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

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Abstract

This paper describes a Problem Based Learning (PBL) environment for a first course in Thermodynamics. Students are challenged through a strong emphasis on design projects that 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 problem-based and design-driven thermodynamics course that show promise for the design integration throughout the Energy Systems Thread. An outcomes-based survey conducted on student achievement of educational outcomes is also presented.

1. Introduction

Creating a problem based learning environment for all 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. Universities reviewed 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. By reviewing Web pages maintained by those institutions and reviewing a number of the published papers [2–6], the review 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 problem based learning (PBL) environment into the classroom. Focusing on this issue, recently PBL has been integrated into the thermodynamics course at Kettering University. This integrated approach 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. The paper provides the author's personal experience in teaching problem based curriculum to Kettering University junior students for six quarters and documents the results showing promise that encourages design integration and problem-based learning in the energy systems curriculum. An outcomes-based survey conducted on student learning is also discussed.

2. Current Status

At present, Kettering University has 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, and heat transfer along with an energy systems laboratory. 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). The mission of the Energy Systems Thread is to provide undergraduate mechanical engineering students at Kettering University the knowledge and the tools required for the analysis of energy related problems and the design of energy conversion devices and machines. Having identified the mission of the thread, one needs to write related educational objectives. The following are the educational objectives of the EST:

EST1. apply the fundamental principles of thermodynamics, fluid mechanics and heat transfer, combined with other engineering, mathematics and science principles, to accurately predict the behavior of energy systems and properly design required energy systems.
EST2. identify, analyze, and experiment with energy systems through *integrated* hands-on laboratory experiences in thermal sciences
EST3. utilize modern numerical and experimental techniques for the analysis and design of energy systems.
EST4. develop a systematic problem solving methodology and needed skills to address open-ended design issues, function in teams properly, and report technical information effectively.

It is important to realize that EST's educational objectives must relate closely to the educational objectives and outcomes of the ME program. The Program Educational Objectives (PEO) of the ME program at Kettering University state that the program produces graduates who:

PEO1. are knowledgeable in the management and use of modern problem solving and design methodologies.
PEO2. understand the implications of design decisions in the global engineering marketplace.

PEO3. are able to formulate and analyze problems, think creatively, communicate effectively, synthesize information, and work collaboratively.
PEO4. have an appreciation and an enthusiasm for life-long learning.
PEO5. actively engage in the science of improvement through quality driven processes.
PEO6. practice in the field of Mechanical Engineering professionally and ethically.
PEO7. are prepared for positions of leadership in business and in industry.

Table 1, from [7], exhibits this relationship and points out where the thread is matching the educational objectives of the ME program and where possible improvements can be made. It is anticipated that other threads within the Mechanical Engineering program would balance the Energy Systems Thread to fully meet the program educational objectives.

Table 1. Energy Systems Thread Objectives (EST's) vs. M.E. Program Educational Objectives (PEO's)

	ME Program Educational Objectives (PEO's)							
Energy Systems Thread Objectives (EST's)		PEO1	PEO2	PEO3	PEO4	PEO5	PEO6	PEO7
	EST1	X		X		X	X	
	EST2	X		X	X	X		
	EST3	X	X	X	X	X		
	EST4	X	X	X		X		

3. Project-Based, Design-Driven Thermodynamics

Kettering is well known for its successful cooperative 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.

In [8], Accreditation Board for Engineering and Technology (ABET) directs the program Engineering Criteria 2000 to a set of outcomes that all the graduates must have. 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 2 exhibits a correspondence map between the educational objectives of the design-integrated Thermodynamics course and ABET's educational outcomes.

Table 2. Design-integrated Thermodynamics educational objectives and ABET's 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	X		X	X		X	X
	CLO4	X	X	X	X	X		X	X		X	X
	CLO5	X	X	X	X	X	X	X	X	X	X	X
	CLO6	X				X	X	X	X	X	X	X

In the above table, the course learning objectives (CLO) 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 development 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.

The cells labeled with "X" are considered as new contribution of the redesigned Thermodynamics course. The design integrated teaching approach addresses the following five key ABET issues:

(1) Students must have the ability to function in multidisciplinary teams. Development of the problem-based Thermodynamics course will enhance students' learning in interdisciplinary (multi-functional) team environment.
(2) Students must have 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 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 curriculum 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 [15]

This taxonomy of learning ensures consistency between the teaching approach/focus (how and what professors provide their students) and assessment methods and features six levels of increasing difficulty for students. A traditional thermodynamics course concentrates on the first three levels. The design-driven, problem-based thermodynamics course engages students in higher order cognitive skills and allows for creativity and technical maturity. Bloom's taxonomy of learning levels are 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).*

5. Sample Projects

The following illustrates the type of projects that are normally carried out by students and their corresponding outcomes and Bloom's taxonomy levels.

Table 3. Thermodynamics Projects and corresponding outcomes and B.T. Levels

Project	Definition	Targeted Outcomes	B.T. Level
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.	a, b, c, d, e, g, i, k	5, 6
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	a, b, c, d, e, g, i, k	5, 6

	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.	a, b, c, d, e, g, i, k	5, 6
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.	a, b, c, d, e, g, i, k	5, 6
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.	a, b, c, d, e, g, i, k	5, 6

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 to design a set of courses meeting those requirements. The evaluation steps are as followed.

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

The results of these evaluations are constantly utilized to improve the course development. The end of the course survey is tailored to capture correspondence of what was done in class to targets set by the instructor on the various outcomes. The "Outcomes-Based Assessment Survey" covers ABET's (a-k) and additional program specific outcomes. This course survey is not a diagnostic-type survey but rather a "perception clarifier," shedding light on whether on not students and the course coordinator have the same "faith" in the course's contribution to the achievement of the program educational outcomes.

One hundred students enrolled in the course Thermodynamics (four different sections taught by three different professors) were encouraged to take the "Outcomes-Based Assessment Survey" and seventy three responded to the call. Figure 1 shows students' perceptions of to what level this course contribution in helping them in achieving the nineteen outcomes stated for the program. Also plotted on the same figure, the course coordinator's perception of the expected level of achieving the same outcomes.

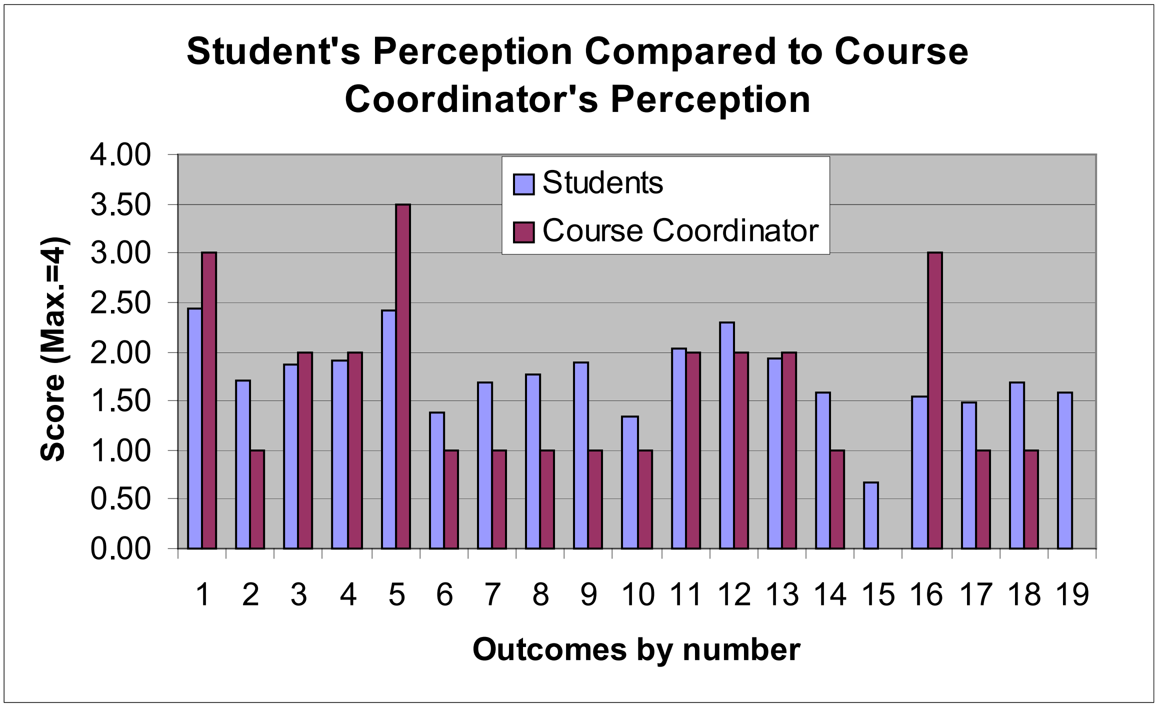

Figure 1. Comparison of students' perception to those of the course coordinator.

4. Improvement Process and Feedback:

Examining Figure 1, one realizes that outcomes 11 (k) and 13 (m) are essentially the same and students indeed responded to them via the same perception. For a course such as Thermodynamics, the major focus is on problem solving and applying the laws of physics and nature. Indeed of the nineteen outcomes (a – s), the course coordinator feels strongly about this course's contribution in meeting outcomes 1 (a) and 5 (e). Students agreed although falling short on the intended level of contribution.

7. Concluding Remarks

NEEDS TO BE COMPLETELY REWRITTEN

Kettering graduates have the reputation for being excellent engineers and have a strong track record of success in business and technical endeavors. Maintaining this status Kettering programs must continue to produce a premium quality student eagerly sought in the mercurial business environment. A new thread called New Energy Systems Thread (NEST) is also proposed for that purpose. The recommended NEST-I project based Thermodynamics curriculum is a key step towards integrating practical design environment into the classroom connecting the science and industry. It is diverse and multidisciplinary. The new educational program objectives and corresponding map in ABET outcomes are also reported. Assessment studies based on these educational objectives is currently under way and will be documented in the near future.

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Need:

(1) References of those who might have tried something similar (design integration in basic engineering courses and real-life PBL applications)
(2) Sample list of statements from students commenting on this approach and their liking for the projects and how their skills and knowledge are enhanced as result
(3) Need data to support achievement of outcomes more than the basic ones normally handled in a Thermodynamics course.
(4) Rewrite concluding remarks
(5) Replace Figure 1 with data supporting the enhancements due to the redesigned course.