Using Active and Cooperative Learning in Industrial Engineering Education

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Abstract

Active and cooperative learning methods recognize that the passive model of the typical college lecture does not work for many students. Instead, active and cooperative learning focuses on the premise that the students can learn best by doing and working with each other. In traditionally structured class periods, students listen to a professor lecture for about an hour. Cooperative learning can replace some of that lecture time with methods designed to get students actively involved during the class period. This paper presents the use of active and cooperative learning techniques applied in Industrial Engineering education. Tips and examples for how to transform a standard lecture into a lecture based on cooperative exercises are given and the authors' experiences with these techniques are detailed. Examples include material from simulation, quality engineering, engineering economy, probability and statistics, database modeling, and project management.

Introduction

The purpose of this paper is to present the use of *active* and *cooperative* learning in Industrial Engineering education. Active learning is predicated on the principle that students learn best by becoming actively engaged in the learning process. The active learning model shifts from the passive model of students absorbing information given to them by professors to a situation in which students are responsible for their learning. The active model shifts the responsibility to the student by engaging them in activities that allow the students to exercise their wide varieties of learning styles. In active learning, we are interested in encouraging students to express their own ideas in oral or written form, in organizing, justifying, and elaborating on their work, and in developing questions that assist in the attainment of their own learning objectives. A basic strategy in encouraging active learning is to facilitate student-to-student interaction. Cooperative learning strategies are designed to motivate the students' interest and help their retention of key ideas by encouraging them to participate in discussions. In this model of teaching, the teacher serves as a facilitator and resource, the students interactively learn from each other, from the teacher, and from the process itself.

Much of the literature on cooperative learning strategies and benefits has focused on non-engineering courses (see e.g., Brufee (1993), Sharan (1990), and Slavin (1993)); however, Mourtos (1997) and Smith and Waller (1995) have written on the subject for technical courses. Smith (1993) and Smith and Starfield (1993), suggest that model building is also an essential element of active learning in the engineering classroom. In addition, the ability to work in supportive groups on problems, see for example Astin (1987) and Johnson and Johnson (1989) can be a significant catalyst for improved learning.

In this paper, we are motivated by the fact that while active and cooperative learning has been studied extensively, and has been shown to be a beneficial teaching technique, its wide spread adoption throughout the Industrial Engineering curriculum has been limited. Our goal is to present background information on active and cooperative learning techniques and to discuss why Industrial Engineering educators should incorporate these techniques into their classrooms. In addition, we will present examples of cooperative learning activities used in Industrial Engineering courses in order to illustrate how to develop these activities and to discuss their use in the classroom. It is our hope that the presentation of these techniques will encourage Industrial Engineering educators to try them in their own courses.

Preparing the Student

Professors are very comfortable with the passive, lecture-oriented classroom model. The passive model places control and responsibilities with the professor. The professor becomes the most actively engaged person in the classroom. The professor is responsible for developing the lecture material, organizing and synthesizing the material, asking questions concerning the material, and presenting the material. The active learning model shifts some of the responsibility and the work to the students. Most students have never experienced this form of teaching in their college careers. Active learning will represent a departure from their expectations and a departure from what is expected of them. It is therefore important to properly prepare the students for this change. For active learning to function appropriately, the students must "buy-into" the experience and clearly understand the new expectations placed upon them.

At the beginning of the course, it is important to make the students aware of this new experience. We recommend discussing with the students how they learn best and modeling short non-threatening examples of simple activities. For example, you might ask them to turn to a neighbor and come up with a list of things that they do to learn effectively. You can then ask the pairs to compare their lists with a group near them and to consolidate their lists into a list that can be reported to the class. You can then ask the groups to report their findings and discuss their results. Not only does this exercise sensitize the students to different ways of learning but it also models the basics of a cooperative group activity.

The discussion of how students learn best will contain in some form the four major elements of active learning given by Meyers and Jones (1993). Figure 1 illustrates this model. In an engineering course, you may also have "working problems" or "doing exercises" as a key element. This is a surrogate for "writing". Ideally, the students will also realize that they have different learning modalities. You might point out that research suggests that learning modalities vary between students, from day to day, and from topic to topic (e.g. see McCalley et al. (1987)). Active learning allows students who rely more heavily on experiential learning to conceptualize and internalize the material presented in class.

After this informal introduction to active learning, it is beneficial to support it with something concrete. We suggest that the course syllabus include a brief overview of the active learning philosophy and a statement of your expectations of the students. You should make it clear that the students' participation during class activities is expected and that participation is an integral part of the learning experience in your course. Depending on the level of the students you may want to include some sort of bonus system to reward those students who enthusiastically engage in the process.

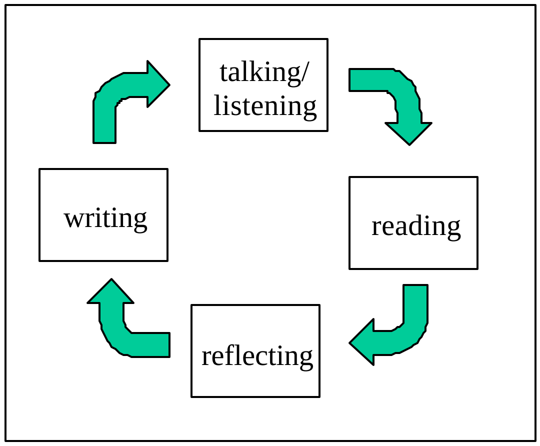

Figure 1: Elements of active learning.

Cooperative Learning Background

Smith (1994) describes cooperative learning as "students working together to get a job done in a classroom where students are concerned about each other's learning in addition to their own." Johnson, Johnson, and Smith (1991) have characterized cooperative learning as having five basic elements:

1) *Positive Interdependence*. Positive interdependence refers to the creation of a learning atmosphere in which the success of the group is dependent upon the success of every individual in the group. Simply assigning a group task is not enough. The reward system and the roles of group members must be structured to foster inter-dependence. A very simple technique used by Karl Smith is to provide only one copy of the task to each group. In that way, the group must share the paper and thus become more dependent on one another.

2) *Face-to-Face Promotive Interaction*. Face-to-Face promotive interaction tries to engage the student in explanations of their learning process to fellow students. The idea is to get students to teach each other.

3) *Individual Accountability/Personal Responsibility.* Individual accountability addresses the issue of assessing individual student work in the group effort. It goes further than individual assessment. Feedback to the entire group of individual performances is a critical part of individual accountability. An example is to randomly call on a team member to present the group's work. This creates the pressure on the group to ensure that every group member understands the work performed by the group.

4) *Collaborative Skills*. Collaborative skills refer to the need to teach students how to function in a group. They should have an understanding of group dynamics, active listening methods, conflict-management, and other social skills necessary to function effectively in a group.

5) *Group Processing*. Group processing tries to engage the students in a self-evaluation exercise. Smith (1994) suggests having the students answer the following two questions: 1) "What is something each member did that was helpful for the group?" and 2) "What is something each member could do to make the group even better tomorrow?"

Structuring groups can be challenging and must be done with consideration of the learning goals. Smith (1994) classifies groups into three categories. The first is informal learning groups which are "short term and less structured." These groups typically last a short time in a class period. The second type of group discussed by Smith (1994) is the formal learning group. Formal learning groups are formed around completing a structured task. The task may take a longer period of time to complete, e.g. 1 or 2 class periods, a couple of days, a week, or a semester. The third is cooperative base groups. These groups are long lasting and supportive in nature. In the next two sections, we discuss informal and formal learning groups in the context of a class period.

Informal Learning Groups and the Lecture

Lecturing is a very effective method for the dissemination of facts and it will undoubtedly remain as key technique in engineering education; however, the introduction of cooperative learning can increase the effectiveness of lecturing. A schematic on how the cooperative learning based lecture proceeds in a one-hour period is shown in Figure 2 (adapted from Smith and Waller (1995)).

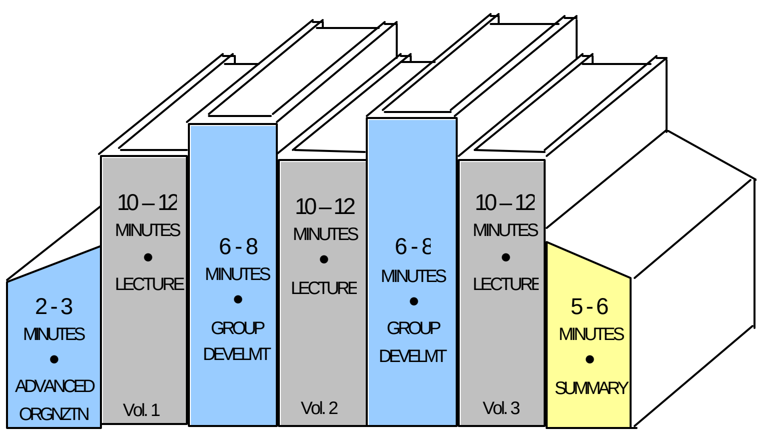

Figure 2. The cooperative learning lecture

In a cooperative learning based lecture, the lecture is divided into segments that promote active involvement on the part of the students. Each segment begins with a mini-lecture on the topic associated with the upcoming group activity. The lectures are intertwined with the use of small informal groups of students assembled periodically to examine, experience, try, discuss, and understand the topic. To maintain the spirit of the "informal" technique, form the groups spontaneously and mix students with different partners. For example, a simple method is to ask the students to work with the person on their right/left (this is sometimes called the *turn to your neighbor* method in the cooperative learning literature). Alternatively, if class size permits, you may randomly pair the students as they come in the room.

The class meeting begins with an advanced organization activity designed to focus their attention on the session topic. The activity may involve collecting thoughts to contribute to a group discussion on an opening question based the reading or exercises assigned for the day. The group development work is usually designed around the "think/pare/share" method. In this method, the 6-8 minute segment is subdivided into three parts: (1) a few minutes to think about the question or exercise independently (think); (2) a few minutes to work in the group (pair); and (3) a few minutes to discuss the problem with the entire class (share). The advantage to this approach is that it gives the individual an opportunity to formulate a contribution to the group's work. Furthermore, they feel they should make a contribution since they were given the time. While the groups are at work, the instructor circulates around the room to coach and encourage them in their work. Finally, the instructor asks the groups to volunteer their responses. Typical group development tasks include summarizing the material, solving a simple problem, and formulating an example of how the theory applies. The cooperative learning lecture concludes with a discussion wherein all of the students contribute to a summary of the main points.

SIMULATION. Exhibit 1 shows how a complete cooperative learning lecture in a simulation would proceed on the topic of entity management. Students who have prepared the reading for the class session can quickly address Questions 1-3 as an advanced organizing activity. (Students who cannot will quickly get the message that the reading assignment was important.) Questions 4 and 5 in the first group development activity lead to a general discussion on the role of distributions in simulation modeling. Questions 6 and 7 in the second activity lead to an introduction of the particulars in building a simulation model. Notice that in this example, the lecture amplifies the issues that the student groups had just addressed. Other classes may be designed just the opposite so that the group development work amplifies or reinforces the lecture topic.

QUALITY ENGINEERING. Exhibit 2 shows how a complete cooperative learning lecture in a design of experiments course would proceed on the topic of factorial designs at two levels. Again, the first group of questions can be easily answered based on even a cursory reading of the assigned material. The first mini-lecture then supports that the topic of the questions by going into detail about the calculation methods. The motivation for the calculations is reinforced visually for the students through their own re-creation of the underlying geometry. The second mini-lecture goes even further in developing one of the three methods, then the students are asked to check their understanding by verifying given calculations. The third mini-lecture discusses how to analyze the factorial design. The class concludes with a discussion of what it all means.

Exhibit 1: Cooperative Learning Lecture Notes on Entity Management
Advanced Organization 1. What names are given to units of traffic in commercial simulation software packages? 2. In a model, can more than one unit of traffic move at a time? 3. What three conditions may force a unit of traffic to stop moving?
Mini-Lecture #1 • a graphical model of units of traffic • block diagrams • “sink” paths
Group Development 4. What is the difference between an arrival time and an interarrival time? 5. How can a sample from a 0-1 uniform distribution be converted to a general uniform distribution?
Mini-Lecture #2 • the simulation clock • base time units • event scheduling
Group Development 6. Write a pseudo-code for a drill-and-casting system that has one drill that must make holes in two castings. 7. Identify in your code steps where a unit of traffic must actually move.
Mini-Lecture #3 • block statements • control statements • comment statements • model files
Summary The creation, movement, and destruction of units of traffic in simulation models.

Exhibit 2: Cooperative Learning Lecture Notes on Factorial Designs at Two Levels
Advanced Organization 1. Name three methods for calculating effects. 2. Why is it important to be able to calculate the standard error of effects?
Mini-Lecture #1 • calculation of effects using geometric diagram • calculation of effects using a table of contrast coefficients • calculation of effects using Yates’ algorithm
Group Development 3. Sketch a diagram that would show the experimental data for a two level design for four factors.
Mini-Lecture #2 • developing a table of contrast coefficients • replicating a design
Group Development 4. Verify the standard error of an effect calculations for the chemical process example. 5. Analyze the effects using a dot diagram or t distribution
Mini-Lecture #3 • analysis of factorials using normal probability paper • normal plots of effects and residuals
Summary Interpreting results of a designed experiment.

Formal Learning Groups and Sample Activities

In this section, we present example activities that can be performed with formal learning groups. Formal learning groups may last for a significant portion of a class period and may even span multiple class periods. Proper time management is critical to the success of these activities. In the context of the cooperative learning based lecture, these activities can serve in the blocks of time labeled group development activities in Figure 2. If the activity is greater than 6-8 minutes, e.g. 30 minutes, then it can take the place of the middle three “books” in Figure 2. In this case, the group activity is the main point of the entire class period.

ENGINEERING ECONOMICS. Exhibit 3 presents an activity that can be used at the beginning of an engineering economics course. The standard presentation of this material is to develop the formulas for the students, summarize the formulas for the various modeling cases, and then to do some example calculations. In this exercise, we guide the students through the model building process. During the advanced organization and first mini-lecture, the topics of simple interest and the time value of money can be introduced. Then, the activity is given to the students. The instructor should visit the student groups as they are processing to check on their progress and to give insights into the modeling process. It's important to have a couple of questions ready to jump-start the students. For example, the instructor might ask, "Can to define a variable to represent the interest rate?" or "How much will you have at the end of 1 year?" To save time, when you see that the groups are converging on "the" answer to each part, pass out an overhead to the randomly selected group so that they can record their solution. At the end of the period or at the beginning of the next period, it is useful to have an "answer" sheet to make sure everyone got the main ideas in the activity. One might extend this exercise with a discussion about modeling and how to critique and use models. The text by Starfield, Smith, and Bleloch (1994) presents this idea of model building for improved student learning.

PROBABILITY AND STATISTICS. Exhibit 4 presents an activity that can be used after a discussion of common discrete probability distributions in an introductory probability and statistics course. Often in modeling, we are faced with a choice of deciding upon the most appropriate model for a given situation. This activity asks students to find the distribution associated with a particular modeling situation. Often texts discuss each distribution in a different section and then given problems for that section. The students know which distribution to use. This activity provides practice for the more common situation of when you do not know which distribution to use. This helps students in real life modeling situations and on test situations. To save time, we do not ask the students to actually calculate the desired quantities. As an extension, the computations can be given as a homework problem. The text by Scheaffer et al. (1996) presents many activities that can be used to illustrate in a hands-on fashion the concepts in probability and statistics.

DATABASE MANAGEMENT. Exhibit 5 presents an activity that can be used after a discussion of structured query language (SQL) in an introductory database management course. In this activity, we assume that prior lecture or activities have covered the basics of how to translate an informal narrative query into the appropriate SQL statement. This activity is a summarizing activity. It pulls together all of the previous work into one example. In addition, the activity not only asks the students to solve the query but it also asks them to document *how they solved the query*. This is a standard assessment technique found in the handbook by Angelo and Cross (1993). In this situation, we are interested in having the students think at a higher level. If they can document how they solve a problem, they can then generalize and reflect on their problem solving skills. They also have the opportunity to see how *others* think when they solve the problem. This can be an important learning experience for the students and is a valuable feedback mechanism for the instructor. Other activities that can be used an information systems course are peer review of projects and activities concentrating on object or entity relationship diagramming.

PROJECT MANAGEMENT. Exhibit 6 presents an activity in project management. It uses what is called the *jigsaw strategy*. In this strategy, each member of a group is given a different section of the material to learn (Aronson (1987)). The members are dependent upon each other to learn all of the material. This is accomplished through student-to-student teaching. In essence, this strategy works on the premise that in order to teach material you must first fully understand the material. Secondly, this example demonstrates how to divide and conquer. This enables a larger quantity of material to be covered while still promoting positive interdependence. When using this strategy, it is important for the instructor to interact with the students. For example, the instructor may want to require a draft of the teaching material be turned in for review and comment. This particular example illustrates the use of the jigsaw strategy in a project management course. The jigsaw strategy works well with "softer" material and motivates the students to dig into the material themselves. Ideally, an organizational behavior case study would follow up this activity. This will motivate the students if they know they will be doing a case on this material and allow the instructor to assess their understanding.

Implementation Issues

When using these techniques the instructor may perceive that they are giving up control of the classroom to the students. In addition, the instructor may sense that the students feel that the instructor is not "doing their job". While the instructor is often not the center of attention during these activities, that does not imply a lack of control or a lack of effort. Smith (1994) suggests that the instructor's role has five elements: (1) setting instructional objectives; (2) pre-instructional decisions including the forming of groups, materials, and group roles; (3) explain task and cooperation; (4) monitoring and intervening to help with cooperation skills and learning; and (5) evaluating and processing of the learning and group interaction. In addition to feeling like you are giving up control, you might feel that using these activities will take up too much time. It is true that activities utilize large amounts of time, but they can also enable deeper understanding and improved motivation. Generally, we can cover the same amount of material, because the students are *capable* of getting to the material.

Successful cooperative learning is not just students working in a group; it incorporates the five elements of cooperative learning in a synergistic manner. Without each of these elements group work can actually be a hindrance to student learning (see Smith (1995) for a further discussion of this point). We have found that randomly picking the groups or picking groups based on student attributes can facilitate learning and team formation. An easy method to randomly select students is to have them fill out a 3 by 5 card with their names and other relevant information at the beginning of the course. These cards can be shuffled and students drawn at random. The cards can also be utilized to record participation scores if your grading scheme includes class participation.

Good methods are needed assess an individual's learning in a group experience. Groups need to be monitored and structured so as to prevent less motivated students from "riding the coat tails" of the more effective team members. The primary examples presented in this paper represent techniques for use in the classroom. If cooperative learning activities are used as homework or projects then grading is an issue that must be seriously addressed. Johnson, Johnson and Smith (1991) cover grading in cooperative settings. A couple of key points to remember: 1) use a criterion referenced absolute scale (don't curve) and 2) structure the grading so that cooperation does not penalize the student. For example, give bonus points to each member of a team if the individual team members' scores are sufficiently high.

Concluding Remarks

This paper outlined the use of active and cooperative learning in typical courses in an Industrial Engineering curriculum. The goal of using cooperative learning in the classroom is to make the student stronger through interaction and communication around the process of academic inquiry. Students improve their thinking and problem-solving skills. To professional engineers, the ability to actively identify, formulate, and solve problems is essential to a successful career.

Johnson, Johnson, and Smith (1998) found that there is a large body of evidence that active and cooperative learning techniques work. For example, they found that there have been over 500 experimental and 100 correlational studies conducted since 1897 involving both children and adults. They concluded that the research on cooperative learning has a validity and generalizability rarely found in the educational literature. Among other things, cooperative learning leads to improvements in achievement, retention, critical thinking, and teamwork skills.

With such strong evidence supporting active and cooperative learning, we believe that it is time that Industrial Engineering programs and curriculums embrace these techniques.

Exhibit 3: Model Building
Objective: To give students practice building mathematical models, working in small groups, presenting solutions to large groups
Setup: Assumes that students grasp the concept of the time value of money, simple interest, and have seen a cash flow diagram. Form random groups of 3 students.
Activity: Each part 10 minutes. **Part 1** Individually, consider the following: If I invest $5,000 today at an annual interest rate of 7% for a period of 3 years, how much will I have at the end of 3 years, if interest is compounded annually? As a group, develop a model to answer questions like the above. Exercise your model. Critique your model. What notation did you use? What were your assumptions? **Part 2** Individually, consider the following: *If I invest $100 at the end of each year at 10% interest for 3 years, how much do I have at the end of 3 years?* As a group, develop a model to answer questions similar to the above. Draw a CFD for the above specific example and for the general case. **Part 3** As a group, consider the following: How might you use part two's model in combination with part one's model to answer questions of the following kind? *What is the present value of a yea-end series of receipts of $600 over 5 years at 8% compounded annually?*
Accountability: Randomly select 1 group of students and then randomly select 1 person from the group to place their models on the board and to explain their models. (15 minutes)

Exhibit 4: What would you compute?
Objective: To give students practice solving, identifying discrete probability distributions, working in small groups, presenting solutions to large groups
Setup: Students should form a group of two. 1. Take 5 minutes to read the problem individually. 2. Take 5 minutes to solve the problem as a group. 3. Compare your group's answer with the answer of a group near you. 4. Record your answer in preparation for presentation to the class.
Activity: In this activity, you are presented with a problem related to discrete probability distributions. For the problem, **1)** define the random variable of interest, **2)** identify the appropriate discrete probability distribution **3)** tell exactly what you would compute to find the answer to the question. Note: You don't have to actually compute the desired answer. *Place problem here*
Accountability: Randomly select 1 group of students and then randomly select 1 person from the group to place solution on the board and to explain their answer. (5 minutes)

Exhibit 5: Documented Problem Solving
Objective: To give students experience solving SQL queries, working in small groups, presenting solutions to large groups.
Setup: Form groups of two students each. Instruct the students to individually read the following query. Then ask them to work together on the solution.
Activity: This problem attempts to illustrate most of the points discussed concerning SQL select statements. This problem refers to the suppliers and parts database given in the handout.

"For all red and blue parts such that the total quantity supplied is greater than 350 (excluding from the total all shipments for which the quantity is less than or equal to 200) get the part number, the weight, the color, and the maximum quantity supplied of that part."

The resulting table should look like this:

P#	WEIGHT	COLOR	MAXQTY
P1	12	Red	300
P5	12	Blue	400
P3	17	Blue	400

One person is responsible for documenting the actual SQL statement. The other person is responsible for documenting how you solved the problem. In other words, what were your steps?

Accountability: Randomly select 1 group of students; have 1 student give explain the answer to the query; have the other student, discuss their problem solving steps. (10 minutes)

Exhibit 6: Material Review
Objective: To have students learn and teach each other technical material.
Setup: Divide material into X sections. Randomly place students into groups with X members. Randomly assign each student in each group a section to cover.
Task: Your task in this group is to learn all of the material on Organizational Structures in Chapter 3 of Kerzner (1995). Work cooperatively to ensure that all members of the group master all of the material. Find a member in another group who has the same section as you. Work with that person to master the material. Develop a method to teach the material to other members in your group. Prepare visual aides for explaining the material. Plan active roles for your group members. Teach your groups members. Find another pair with the same section of material to present. Review all materials. Revise both pair's materials using the best material from both presentations.
Accountability: During class, randomly select 1 group of students. Working with their paired partner have each member of the group teach the entire class their material. Each student pair is responsible for turning in their teaching materials.

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