A Problem-Based Learning Method for Teaching Thermal Systems Design

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1. INTRODUCTION

Most design courses in ABET accredited mechanical engineering programs contain two components - a lecture component and a design component. The lecture is to teach specific concepts and principles and the design is to develop the student's decision making skills based on the application of engineering principles. Faculty members teaching these courses are often confronted with the challenge of integrating these two components to help students learn the subject in the most effective manner. In the past ten years, the authors have tried several methods to achieve such a goal and found that a problem-based learning (PBL) [1] is a very promising method to address the problem. This method is in essence a guided design process which mixes student-centered learning with a structured course syllabus. This paper is to discuss how PBL is used in teaching the Thermal Systems Design course.

Thermal Systems Design is a required 3-credit hour course in our Mechanical Engineering curriculum. The course is for senior students after they have completed Thermodynamics, Fluid Dynamics, Applied Thermodynamics, and Heat Transfer. Two-thirds of the course is designated as engineering design and one-third as engineering science. The class meets four hours per week with two hours for lectures and two hours for discussions. The main objective of the course is to apply basic principles in thermo-fluid area and design methodology to design energy systems.

The lecture component of the course is to teach certain new topics not covered in traditional thermal science courses but important to the design of thermal systems. These topics include piping systems design, heat exchanger design, pumping system design, and modeling of thermal systems. Without this background knowledge, students cannot work effectively on designing thermal systems.

The design component of the course is conducted by student design teams with emphasis on real-life projects. Before the introduction of problem-based-learning method, each team would work on a semester-long project, most of them sponsored by local industries. The themes of these industrial projects were often quite diverse and did not present a common topic to be covered in lectures. The lecture thus became a subject-based learning [2] which is not conducive to long-term retention of knowledge. The problem-based learning, on the other hand, is an effective method to address this issue.

2. PROBLEM-BASED LEARNING IN THERMAL SYSTEMS DESIGN

Problem-based learning is a student-centered learning method in which course materials are organized and taught around a given problem. Since the problem is given at the outset of the course, students are aware of what they need to know in order to solve the problem. After this stage is set, students would be able to conduct a purposeful search of knowledge through lectures and cooperative learning within their own design teams. This creates a favorable atmosphere for active learning. On the other hand, the instructor could also organize lectures relevant to the given problem on a need-to-know basis. In this way the lectures can be characterized as application-oriented as well as a need being delivered in a just-in-time manner. These two aspects help motivate students to become active participants in lectures.
In recent years, PBL has been gaining popularity because of its effectiveness and flexibility. It can be implemented in many ways in accordance to the course requirement and instructor's choice.

There are two common concerns with regards to implementing PBL method [2]. The first is that with the method instructors may not be able to cover the same breadth of content as the subject-based approach. The second is that the method requires small student-to-instructor ratios, a condition difficult to fulfill because of financial constraints. Our experience showed that these concerns can be dealt with by (a) careful selection of projects and instructional formats; and (b) effective use of discussion sessions.

Instead of working on one semester-long project, we adopted a new format which would require students design teams (each team had three to four members) to work on several common projects provided by instructors. This new format not only allowed instructors to carefully tailor the projects to match the lecture subjects with sufficient breadth, but also made the entire class focus on the same problem at the same time. Since the entire class would work on the same problem, instructors can provide close personal guidance to students.

As pointed out by Woods [3], success of the PBL method depends on proper guidance from the instructor. In this course, the main avenue to provide this guidance is through the weekly discussion sessions, which will be discussed later in this paper.

3. IMPLEMENTATION

There were two issues in the implementation, namely, the selection of design projects to ensure breadth, and the management of discussion sessions to encourage active participation from students.

(A) Selection of Design Projects.

In the Fall of 1996, the course was organized around two design problems. They were: (a) the design of a steam condenser, and (b) the design of a diffuser plate for a two-stage centrifugal pump. These two projects were selected for the following reasons: (a) they were closely related to lecture topics; (b) they required the use of a wide scope of technical knowledge to solve them; and (c) they were related to test equipment in our lab facilities so that students could work on them and gain practical experience.

1) Project I - Steam Condenser Project.

The project consists of two aspects: (1) to perform a preliminary design of a steam condenser for an existing steam turbine unit, and (2) to perform a detailed rating analysis of an existing steam condenser.

The study included the following topics:

(i) In the preliminary design, the students were required to determine the cooling capacity of the condenser required by the steam turbine; the selection of a heat exchanger for that purpose; and selection of materials for the construction of the exchanger.

(ii) For the rating analysis, students worked on the existing shell-and-tube heat exchanger which has one-shell pass and four-tube passes. The project involved with working on the following problems:

- Determine the positioning of the condenser - should it be put vertically or horizontally? Of these two positions, which one would yield higher cooling rate?
- Determine the maximum cooling capacity achievable under fouling and without fouling conditions?
- Design the header to ensure uniform distribution of flow among tubes.

- Evaluate the effect of cooling water flow rate on the condensation rate.

- Predict the pressure loss for the two fluids in the condenser.

- Recommend a cooling water flow rate for the lowest operating cost and fouling prevention considerations.

- Design an instrumentation system to monitor and evaluate the performance of the condenser.

- Conduct experiments on the condenser and compare experimental results with theoretical prediction.

Lecture and discussion sessions were organized around the above problems which covered most of the topics related to heat exchanger design given in our textbook [4]. Certain topics in the textbook were reinforced to provide the knowledge needed for the design. These included the condensation heat transfer, fouling analysis, and header design.

Through this project, students learned how to integrate principles from heat transfer, fluid mechanics and thermodynamics to solve real-world problems. Such integration also deepened their understanding of basic principles.

2) Project II - Design of a diffuser for a two-stage centrifugal pump.

This project was to modify the design of a diffuser plate in order to improve the overall performance characteristics of the pump. It included the following two aspects: (1) to study the hydraulic aspect of pumps and the design of pumping and piping systems; and (2) to apply the statistical design of experiments (DOE) method to the design process. These two aspects can be broken down further into the following tasks:

- Investigate the design features of the existing diffuser plate; calculate the contour of the vanes in the diffuser ring and compare with the actual design; and calculate the velocity in the diffuser ring and the return flow passage.

- Construct a cause-and-effect diagram through brainstorming sessions.

- Examine the flow features through conducting experiments on a flow visualization stand to identify factors most relevant to the diffuser performance.

- Generate ideas for modifying the original design; and build models for testing.

- Design an experimental test stand; and prepare an experimental matrix with the DOE technique.

- Obtain experimental data; identify and deduce the response variable from the data.

- Analyze the data with DOE; identify design parameters and interaction between parameters most relevant to the plate performance.

Through the project students thoroughly learned topics such as the internal workings of pumps, interaction between stages, hydraulic characteristics, relation between a pump and piping system characteristics, and flow measurements. They also learned a powerful technique in statistical design of experiments.

A commercial statistical software package was used to conduct DOE studies for identifying critical design factors and finding the optimum solution. Students learned how to use this software with PBL approach with relative ease.

(B) Discussion Session

Discussion session was held weekly. Each session contained four to five design teams. Prior to the discussion, each design team was required to hand in a weekly progress report and a plan for next week. Quality of weekly reports would play an important role in the semester grades. This step would ensure active student participation in the discussion because every one was well prepared. The discussion session usually started with an oral report by one or two design groups, followed by discussion in the open forum.

The discussion usually focused on the following three items:

- checking and validating progress made in the previous week;

- exchanging and exploring ideas;

- making plans for the following week.

Through this process the instructor can evaluate students' approaches and progress, point out errors and inappropriate methodologies, raise questions to encourage critical thinking, and provide personal guidance to all students.

4. CLOSURE

Our method to implement problem-based learning provided a balance between student-centered learning and a structured framework of lectures and instructions. Through this approach, we were able to incorporate teamwork, critical thinking, and real-world applications into the teaching of the Thermal Systems Design course. The approach also made the students become more active and attentive participants in lectures and in discussion sessions. This positive attitude helped them learn the subjects in a more effective manner.

5. REFERENCES

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