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CONCEPTS

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The Use of Active Learning Strategies in the Instruction of Reactor Physics Concepts

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Historically, the Nuclear Engineering programs in this country have produced high quality graduates who have met the needs of industry, and have attracted a large number of foreign students. Reactor physics and computation have been strengths of the traditional curricula in those programs.

However, a number of factors have motivated change in the traditional curricula of nuclear engineering programs. The downsizing of the domestic nuclear industry and the shift away from tasks associated with power plant design have resulted in a broadening of the curricula of many Nuclear Engineering programs ¹. The reduction in the number of students entering Nuclear Engineering programs has prompted such alternatives as the delivery of curricula to a potentially larger student population through various forms of technology-based, distance education ^{2,3}. New criteria for the accreditation of engineering programs require ongoing evaluation and improvement of the effectiveness with which each program achieves its own objectives ⁴. Such an emphasis on ongoing evaluation and improvement will require corresponding changes in the curricula that support these objectives.

Both Nuclear Engineering curricula and curricula delivery systems will continue to evolve in response to the constituencies that are motivating change. The precise results of these changes are uncertain. However, in general, Nuclear Engineering

programs are likely to become more heterogeneous than in the past, as the programs become more responsive to the needs of particular constituencies.

Instructional strategies need to become more heterogeneous to keep pace with broader curricula and more diverse delivery systems of Nuclear Engineering programs. Most instruction will continue to be conducted by the traditional lecture illustrated on chalkboards, overhead projectors, or by Powerpoint presentations. One advantage of presentation of material by lecture is efficiency. Lectures can cover relatively large amounts of material in short periods of time ⁵. However, some instructional objectives are more effectively achieved and some instructional delivery systems are more effective if instructional strategies are used that further promote the active mental processing of new concepts and skills. These active learning strategies aid the learning process by engaging the student in some activity that requires creative mental processing of the new curricular material during or shortly after its presentation ⁶. Such alternative instructional strategies need to be explored to determine the strategies that will provide the most effective and efficient instruction as program objectives and delivery systems evolve.

In this paper, three active learning strategies are discussed that are being used in courses on Reactor Theory and Reactor Design taught at the Bettis Atomic Power Laboratory. The strategies, Cooperative Group learning, Tutorial Computer-Based instruction, and Case-Based learning, are described in the context of their applications in the courses. The results of the use of these strategies are summarized, followed by conclusions.

Cooperative Group Strategy

A Cooperative Group instructional strategy is being used to teach an introductory unit on neutron transport and diffusion theory that was formerly presented in a traditional lecture/discussion style. Students are divided into groups of two or three for the duration of the unit. Class meetings are divided into traditional lecture/discussion segments punctuated by cooperative group exercises. The group exercises were designed to require the students to elaborate, summarize, or practice the material presented in the lecture/discussion segments. Group collaboration on homework assignments and in studying for the unit exam is encouraged.

The conceptual basis for Cooperative Group strategies is that students learn more effectively by cooperating with each other than by competing or by working individually⁷. This has been found to be particularly true in learning complex tasks related to science and technology.

The structure of the classes was modified extensively with the adoption of the Cooperative Group strategy. The transport and diffusion unit previously consisted of seven classes that were each two hours in length. An eighth class was added to accommodate the cooperative exercises. The classes were divided into lecture/discussion segments and cooperative group exercise. The initial introductory lecture/discussion segment in the unit is approximately 1.5 hours in length. However, all subsequent lecture/discussion segments are shorter, lasting an average of approximately 30 to 40 minutes. The lecture/discussion segments were separated by ten Cooperative Group problem solving exercises during the course of the unit. During

these exercises the instructor observed the groups, and guided their problem solving processes by offering hints and assessments of progress.

The Cooperative Group problem solving exercises ranged from 20 to 50 minutes in length, with an average length of approximately 30 minutes. These exercises were designed to require the student to elaborate upon, summarize, or practice the material presented in the lecture/discussion segments. For instance, in an exercise intended to elaborate on a qualitative presentation of the Boltzmann Transport equation for neutrons, students were asked to develop the precise functional forms for the terms in the equation. The students were first given five minutes to consider the problem individually. The students were then given approximately 25 minutes to develop a cooperative group solution. At the end of the period, a single student was chosen randomly to present the solution developed by his or her group. This pattern of individual reflection and cooperative group problem solving followed by random student presentations was followed in the cooperative exercises throughout the unit.

Cooperative group activity was also encouraged outside the classroom. Specifically, groups were encouraged to collaborate in studying for examinations and in completing homework assignments. Students were given the option of either submitting a single set of solutions for the group, or submitting sets of homework solutions prepared by individuals. However, if the group chose to submit solutions as individuals, one of the submittals was randomly chosen for the purpose of assigning the group a grade for the assignment. (All homework solutions submitted by the students were critiqued by the instructor and returned to the students.)

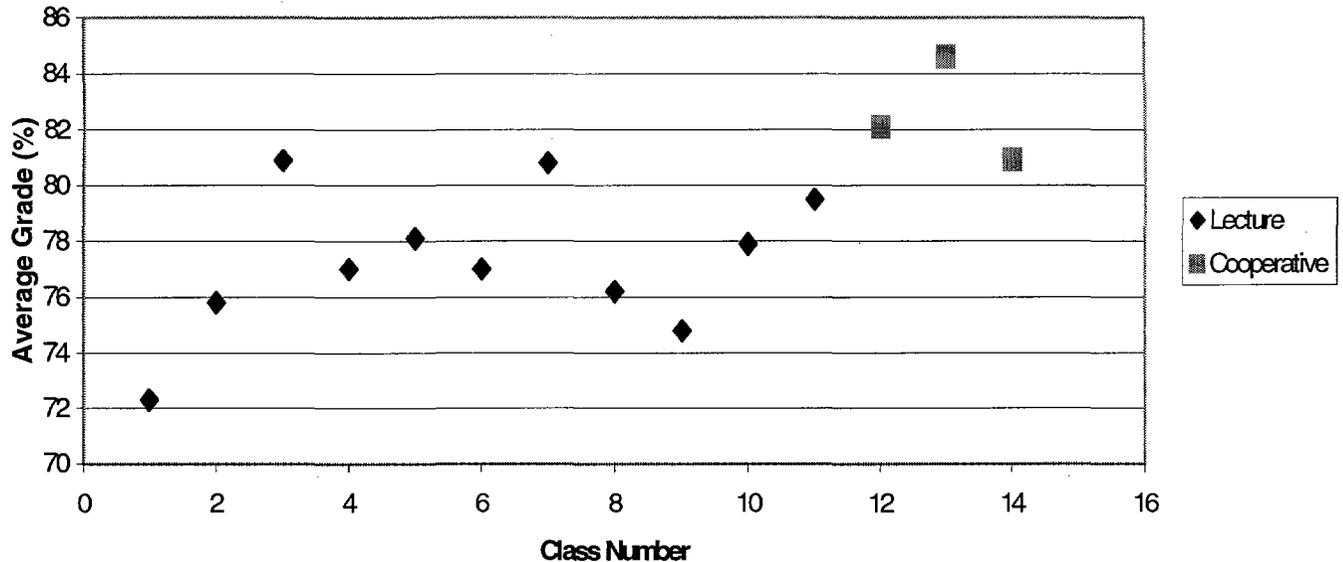
Students were encouraged to cooperatively study for examinations by adjusting each individual's grade on the unit exam by a "group achievement" factor, which depended on the performance of all of the group members. In most of the classes that have used cooperative strategies, each group member's exam grade was increased by four percent only if all group members scored four percent higher than they had scored on the first exam in the course (or scored above 90%). Although this incentive proved to be challenging, it has been viewed favorably by the students.

The initial results of implementation of this method were reported in a recent paper⁸. At that time, results were available for student performance on the unit exam for two classes using the cooperative group method and for eleven classes using the prior lecture/discussion method. A single factor ANOVA analysis was performed of the unit exam scores of the students in the thirteen classes. Each class was treated as a separate group. The exam scores used were prior to adjustment by cooperative group bonus factors. This analysis attempted to show that there was statistical evidence that two populations were represented in the data (cooperative and non-cooperative populations). Although the results of the two classes in which the cooperative group method was employed on the unit exam were above the average of eleven prior lecture/discussion classes, the ANOVA analysis did not provide evidence that the cooperative results differed significantly from prior lecture/discussion classes.

Subsequent to the publication of Reference 8, the Cooperative Group method was used in two additional classes. Although the results of the unit exam for only one of these classes is presently available, the ANOVA analysis now indicates that two populations are represented in the data significant at the 90% confidence level. The

average on the unit exam of the Cooperative Group students is now 82.5%, while the Lecture/Discussion students averaged 77.7%. The distribution of class average scores is shown on Figure 1.

Figure 1 Average Unit Exam Scores



In addition, the students feel that the cooperative group format is both more educationally effective (86%) and more enjoyable (71%) than the lecture/discussion format. Students typically report that they leave Cooperative Group classes understanding the material better than from classes using the traditional format.

Tutorial Computer-Based Instruction Programs

Two Tutorial Computer-Based Instruction (CBI) programs have been implemented to present new information on uranium cross sections and on self-shielding. Both CBI programs were developed in Tutorial format ⁹, including an introductory segment,

followed by the presentation of new material, and exercises that assess the student's acquisition of the learning objectives and provide feedback and remediation.

The purpose of the modules is to provide instruction in areas that are not covered in class due to time constraints. Other advantages of CBI are well documented. CBI can provide immediate feedback, be highly interactive, be implemented in a multimedia format, and play a natural role in technology-based distance education. The primary disadvantage of CBI is the large amount of time necessary to create the instruction ¹⁰. CBI can require several hundred hours to develop an hour of instruction, which is a factor of three or four times larger than traditional instruction.

To devote more class time to complex concepts in the Reactor Theory course, a CBI program is used to present some less-complex information on uranium cross sections and the Doppler effect to students outside of class ¹¹. Although not conceptually complex, an understanding of this material is necessary later in the course. Approximately one hour of classroom instruction on fuel cross sections and related topics was replaced by the CBI program, which presents the same information in an interactive, multimedia format.

The Uranium CBI program consists of six lessons covering U235 and U238 cross sections, both fast and thermal, and related issues such as Doppler broadening of resonances. Within the lessons, material is presented to the student using text, diagrams, cross section plots, animations, and student activities (such as drag-and-drop labeling of a cross section plot). The student is questioned to determine the level of mastery of the learning objectives. Remediation and reinforcement are implemented when appropriate. After completing each section, the student is asked to compose a list

of statements summarizing the section. Finally, the student is provided with a performance summary upon exiting the program. Students are assigned the completion of the CBI lessons as homework.

A second CBI program has been implemented to support the conceptual understanding of a computer program that students use to assess self-shielding in a core design project. Although the conceptual basis for the program is presented in class, additional rehearsal and elaboration of the in-class presentation was necessary because of the conceptual complexity of the materials. A separate lesson in the CBI program was developed corresponding to each module in a computational program that students use to design self-shielded core structures. The lessons cover the concepts involved in each of the stages of the self-shielding calculation. In addition to the types of exercises included in the Uranium cross section tutorial, the self-shielding Tutorial asks the students to construct flow charts and concept maps of some of the more complex concepts. The results of these constructions are assessed by the computer, which provides appropriate feedback.

The implementation of these Tutorial CBI programs has resulted in test performance that is slightly above the average of previous classes, but not significantly higher. For instance, an ANOVA analysis was performed on the results of a single problem relating to self-shielding that appeared on the unit exam. This problem was chosen because it had been used in six different classes prior to using the CBI program. The same problem was subsequently used in three classes following the implementation of the CBI program. A single factor ANOVA analysis was performed of the problem scores of the students in the nine classes. Each class was treated as a separate group. This

analysis attempted to show that there was statistical evidence that two populations were represented in the data (pre-CBI and CBI populations). Although the average of the students in the classes that used the CBI was 88% and the average of the pre-CBI students was 81.3%, there was insufficient evidence to conclude that two separate populations were represented in the data.

Subsequent results from the use of both of the CBI Tutorials typically show slightly improved average scores, but are yet to show significant differences from classroom instruction.

Student opinion generally has favored the use of the CBI programs, particularly when the CBI was viewed as an aid to understanding the material. Of the forty students questioned about the Uranium CBI program, 35% preferred the CBI to a classroom presentation of the same material, 20% preferred the classroom presentation, and 45% had no preference. The most common reason cited for preferring the Uranium CBI presentation was that students could proceed at their own pace through the material. Other reasons cited for preferring the CBI were that the information was effectively displayed, and the CBI programs differed from typical classroom instruction. The reason most frequently cited by those who preferred a classroom presentation was the ability to directly question the instructor during the lesson. Of the nine students questioned about the self-shielding CBI program, approximately 78% preferred the approach that included the CBI program, predominately because it was believed to promote a better understanding of the material. These student preferences are consistent with those reported in other implementations of CBI ¹⁰.

Case-Based Learning Strategy

A Case-Based Learning strategy has recently been introduced in the Reactor Theory course to teach how the response of a reactor core to coolant temperature changes depends on the characteristics of the core. Students are required to construct an assessment system that will allow them to accept or reject temperature coefficient measurements being made on experimental reactors. Students are provided with a case book including temperature coefficient information for five real nuclear reactors, and additional literature discussing the general reasons for temperature coefficient variations in cores. Students assess the information in stages. The shared analysis of the students leads to a consensus expectation for the behavior of a reactor as the coolant temperature changes.

Case-Based learning differs substantially from traditional approaches to instruction¹². Traditional instruction often presents new concepts in an abstract form first, followed by particular examples. Case-Based learning reverses this order by presenting the student first with a number of particular, realistic examples. From this information, the student develops the ability to solve new problems by adapting the solutions of the known particular cases.

Case studies reported in the literature have various characteristics. Camerius describes several different types of case studies¹³. The case being developed for the Reactor Theory course falls into the category of Analytical Case studies¹³. Analytical cases focus on a fairly narrow problem (temperature coefficient characteristics) that is related to a particular subject area (Reactor Theory). However, the case study method is also amenable to cases that are open-ended and interdisciplinary in nature.

Case-Based Learning strategies have advantages and disadvantages. Case-Based strategies require a high level of thought and activity by the students, typically promote the development of higher order thinking skills (analysis, synthesis, evaluation), can be a vehicle for multidisciplinary team studies, and are usually well received by the students¹⁴. However, case studies are somewhat difficult to construct, and are time-consuming both to develop and to conduct.

The Case-Based approach begins by orienting the students to a realistic scenario and problem. The practical importance of the subject is communicated to the students through several articles that discuss the utility of temperature coefficients and real issues that practicing engineers face in this area. Students are then introduced to the problem that they will address. The problem being developed requires that the students construct an assessment system that will allow them to accept or reject temperature coefficient measurements being made on experimental reactors.

In the second stage, the students are presented with a large group of particular, realistic cases. In the Reactor Theory course, students are presented with background information and temperature coefficient data for five reactors in the form of a case book. Both general information on the reactors and information on the variation of temperature coefficients is included in the case book. Each student was asked to infer the general characteristics of temperature coefficients from the information in the case book. Students then present their conclusions in a class discussion. The instructor acts primarily in the role of a group leader (discussion organizer), and not as a subject matter expert. From the discussion, the students developed a consensus description of the general behavior of temperature coefficients in reactor cores.

After the individual cases have been assessed, literature discussing the general reasons for temperature coefficient variations in cores is provided to the students. The students then review the literature and develop a theoretical basis for the trends that were observed in the temperature coefficient data. The same strategy, individual reflection followed by group discussion, is used to build a consensus on the theoretical bases explaining the data.

Finally, the students are asked to accept or reject new temperature coefficient measurements. Temperature coefficient measurements on a new core are provided to the students. The students must analyze the new data, accept or reject the validity of the data, and support their decision.

The results on the unit exam after the initial implementation of the Case-Based strategy were nearly identical to the average results achieved using the traditional lecture approach in previous classes. However, the population of students was small (seven students), and a number of lessons learned will be incorporated in the Case-Based strategy that may improve results in the future.

The initial trial of the Case-Based approach was performed with seven students. All five of the students that responded to the survey stated that they preferred the Case-Based approach to the lecture format used in other lessons in the unit. The most common reason cited for preferring the Case-Based approach was that the active participation of the students promoted learning. All five of the students also agreed that the Case was realistic.

Summary and Conclusions

Each of the Active Learning strategies employed to teach Reactor Physics material has been or promises to be instructionally successful. The Cooperative Group strategy has demonstrated a statistically significant increase in student performance on the unit exam in teaching conceptually difficult, transport and diffusion theory material. However, this result was achieved at the expense of a modest increase in class time. The Tutorial CBI programs have enabled learning equally as well as classroom lectures without the direct intervention of an instructor. Thus, the Tutorials have been successful as homework assignments, releasing classroom time for other instruction. However, the time required for development of these tools was large, on the order of two hundred hours per hour of instruction. The initial introduction of the Case-Based strategy was roughly as effective as the traditional classroom instruction. Case-Based learning could well, after important modifications, perform better than traditional instruction.

A larger percentage of the students prefer active learning strategies than prefer traditional lecture presentations. Student preferences for the active strategies were particularly strong when they believed that the strategies helped them learn the material better than they would have by using a lecture format. In some cases, students also preferred the active strategies because they were different from traditional instruction, a change of pace. Some students preferred lectures to CBI instruction, primarily because the CBI did not afford them the opportunity to question the instructor during the presentation.

Active learning strategies are not a 'Silver Bullet', but can be part of an arsenal of useful instructional strategies. The use of active learning strategies, such as the strategies summarized above, will certainly not replace lecture-discussion within the foreseeable future. Lecture remains the most efficient manner of presenting information, and requires a lower level of effort to develop. However, some active learning strategies can improve student learning, are more motivating to students, or are readily adapted to use in technology-based distance education. In some learning situations, the advantages of active learning strategies are important enough to motivate the adoption of these new strategies in Reactor Physics education.

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