Session 2477

Collaborative Learning in Small Groups in a Mathematics Intensive NE Course

Kuruvilla Verghese, Douglas E. Peplow
Department of Nuclear Engineering
North Carolina State University
Raleigh, NC 27695-7909

Abstract

Several of the generally required nuclear engineering undergraduate courses are intensive in mathematics and physics, for example, courses in reactor analysis and thermal hydraulics. The conventional lecture/lab format is usually unsatisfactory for such courses. Translating the physics into mathematics and vice versa are often lost on the students while they struggle with the mathematics. The result is a lot of rote learning without much understanding and critical analysis. This problem is exacerbated when the course is a prerequisite for upper level courses and coverage of the syllabus is deemed important. Over the last four years we have been trying the approach of collaborative learning in small groups in a junior level course in reactor analysis to overcome some of the deficiencies. We have found that formal classroom lectures are important in such a course but student understanding can be improved through mandatory collaborative learning sessions in small groups outside the lecture classes. Groups of two to three students meet in separate rooms once each week for two hours teaching each other to answer questions that are posted in their course locker. The questions are concept-based covering the lecture material for the prior week. Graduate student volunteers and the the instructor serve as guides but not tutors. The primary goals are to provide an enquiry-guided learning environment, to discourage rote learning and to make the subject more enjoyable.

1. Introduction

College teaching methods have gone through a revolution in recent years with the concept of active learning shown to be the way for students to learn. There is a vast amount of education literature that has established that active participation in the class room as opposed to passive listening keeps students better motivated in the subject, helps them retain and use the course material and develops critical thinking and communication skills. There are numerous modes that have been established as effective ways for the instructor to promote active learning[1–4]. A typical example is where the instructor would set up small groups within the class room and pose short-answer questions or problems that deal with a concept that had been taught and the student teams would take a few minutes, typically two to three minutes to confer among their team to come up with an answer. All of the answers will then be presented to the class and debated. There is little doubt that active learning in small groups does achieve the educational goals very well when properly implemented and that it can be used effectively in courses at all levels.

The difficulty that arises in certain intermediate level engineering courses is that it is in these courses that the students are expected to learn the applications of physics concepts to engineering problems. Normally, this will require that the students are expected to learn mathematical modeling of the physical problem, methods of solution of the mathematical model and interpretation of the math results in terms of physical reality. This transition from physics to mathematics and back to physics is not trivial for students in engineering science courses and active learning methods can be devised and implemented in the class room to help them along but it is a slow process. Generally, proponents of active learning methods in class would agree that subject coverage has to be less than under the passive method of hour-long lectures, but that considering the benefits to the learning process, it is worth sacrificing subject coverage to some extent. One difficulty with that results from the over-filled syllabi required of course sequences in most 4-year engineering curricula; the coverage of subject in a course among a two or three semester sequence (or in a course that serves as prerequisites to one or more other courses) is important and can not be sacrificed much.

A typical case in point is a course in nuclear reactor analysis taught in our department in the second semester of the junior year. This is a 4-credit course which concentrates primarily on reactor statics. The outline of the course is in the Appendix. There are 2.5 hours of class room time and a 2.25 hour laboratory per week. The class size is usually small with about 12-15 students. Much of the material taught in this course is required knowledge in several of the senior-level courses (reactor systems, thermal-hydraulics, fuel cycles, senior design). Students enter this course after completing an introductory course in neutron physics and elementary reactor theory (through one-group diffusion in homogeneous media and point reactor kinetics) with a C grade or better. They typically will also have had a semester course in differential equations and will be taking a second differential equations course concurrently. Students find reactor analysis to be intensive in the use of mathematics and physics and fast-paced. They feel that they comprehend the concepts presented in the class room but many recognize difficulty in applying them. The difficulty comes primarily from the mathematical rigor required and its connection to physics. The physics is lost on the students as they struggle with the mathematics which becomes in their mind the end in itself rather than the means to the end. The result is a lot of rote learning without much understanding and critical analysis.

This paper describes an out-of-class small group learning program that we have developed and implemented during the last four years to try and reap the benefits of collaborative learning without sacrificing subject content. This program was instituted as a project for one of the authors (DEP) under NCSU's "Preparing the Professoriate" program (PPP). PPP provides a one-year mentored teaching experience to a few select senior PhD students who aspire to have an academic career[5].

2. Out-of-class Small Group Learning Activity

Students are required to register for an extra 2.25 hour period per week for an out-of-class group learning session. This ensures that they all will have the same time each week dedicated for this activity.

Graduate student volunteers are recruited as tutors based on their familiarity with the course subject during the semester prior to the semester of the course to help with the collaborative learning activity. The graduate student response to this volunteering opportunity has been excellent so far and primarily the best students of the department have ended up volunteering to be tutors. The teaching assistant for the course serves as the co-ordinator of the group study under the guidance of the course instructor.

Just prior to the start of the semester, the instructor divides the class into groups of two to three students. The group composition is such that each group will consist of mutually compatible students of approximately the same intellectual level. We believe this to be better than random mixing or forming groups consisting of students with widely different intellectual levels and abilities. Data from instructors of prior courses taught to the same cohort of students are used in forming the groups.

The students are given a detailed set of instructions on what is expected of them during the collaborative learning sessions. Each week, three to four days prior to the learning session, a set of questions are posted in the course locker (a directory allocated to each course on the computer network). The questions are based on that week's course material and they usually have short answers. The aim is to get the students to think beyond the normal breadth of the course. The questions may be conceptual, application-oriented or even mathematical. They differ from standard homework problems in that they demand greater breadth but not as much depth. The students are expected to make an earnest attempt at solving all of the questions before coming to the study session. Just to provide a flavor of the types of questions, a few are shown in the Appendix. The questions are jointly formulated by the coordinator and the instructor. The questions and solutions are made available to all tutors prior to the group session.

The groups meet in separate rooms that have blackboards. The goal of the study session is to get the students to learn as much as possible on their own and from their team mates rather than from the tutors. The tutors' role is to ask questions directed at getting the students to think about the questions, implied assumptions, ramifications of the answer and most of all, to learn to vocalize thoughts succinctly. Although called tutors, they are not to turn the session into a tutorial with one-way information flow. The students direct their questions at each other and not at the tutor. A tutor may stay with a group only for a few minutes at a time unless the group gets really stuck on a question. Tutors rotate around between groups and thereby, become thoroughly familiar with the strengths and weaknesses of individual students. The tutors also thus acquire the teaching skills necessary to meet the needs of different types of learners[6]. It is deemed important for the instructor also to be a tutor and carry an equal share in these sessions.

Typically there will be about 12-13 collaborative learning sessions during the semester. Each student does all of the work in a notebook which is collected about three times during the semester without prior warning. The books are graded on the basis of completeness of solutions, clarity of thought and simply, the professionalism displayed. 15% of the final course grade is allotted to the collaborative learning component and it is assigned on the basis of active participation and the notebook grades.

3. Results and Conclusions

Assessment of this project has not been done in detail because of the small number of students per year but the following two points give us confidence that the out-of-class collaborative learning has yielded benefits to the student:

- The course grades have shown a significant improvement as compared to the years prior to the implementation of this program. An impetus for initiating this project was that the failure rate in the course was approximately 10%; over the past three years, only one out of a total of 31 students have failed. The fraction receiving low grades has also decreased since the inception of this program.

- Student evaluations indicate that they believe that the learning sessions have helped them in their understanding of complicated material which they otherwise would have learned by rote memorization.

An intangible benefit has been the involvement of the volunteer tutors. The quality, motivation and enthusiasm of the tutors has been inspirational. It has not only resulted in greater comraderie between senior graduate students and undergraduate students but also the graduate students have received at least a small degree of mentored experience at teaching. Presumably, they also benefited from learning the subject of reactor analysis better.

The collaborative learning program described here may have a few negative aspects in the minds of some instructors. First of all, it is labor intensive for the instructor but, on the other hand, it is also true that restructuring any course to provide active learning involves much greater preparation time than for a traditional lecture-based passive learning experience. Secondly, a few of the students may have been frustrated by the shortage of time to devote to the study sessions particularly towards the end of the semester as assignments in competing courses piled up. All in all, we believe that the student experience has been good and beneficial. This program, while not a panacea by any means, may be adapatable to courses of the type described here.

4. Appendix: A Brief Course Outline

   1. Neutron Physics Concepts
      - (a) Flux, Current, and Sources
      - (b) Differential Cross Sections and Nuclear Data
      - (c) Reaction Rates
   2. Neutron Balance Equations
      - (a) Boltzmann Transport Equation
      - (b) Continuity Equation
      - (c) Fick's Law and the Diffusion Equation (Review)
      - (d) One-Speed and Multigroup Diffusion Equations
   3. One-Speed Diffusion Theory
      - (a) Elementary Fixed Source Problems and Solutions (Review)
      - (b) Diffusion Length (Review)
      - (c) Flux Shapes and Power Peaking in Bare Homogeneous Reactors (Review)
      - (d) Effect of Reflectors (Review)
      - (e) Multiregion Reactors and Numerical Solutions
   4. Multigroup Diffusion Theory
      - (a) Two-Group Reflected Homogeneous Reactor Flux Shapes and Criticality
      - (b) Multiregion Reactors and Numerical Solutions
   5. Neutron Moderation
      - (a) Kinematics of Epithermal Neutron Scattering (Review)
      - (b) Lethargy, Collision Density, Slowing Down Density
      - (c) Basis of 1/E Spectrum Approximation
      - (d) Continuous Slowing Down Model
      - (e) Effect of Resonance Absorption
      - (f) Epithermal Spectrum and Group Constants
   6. Neutron Thermalization
      - (a) Maxwellian Distribution and the Principle of Detailed Balance
      - (b) Effects of Leakage, and Absorption on the Thermal Spectrum
      - (c) Thermal Scattering Kernels
      - (d) Thermal Spectrum Calculation Using the Proton Gas Model
      - (e) Thermal Group Constants
   7. Heterogeneous Reactors
      - (a) Equivalent Lattice Cell
      - (b) Basic Aspects of f,ϵ, and p Calculations
      - (c) Disadvantage Factor by the ABH Method
      - (d) Multigroup Cross Sections for Heterogeneous Cells
   8. Burn-Up and Fission Product Effects
      - (a) Fission-Product Poisoning by Xenon and Samarium
      - (b) Isotopic Depletion Equations

5. Appendix: Sample Problems Used in Group Learning Sessions

1. Physically, what is the difference between these expressions?

$$\int_0^\infty \Sigma_s(\vec{r}, E' \rightarrow E)\phi(\vec{r}, E')dE$$

$$\int_0^\infty \Sigma_s(\vec{r}, E' \rightarrow E)\phi(\vec{r}, E')dE'$$

$$\int_0^\infty \Sigma_s(\vec{r}, E \rightarrow E')\phi(\vec{r}, E)dE'$$

What does each represent?

2. Think of various examples of modeling problems of practical importance in a power reactor or of radiation transport for shielding, medicine, etc., and argue that the Boltzmann Transport Equation encompasses the model for all of these. Can you think of any exceptions?

3. Compare the neutron diffusion equation for a non-multiplying medium and the heat conduction equation.

$$\frac{1}{v}\frac{\partial\phi(\vec{r},t)}{\partial t} = \vec{\nabla}\bullet D(\vec{r})\vec{\nabla}\phi(\vec{r},t) - \Sigma(\vec{r})\phi(\vec{r},t) + S(\vec{r},t)$$

$$\alpha\frac{\partial T(\vec{r},t)}{\partial t} = \vec{\nabla}\bullet k(\vec{r})\vec{\nabla}T(\vec{r},t) + S(\vec{r},t)$$

   (a) What would a term proportional to $T(\vec{r})$ added to the heat equation represent?

   (b) How would solutions techniques vary for the two equations?

   (c) What type of source terms are there that are dependent and independent of the variable in each equation?

4. Sketch the shapes of the neutron flux distributions in the following cases and briefly and clearly explain the physical reasons for the shapes that you have drawn.

   (a) Radial 1-group flux distribution in a reflected infinite cylindrical reactor;

   (b) Radial 2-group (fast and thermal) flux distributions in a reflected infinite cylindrical reactor;

   (c) 1-group flux distribution in a system consisting of a non-absorbing moderator slab sandwiched between two slab reactors of equal thickness;

   (d) 1-group flux distribution in a system consisting of a strongly absorbing material several mean free paths thick sandwiched between two slab reactors of equal thickness;

   (e) Thermal flux distribution in a large tank of water with a point source at the center emitting fast neutrons;

5. For the thermal neutron scattering kernel for monatomic hydrogen ($A = 1$) and monatomic carbon ($A = 12$)

(a) Compute and plot $\frac{\Sigma_s(E' \to E)E'(1-\alpha)}{\Sigma_{s0}}$ over the range (0,1) against $\frac{E}{E'}$ on the x-axis covering the range (0,2) for different values (viz., kT, $5kT$, $25kT$ and $200kT$) of the initial energy E'.

(b) Interpret the plots in physical terms.

(c) For both hydrogen and carbon, calculate and tabulate the fractions of neutrons that downscatter and those that upscatter for the four different initial energies given in the above problem. Discuss the results.

6. Explain why

(a) Low energy resonances in the absorption cross section of the ^{238}U and the Pu isotopes are more important in light water reactors than the higher energy resonances, and

(b) The NRIM approximation is more valid for the low-energy resonances than the NR approximation.

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KURUVILLA VERGHESE

Kuruvilla Verghese is Professor of Nuclear Engineering at North Carolina State University. He also serves as the Director of Graduate Programs within the same department. He received his PhD at Iowa State University in 1963 and has been on the academic faculty of the current institution since then. He teaches courses primarily in reactor analysis and is currently involved in nuclear applications in medical research.

DOUGLAS E. PEPLOW

Douglas Peplow recently completed the requirements for his PhD in nuclear engineering. His dissertation topic was Monte Carlo Image Simulation and Parametric Uncertainty Analysis for Digital Mammography. He and Kuruvilla Verghese have collaborated on both teaching and research projects.