INTEGRATING THEORY, DESIGN, AND PRACTICE IN A MECHANICAL ENGINEERING DESIGN COURSE*

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Industry representatives stress that engineering education should prepare students for the real-world problem-solving situations by providing students opportunities to acquire competence in team building, interaction, and inter-disciplinary skills. The ABET Criteria 2000 accreditation requirements for engineering programs show that future curricula will be strongly influenced by these industrial requests. Two recent studies by engineering educators, sponsored by National Science Foundation and National Research Council, emphasize the need to tailor engineering curriculum to meet industry requests. A review of various instructional methodologies to fulfill these industry needs identified the case study method as the most suitable instructional technique to enhance active learning techniques in engineering classrooms. Therefore, an inter-disciplinary team of engineering and management professors developed a series of case studies as part of an innovative curriculum.

INTRODUCTION: GOALS AND EDUCATIONAL OBJECTIVES:

The first goal of this curriculum innovation is to bring theory, design, and practice together. In order to achieve this goal, the learning objectives are that the students must (a) consider technical, financial, credibility, and management issues in making decisions, and (b) work in teams and communicate effectively. The second goal of this curriculum innovation is develop students' higher-level cognitive skills. In order to achieve this goal, the learning objectives are that the students must (a) identify criteria, (b) analyze alternatives, (c) make a choice, (d) defend the choice, and (e) be active learners.

METHODOLOGY:

These goals and objectives were achieved by an instructional methodology that consisted of (a) developing a series of written case studies in conjunction with industry partners, (b) adding competency material on engineering and business topics that students may use as reference, (c) creating multimedia versions of the case studies, (d) administering the case studies in engineering classrooms, and (e) evaluating the effectiveness of the case studies in achieving the goals and objectives.

Developing a Series of Case Studies:

The first case study, *Della Steam Plant,* was developed with the cooperation of an executive in charge of predictive maintenance at the central office of a power plant. Data was gathered through visits at the plant and interviews with engineers. They were integrated together with the technical, financial, people, and risk information in order to create a draft of the case study. After the engineers and managers from the power plant reviewed and revised the case study, it was further improved based upon feedback obtained from conference presentations, classroom discussions, and publication in a refereed journal. The second case study, *Crist Power Plant*, dealt with the cost and risk issues faced by a plant manager when he had to decide between five alternatives in maintaining a turbine-generator unit. Expert system software was used to analyze the decision-making strategies of these engineers. The third case study, *Solid Rocket Booster Field Joint Design* case study, illustrates the ethical, safety, reliability, risk, schedule, and cost factors that were involved in the field design of a Solid Rocket Booster. Students were given an opportunity to develop alternate designs of the field joint and identify the ethical issues that arose as time and cost pressures forced the engineers to choose between the options of adding shims and doing a complete redesign.

Adding Competency Material:

In order that students with little background in the power plant industry could effectively analyze the *Della Steam Plant* and *Crist Power Plant* case studies, competency materials on the topics of vibration analysis, predictive maintenance, decision theory, and power plant economics were developed. Similarly, competency materials on engineering ethics and engineering design were developed for the *Solid Rocket Booster Field Joint Design* case study.

Creating Multimedia Version of the Case Studies:

The final version of the *Della Steam Plant* case study and competency material became the basis of a CD-ROM courseware that integrated videos, photographs, and text. The case study methodology and associated CD-ROM for the *Della Steam Plant* case study was selected as the winner of the 1998 Premier Award for Excellence in Engineering Courseware sponsored by John Wiley and Sons and NEEDS (a NSF coalition). The judges lauded the ability of this courseware to develop higher-level cognitive skills. Two videos were created to support the *Crist Power Plant* case study. A web site and video were developed to support the *Solid Rocket Booster Field Joint Design* case study.

Administering the Case Studies in Engineering Classrooms:

About 180 students in engineering and business programs have participated in analyzing these case studies at Auburn University, Alabama A&M, University of Pittsburgh, and Embry-Riddle University during 1997 to 1999. Based on their positive feedback to the case study administration, we developed a ME 260 (Concepts in Engineering Design) course based fully on the case study methodology. The inter-disciplinary team created a monograph that included instructions on analyzing the case studies, the three case studies, and associated competency materials. The monograph was supplemented by CD-ROMs, videos, and web sites. Student assignments were created for each case study. For example, in the *Della Steam Plant* case study, two groups assumed the roles of the plant engineer and the original equipment manufacturer (OEM) engineer and defended their individual recommendations. Another group assumed the role of the manager and resolved the dilemma faced by him, as he had to choose among the two conflicting recommendations. A fourth group discussed how the problem could have been avoided if the plant chose to implement new technologies. The students worked together to analyze the recommendations, evaluate them against the criteria, and then created presentations that were discussed in the class.

Evaluation of the Effectiveness:

As part of evaluation of the effectiveness of the case study, the students in a ME sophomore level class, Concepts of Engineering Design (ME 260) offered in Fall 1998 were given two separate evaluation forms at the end of each case study discussion. The results in this section represent the reactions of the 23 students to the Della Steam Plant Case Study who used the CD-ROM in their discussion. Evaluation I consisted of 24 bipolar descriptors. In other words, an item on the evaluation form would represent the concept of clarity on a 5-point continuum from unclear to clear, or the case study's relevance on a continuum from irrelevant to relevant. Because the four constructs derived from Evaluation I yielded substantial reliability levels (with anything above .60 considered acceptable), the 24 separate questions within the survey could be meaningfully organized and reported by these four distinct descriptors of the case study. Table 1 shows the medians for responses on the four separate constructs.

Indeed, the medians for all four constructs are well above a rating of 3, indicating that students rated the case study on the positive side of the continuum. In fact, as demonstrated by the two constructs with medians of 4.0, the students found the case study particularly important and valuable as well as relevant and useful--important elements in effective learning.

Evaluation II asked the respondents to indicate the extent of their agreement with 16 evaluatory statements on a 5-point Likert scale. Some sample items include statements such as "I improved my ability to evaluate critically technical and managerial alternatives" or "I learned to design." The response scale progressed from a rating of 1 that represented the least positive or least favorable response of "Strongly Disagree" to a rating of 5 that represented the most positive or favorable response of "Strongly Agree." In addition, Evaluation II ended with three open-ended questions that asked the students to provide written responses concerning the strengths and weaknesses of the Della Steam Plant Case Study as well. Substantial reliabilities for Evaluation II suggested specific constructs, which made an analysis of the data manageable and meaningful. The reliabilities are above the established criteria of .60 for all the constructs. The medians for these five constructs derived from Evaluation II are reported in Table 2. This table illustrates that the reactions of the students to these various aspects of the Della Steam Plant Case Study were favorable. In other words, the Della Steam Plant Case Study appeared to be well received and educationally advantageous to the students.

Table 3 summarizes how the educational objectives have been met based on the quantitative evaluations provided above and on the comments from the students.

Similar evaluations are available for each of the case studies administered in this course. In view of space restrictions, we have limited our discussion to the evaluation of one case study in this paper.

INNOVATIONS: The innovative features of this curriculum are that:

- It enhances student-centered learning since they are actively involved in solving the problem.
- It captures the expertise and experiences of industry participants and an inter-disciplinary academic team thereby enhancing the asynchronous and synchronous learning experiences of the students.
- The use of multi-media technology facilitates non-sequential processing of information by the students thereby closely reflecting their thinking patterns.

STRATEGIES TO USE IN ADMINISTERING CASE STUDIES IN ENGINEERING CLASSROOMS: Based on our experience, we offer the following suggestions as strategies to use in administering case studies in engineering classrooms:

- **Case studies**

1. There are not many technical case studies that could be directly used in engineering classrooms. It is critical that faculty members from the engineering institutions develop technical case studies. Our experience in this area suggests that these case studies will be meaningful if they relate to a problem that actually happened in an industry. Hence, the development of these case studies should be done in partnership with an industry.

2. The quality of these case studies will be enhanced if they are subjected to peer review process in conferences and journals. We suggest that the technical case studies be peer reviewed and tested in classrooms before they become part of engineering curricula.

3. Competency material relating to the needs of the case study be developed and shared with the students

before they are assigned to analyze the case studies. This is different from the traditional case studies developed by business schools. Such a strategy is essential because of the multi-disciplinary nature of the real-world problems that are being addressed in these case studies. It is important to provide background material on the disciplines that have a significant role in the case study.

4. Organizations need to be created that could be the repository of such well-tested case studies both at the regional as well as at the national level. Search schemes need to be implemented so that teachers can retrieve the case studies based on factors such as, disciplines addressed, topics, industry sector, geographical location, ratings, etc.

- **Student**

1. Encourage the students to work in teams. Teaming exercises and guides might help improve group interaction.
2. Provide opportunities for different students to lead the team for different case studies thereby providing opportunity for all students to participate in the discussion.
3. Encourage teams to communicate with each other and the instructor. Tools such as electronic journals, e-mail, and chat rooms are very helpful in achieving this objective.
4. Emphasize that the instructor expect the students to carefully read the technical information in the case studies in order to analyze the problem.

- **Teacher**

1. The teacher's role becomes that of a facilitator and not a leader of the class. This is rather difficult for most teachers, but requires practice before they can leave control of the class to the students. At the same time, the teachers have to be careful to ensure that the students do not steer the class into unrelated topics.
2. The teacher has to encourage the students to perform group work. Reference to research material on group work might be helpful to the teachers.
3. A major issue is that of grading the presentation and write-up. The teacher has to create an evaluation formula that needs to be shared with the students. The clearer the teacher's objectives are to the students, the better the chances are that his/her expectations will be met.
4. It is critical to establish a mechanism to provide feedback to the students about their performance. Evaluation questionnaires similar to the ones we have used would provide valuable information on the utility of case studies in your classrooms. In addition, students could be requested to submit individual e-journals that document their progress on acquiring higher-level cognitive skills throughout the course.

- **Administration**

1. The administration has to be responsive to the use of case studies in the classroom. Since this is a new methodology, traditional accrediting agencies may not look at them favorably. An effective evaluation strategy that incorporates measurement of learning in the classrooms and reporting it to the administrator might be able to relieve the traditional biases against this methodology.
2. Educating the administrators about the value of the case studies in classrooms is essential if such a program has to succeed.

SUMMARY: The evaluation shows that the case study method of instruction appeared to fulfill the primary objectives of this class by combining theory and design with practice as well as encouraging the use of higher-order thinking skills within the students. We are developing a textbook that includes the case studies and the competency materials for use in engineering classrooms. This book published by Prentice Hall Publishers will be available in Fall 2000. The case study method has generated interest from faculty members from University of Pittsburgh and Alabama A&M University who report that student interest on engineering topics increased. We believe that widespread implementation of this innovation has the ability to better prepare engineering students for real-world problem solving situations and retain their interest in engineering subjects.

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Interesting and Exciting	Important and Valuable	Instructionally Helpful	Relevant and Useful
3.4	4.0	3.8	4.0

Table 1: Medians per Construct in Evaluation I

Perceived Skill Development	Self-Reported Learning	Intrinsic Learning and Motivation	Learn from Fellow Students
3.8	4.0	4.0	4.0

Table 2. Medians per Construct in Evaluation II

Educational Objectives	**How Della CD-ROM Achieved these Educational Objectives**
The course material needs to: - *Connect engineering courses to real-world problems* - *Provide excitement of discovery* - *Motivate active learning*	- *Quantitative analysis (significant scores on constructs of interesting and exciting, important and valuable, relevant and useful)* - *Supporting statements from students.* - *Paper on the methodology won the outstanding engineering education paper (Raju and Sankar, 1997, Raju and Sankar, 1996).*
The course material needs to: *- identify criteria to solve problems in unstructured situations* *- analyze alternatives given multiple criteria* *- make a choice and defend the choice persuasively* *- be actively involved in learning situations*	- *Quantitative analysis (significant scores on constructs of perceived skill development, intrinsic learning, self-reported learning, and learn from fellow students).* - *Supporting statements from students.* - *The judges of the 1998 Premier Award commended it for its ability to improve higher-level cognitive skills (Raju and Sankar, 1998, Raju and Sankar, 1999).*

Table 3: Achievement of Educational Objectives by Della Case Study

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