global significance. They can apply their knowledge in designing vehicle HVAC, cooling household computer box, and jet engine nozzle for futuristic high-speed air transportation.

(3) Students must engage in lifelong learning. The design integration of practical and industry related problems into the classroom will certainly pave the way for inspiring students' interest and fostering their creativity in the field of thermal sciences. This will sustain their interest into a lifelong learning process as they encounter concepts of fluid mechanics and heat transfer.

(4) Students must have the ability to apply and extend knowledge of mathematics, science and engineering. The framework will not only enable students to apply their understanding of mathematics into fluid-thermal sciences but extends it to more coupled and complex engineering problems.

(5) Students must gain enhanced ability to identify, formulate and solve engineering problems. The project-based environment will serve as a tool to educate and expose multidisciplinary students to a practical design environment where they will be able to identify simple to increasingly involved engineering problems, and design realistic solutions, promoting greater interaction and interdisciplinary research.

4. BLOOM'S TAXONOMY OF LEARNING[11]

This taxonomy of learning ensures consistency between the teaching approach/focus (how and what professors provide their students) and assessment methods. It features six cognitive levels of increasing difficulty for students. Bloom's taxonomy of learning levels are summarized as follows:

1. *Knowledge: (List, Recite)*
2. *Comprehension (Explain, Paraphrase)*
3. *Application (Calculate, Solve)*
4. *Analysis (Classify, Predict, Model, Derive, Interpret)*
5. *Synthesis (Propose, Create, Design, Improve)*
6. *Evaluation (Judge, Select, Justify, Recommend, Optimize).*

A typical thermodynamics course concentrates, at best, on the first four levels. The design-driven, project-based thermodynamics course engages students in higher order cognitive skills and allows for creativity and technical maturity.

5. SAMPLE PROJECTS AND STUDENTS' WORK

Table 2 illustrates the type of projects that are normally carried out by students. The projects are structured to a certain extent to ensure completion and achieving related deliverables. An outline of a sample project timeframe is as follows:

Week #3: Students select a project and form a team based on interest and submit their "pick" to their instructor.

Week #4: Students present current state of knowledge on the project and identify specific goals (Gantt Chart)
Week #6: Students present a progress report and identify tools needed to accomplish project goals.
Week #8: Students present another progress report and identify additional tools.
Week #11: Student teams submit a written technical report and make technical presentations.
The nature of the projects gives students practice in levels 5 and 6 of Bloom's taxonomy. This requires them to think critically and systemically. It should be noted that these projects target outcomes (a), (b), (c), (d), (e), (g), (h), (i), and (k) to a great degree and outcomes (f) and (j) to a lesser degree.

Table 2. Sample Thermodynamics Projects

Project	Definition
Car HVAC	Design HVAC requirement to keep the inside of a car at a certain temperature. Factors include solar load, convection and conduction. Calculate the total heat generated and the amount of heat to be taken out/added by cooling/heating. Estimate the size of the blower.
DPU Cooling	Design a cooling method for a Data Processing Unit given certain limitations. Convection and radiation will cool the DPU unit. Calculate the required convection coefficient for certain acceptable temperature of the unit. Determine the need for natural/forced convection.
Power Plant	Design a power plant for maximum efficiency. Compare its efficiency with standard Rankine cycle. Show for a certain input of energy, how the work produced by the turbine increases with added reheater, and intercooler for a regenerative cycle.
Refrigerator	Find the maximum performance of a refrigerator in a room. Factors affecting the room include radiation, conduction and convection. Calculate the maximum theoretical performance of the fridge. Then find the best refrigeration cycle for maximum performance.
Jet Propulsion	For operation at steady state, determine the necessary design requirements for maximizing the air jet at the nozzle exit. Minimum acceptable speed of the airplane is 600 mph.

It may be worth featuring some sample students work in dealing with these projects. The following Figures 1a-b is a subsection of students' report on a jet propulsion design project. The objective is to create a program (Combustor Fuel Consumption Estimator) that, for given design specifications of an airplane jet engine, and the speed and altitude desired for operation, determines fuel consumption.

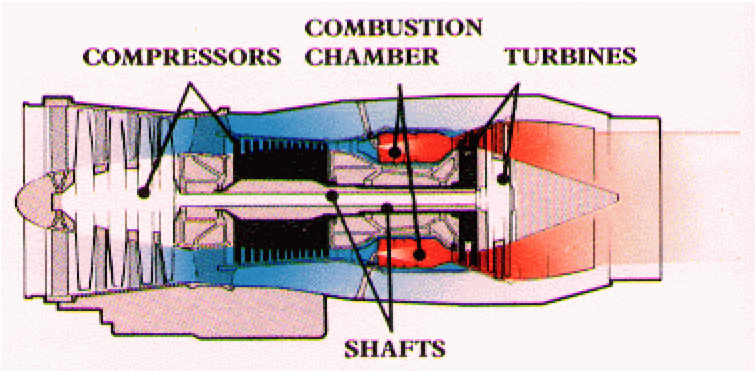

Figure 1a. Schematic of Jet Engine.

Jet Engine Fuel Consumption Tool

Please Enter Conditions:		
Altitude(m)	**Desired Speed(m/s)**	**Drag Coefficient**
10000	285	0.5
Reference Area(m^2)	**Inlet Diameter(m)**	**Number of Engines**
10.4	3	4
Total Fuel Consumption(L/Hr)		**Fuel Consumption Per Engine(L/Hr)**
6812.1		1703.0

Atmospheric Conditions		
Temp(K)	**Press(Kpa)**	**Density(kg/m^3)**
230.4	26.7	0.4

Total Thrust Needed(N)	Thrust Needed Per Engine(N)
71881.8	17970.5

Stages Of Jet Engine			
@Diffuser Inlet(Atmospheric Conditions)			
h_0	P_{r0}	P_0	T_0
221.9	0.5	26.7	230.4

@ Compressor Inlet			
h_1	P_{r1}	P_1	T_1
256.5	0.9	51.6	284.9

@ Combustor Inlet			
h_2	P_{r2}	P_2	T_2
531.5	10.4	569.9	525.7

@ Turbine Inlet			
h_3	P_{r3}	P_3	T_3
576.6	14.6	569.9	562.6

@ Nozzle Inlet			
h_4	P_{r4}	P_4	T_4
301.5	1.7	66.0	324.4

@ Nozzle Outlet			
h_5	P_{r5}	P_5	T_5
252.3	0.7	26.7	281.3

Nozzle Exit Velocity(m/s)
287.2

Figure 1b. Sample section from student project report.

6. EVALUATION

The significance of the developed thermodynamics framework for design-integrated classroom environment is being constantly evaluated using questionnaires to develop alternative requirements and continuously improve. There are a number of guides and sources in the literature for carrying out such assessment activities in the classroom [12-14]. The evaluation steps for this course are as follows:

(1) Run a student survey that shows how broadening the thermodynamics course has increased students' knowledge and appreciation of the subject.
(2) Evaluate essays from students explaining their perception about the redesigned course.
(3) Assess projects that extend beyond the boundary of a first course in thermodynamics to fluid mechanics and heat transfer concepts.
(4) Utilize an assessment committee to evaluate the contribution of the redesigned course in meeting program outcomes.

Students value the project-based, design-driven atmosphere as documented via their comments as follows:

- "During the development of the software for the (Jet Engine) project, we were able to see general relationships between the different input variables and the output velocity of the jet engine…We were also able to see a non-linear relation between the heat input from the combustor (fuel) and the final velocity (thrust)."
- "This project (DPU cooling) was a very informative and useful one. While we were working on this project, we gained a deeper understanding of the concepts of conduction, convection and radiation. We began to see how they, as well as space and cost constraints, come into play when engineers are designing products. … Overall, this project was one of the best things to prepare us for the workplace that we have encountered and we are that much better of having done it."
- "The design project of a HVAC system gave us an experience to relate Thermodynamics to everyday life. While working on the project, our group learned a lot more about Thermodynamics than we would have by sitting in lectures."
- "Quite possibly the greatest thing we learned was how to research information on equations and constraints to compute the values and design parameters of the given problem or query.

Before this project we had not looked into the practical and everyday applications of Thermodynamics."

- "We found this project to be very beneficial to the application of the knowledge gained in the class to an actual use of the information. This project facilitated cooperation and teamwork in order to complete the task to the standards."
- "Everyone in our group agreed that this design project (Power plant) was a great learning experience. We learned how to approach a broad thermodynamic design problem as opposed to more narrow homework problems. The entire group gained a new understanding of how gas turbine power plants work and how to improve their efficiency. … This application of the thermodynamic knowledge to a real world design gave us a lot of confidence that we have a good grasp of the fundamentals of thermodynamics."

This instructional approach, design-driven and project-based, although featured here for Thermodynamics, it can be applied to any engineering course adding relevance and excitement to the course. Indeed, it was carried out on Fluid Mechanics and Heat Transfer. Typical Fluid Mechanics and Heat Transfer courses place a strong emphasis on applying the laws of physics and nature (EC2000's outcome a) and formulate and solve fluid mechanics/heat transfer problems (EC2000's outcome e). Students participated in an outcomes-based end-of-course survey rating the contribution of the course in helping them achieve outcomes (a) through (k). Students were asked to choose among five choices for each of the outcomes. The five choices were: High Contribution, Above Average, Average, Below Average, and Not Applicable. Twenty five students in the course Fluid Mechanics took the survey while twenty of them took it in Heat Transfer. The survey results (Figures 2a & 2b) are displayed in terms of an overall rating level for each of the outcomes.

The overall rating level, shown as the ordinate of the figures 2a and 2b, was obtained via:
Overall Rating Level = (4 * # of responses for high + 3 * # of responses for above avg + 2 * # of responses for avg + 1 * # of responses for below avg + 0 * # of responses for NA) / Total # of responses.

The results show that students perceive meeting more outcomes (than just (a) and (e)) and they believe that the new teaching/learning approach addressed to an appreciable level other important outcomes. It should be noted that the results presented here are perception-based and not an assurance that student indeed achieved these outcomes to the indicated levels. In other words, this survey is not a diagnostic-type survey and other assessment methods should be used to verify students' achievement of the educational outcomes. In fact, students' work (projects) were examined carefully for their treatment of every outcome and tend to validate the indicated levels by the students.

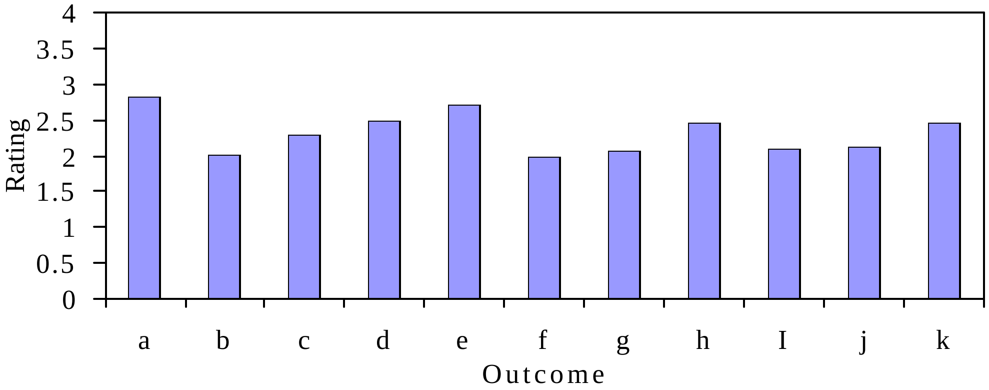

Figure 2a. Students' Overall Rating Level of Outcomes Achievement in Fluid Mechanics.

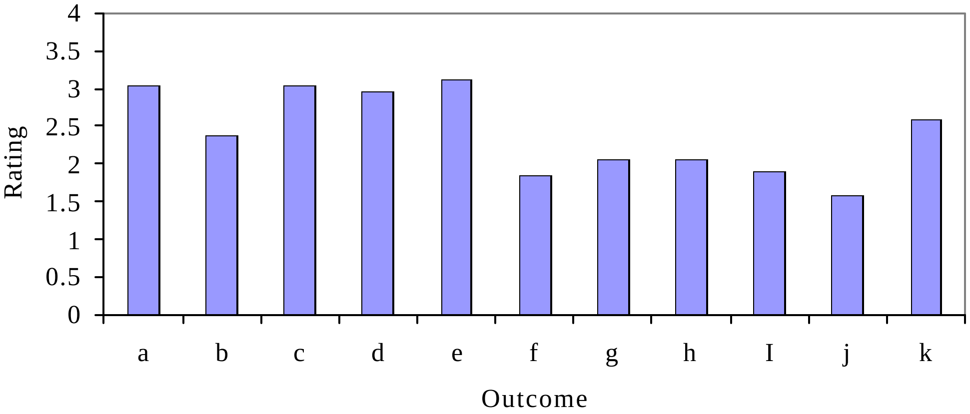

Figure 2b. Students' Overall Rating Level of Outcomes Achievement in Heat Transfer.

7. CONCLUDING REMARKS

A project-based learning environment through the integration of fluid mechanics and heat transfer fundamentals is successfully applied in a first course of Thermodynamics at Kettering University. Design projects range from determining the blower size of an automotive HVAC system, to adept selection of nozzle diameter for a jet engine at a specified speed. These design projects are used as the platform for students to solidify their knowledge of thermal fluid systems. Students input document the success of this approach emphasizing that design-project-integrated learning expands the boundary of their thermodynamics knowledge. An outcomes-based survey on student achievement of educational outcomes also shows promise for the use of projects and design integration throughout the Energy Systems Thread.

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SUBRATA ROY

Dr. Roy is an assistant professor at Kettering University. His area of expertise is computational fluid dynamics and heat transfer. His current activities involve teaching Thermodynamics, Fluid Mechanics, Heat Transfer, and Finite Element Methods; developing new courses, and performing collaborative research with NASA and US Air Force. Prior to joining the faculty at Kettering, Dr. Roy worked for 5 years in aerospace and heavy industry.

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K. J. BERRY

Dr. Berry is Professor and Department Head of Mechanical Engineering at Kettering University. His area of expertise is Finite Element Methods applied to modeling and analysis of thermal fluid systems. He is very active relative to innovative curriculum development for the integration of computational tools to stimulate student's life-long learning, to expand student's breadth of subject matter knowledge, and to enhance student's understanding.

Project-based learning is an instructional approach designed to give students the opportunity to develop knowledge and skills through engaging projects set around challenges and problems they may face in the real world. Project-based learning, or PBL, is more than just projects. As the Buck Institute for Education (BIE) explains, with PBL students "investigate and respond to an authentic, engaging, and complex problem, or challenge" with deep and sustained attention. Thermodynamics deals with the transfer of energy from one place to another and from one form to another. The key concept is that heat is a form of energy corresponding to a definite amount of mechanical work.Â The laws of thermodynamics describe how the energy in a system changes and whether the system can perform useful work on its surroundings. Is thermodynamics physics? Yes, thermodynamics is a branch of physics that studies how energy changes in a system. The key insight of thermodynamics is that heat is a form of energy that corresponds to mechanical work (that is, exerting a force on an object over a distance). Where only a single-semester course in chemical engineering thermodynamics is provided, these chapters may represent sufficient content. The book is comprehensive enough to make it a useful reference both in graduate courses and for professional practice. However, length considerations have required a prudent selectiv- ity. Thus, we do not include certain topics that are worthy of attention but are of a specialized nature.