CEAL: Cooperative Learning Coupled With Hands On Experimentation in a Junior Level Fluid Mechanics Laboratory

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Abstract

Recent curriculum changes in the Civil and Environmental Engineering Department at the University of Michigan added a three-hour laboratory section to the existing junior level civil engineering Fluid Mechanics course. One important goal in adding this laboratory section to the course was to maximize student learning of the concepts introduced in the course lecture. To facilitate this goal, the laboratory section was divided up into hands on experimentation and demonstration sessions. Furthermore, the documented success of cooperative learning inspired us to include principles of cooperative learning into the laboratory structure as well. As a result, CEAL was created. CEAL stands for Cooperative and Experimental Learning Initiative. Additionally, a course web page with video, pictures, and software applications was developed to supplement student learning. This paper introduces the fundamental concepts behind CEAL and outlines practical examples on how it was implemented into the laboratory structure of the aforementioned course. Finally, results of student surveys gathered through an implemented feedback system are presented along with lessons learned. The overall positive feedback about the class indicates that students learn better in cooperatively structured group settings in which lecture material is presented in a visual manner coupled with hands on experimentation. Also, group processing in which student group members discuss how well they are achieving their goal of effective working relations seems to play an important role in establishing and maintaining cooperative learning groups.

I. Introduction

An increasing number of people in our society are turning to educational institutions to increase their level of knowledge and thus become more competitive in a technologically advanced working environment. Educational institutions are viewed not only as cradles of knowledge but also as places which foster one’s ability to personally become successful and to contribute to the overall welfare of society. Along these lines, we determined that our goal as educators should be both to maximize student learning and to give our students the necessary skills to succeed. Thus, in designing a junior level engineering Fluid Mechanics course in the Civil and Environmental Engineering Department at the University of Michigan we took these goals as our guide.
It is important to define the meaning of ‘success’, i.e. what skills do we wish to develop in our students in order for them to be successful? “Psychological studies of success and failure in our society reveal that one of the most important characteristics of successful people is accurate perception”\(^1\). In other words, the key to success seems to be the ability to accurately perceive what is required in a given environment. Needless to say, different environments require different standards for success. For example, the ability to understand details and the potential to perform research may be two very important factors influencing the success of researchers in academic settings\(^2\). We believe that in an undergraduate level, it is not realistic to expect many of our students to pursue advanced academic careers. Quite to the contrary, it is our conviction that a majority of undergraduate students perceive their undergraduate degrees as intermediary steps toward a career in the industry. As a consequence, we decided to base the skills our students need to succeed on the requirements of the engineering industry. Valuable skills sought after in candidates for industry jobs are strong communication skills (oral, written, and computer), problem solving and critical thinking skills, an ability to manage and make sense of large amounts of data and information, and an ability to work in interdisciplinary teams to solve increasingly complex problems.\(^2, 3, 12\)

The *Fluid Mechanics Laboratory* course described in this paper aims to maximize student understanding of fundamental fluid mechanics concepts and provide students with necessary skills to succeed in an industry environment. These goals were accomplished by a) the instructional use of laboratory facilities and multimedia and b) implementation of principles of cooperative learning into the class structure. As a consequence, CEAL was developed. *CEAL stands for Cooperative and Experimental Learning Initiative.*

*Tell me, and I forget  
Teach me, and I may remember  
Involve me, and I learn*  
*Benjamin Franklin*

We had the opportunity to take advantage of the laboratory facilities the University of Michigan has to offer in order to *involve* our students in the study of fluid mechanics. For example, we were able to utilize a fifty foot long by 1 foot wide flume for free surface flow studies, a centrifugal pump instrumented for measuring pump characteristics, a pressurized mineral oil tank connected to a pipe with several pressure taps along its sides for the study of laminar and turbulent pipe flow, and an Acoustic Doppler Velocimeter to study the influence of turbulence on velocity profiles. Furthermore, we designed tools and equipment aimed at helping students visualize principles involving concepts of energy, momentum, boundary layer development, lift and drag etc. Examples of the experimental setups can be found on the course web page\(^4\). All the laboratory experiments were complimented with detailed handouts and video images accessible through the Internet. For a sample of visual tools please refer to the course web page\(^5\). It is worth mentioning that most of the experimental setups and virtually all the demonstrations have been designed by
the co-author Steven J. Wright over the course of twenty some years in his involvement with
teaching at the University of Michigan.

As previously mentioned, the documented success of cooperative learning\textsuperscript{3,6} encouraged us to
incorporate cooperative learning principles into the course structure. On the web page of The
Cooperative Learning Center at The University of Minnesota\textsuperscript{7}, cooperative learning is defined as
“the instructional use of small groups so that students work together to maximize their own and
each other’s learning”. P.K. Imbrie\textsuperscript{13}, on the other hand, defines cooperative learning as students
working in teams on problems and projects under conditions that assure both positive
interdependence and individual accountability. Finally, co-author Don Carpenter sees cooperative
learning as the active engagement of student teams to meet a common goal of discovering and
applying course material. The emphasis in all these definitions seems to be to increase student
learning through cooperative group work among the students. This is also what we emphasized in
developing CEAL.

The current paper is divided into five sections. Section II provides a brief background of the fluid
mechanics Laboratory course itself. Section III provides an overview of the concept of cooperative
learning and how cooperative learning principles were blended with hands-on learning experience
to create CEAL. The student feedback mechanism utilized within the framework of CEAL is
presented in section IV. Finally, results of the surveys and lessons learned are presented in section V.

II. Background of the Fluid Mechanics Laboratory course

The revised course CEE325 Fluid Mechanics was first introduced in the fall of 1999 as a result of
curriculum changes in the Civil and Environmental Engineering Department at the University of
Michigan. The College of Engineering bulletin describes this course in the following manner:
“(CEE325 teaches) principles of mechanics applied to real and ideal fluids. Topics include fluid
properties and statics; continuity, energy, and momentum equations by control volume;
dimensional analysis and similitude; laminar and turbulent flow; boundary layer, drag, lift;
incompressible flow in pipes; free-surface flow; adiabatic flow of ideal gases in conduits; fluid
measurement and turbo machinery.”

Prior to the curriculum change, CEE325 was offered as a three credit hour lecture course. It
consisted of a lecture and weekly homework assignments. In the new curriculum, the credit hours
have changed to four. Three of those credit hours are allocated for lecture and one credit hour is
allocated as a weekly laboratory section taught by Graduate Student Instructors. This laboratory
section may be either a discussion/demonstration session or hands-on laboratory experimentation
session. These sessions are taught alternately throughout the semester. The lecture itself has not
changed fundamentally from how it was taught prior to the fall of 1999. The overall enrollment in
the class when it was taught in the fall of 2000 was 65. The students were subdivided into four
laboratory sections meeting at different days of the week.
The discussion/demonstration sessions are aimed to help students apply concepts covered in the lectures to “real” applications as demonstrated by the instructor. This session is structured in the following manner. The instructor gives a brief summary lecture about the principles of a demonstration followed by the actual demonstration itself. Afterwards, a discussion question related to the demonstration is asked. Following the question, the students discuss the subject with their classmates.

The purpose of the experimentation session is to give students a feel for how measurements are conducted and how they can be used to verify or test theoretical considerations outlined in the lecture. The experimentation session is structured in the following manner. The instructor gives a brief summary of the purpose of the experiment, the devices that will be used, and how to operate them. Afterwards, the students go to the laboratory and, under the supervision of the instructor, conduct the experiment. Finally, the students are expected to write formal laboratory reports with their group members. In these reports, students are expected to analyze the data they gathered and answer questions as they relate to the material at hand. For example, in the orifice experiment laboratory, the students were first given a theoretical treatment of water discharging through orifices. Documentation on the lecture together with a picture of the orifice apparatus can be found on the course web page. Later on, the students were taken down to the laboratory and the instructors showed them how to operate the apparatus and gather the data. Examples of data gathered are discharge (volume of water leaving the orifice per unit of time), water elevation inside the tank from the water surface to the centerline of the orifice opening, the distance the jet of water leaving the orifice travels before it hits the floor, and the dynamic pressure at the exit of the orifice opening measured with a pitot tube. Examples of questions the students needed to answer include “Does there appear to be a trend in the variation of the discharge coefficient with the water elevation inside the tank” (measurement uncertainty application) and “Does the drainage time you calculated agree with experimental results? If it does not, why do you think?”

III. CEAL: Cooperative and Experimental Learning Initiative

CEAL blends principles of cooperative learning with hands-on experimentation to improve student comprehension. Cooperative learning is an essential part of CEAL. The definition of Cooperative Learning generally places cooperative groups into one of two categories: informal cooperative groups and formal cooperative groups. In this course we utilized both types of groups.

In informal cooperative groups, students form temporary groups of three to four students to perform tasks such as answer questions or summarize a lecture. The goal is to share each other’s ideas, listen to each other’s viewpoints, and create an answer every group member agreed upon. Within the framework of the Fluid Mechanics Laboratory, informal cooperative groups were used in the discussion/demonstration section of the course. After asking a question relevant to the demonstration for that particular week, the instructor breaks the students into groups of three to
four students. The students then are encouraged to formulate the answer to the question by discussion within their groups. During the discussion, the instructor goes to each group to address specific questions they might have. Following the discussion, the instructor randomly calls on individuals in groups to summarize the answer of the group. For example, when we explained the process of cavitation and pressure distribution in accelerating fluids to students, we first directed them to the class web site on cavitation \(^{14}\). This website supplemented the theoretical discussion of the matter with some images on the production and effects of cavitation on propeller blades. Afterwards we showed our students a cylinder with very low-pressure air on top of a water column (Figure 1). We wanted them do discuss with their group mates and find an answer to the following question (as presented in the documentation on the course web page \(^{14}\)) Which direction do you think we need to ‘jerk’ the cylinder in order for cavitation to occur? Up or down? At the end of the discussion, the instructor demonstrates the process of cavitation using the cylinder. The demonstration has a ‘visual’ impact in that cavitation is illustrated by the visual appearance of vapor bubbles at the bottom of the column along with a distinct production of acoustic noise. Finally, the instructor randomly calls upon individuals to summarize the answers of their groups. Any inconsistencies or ambiguities are addressed both by the instructor and the students in the demonstration session.

![Figure 1: Cylinder used for the cavitation demonstration](image)

The goal of the formal cooperative groups was to create an environment in which students could share, listen, and discuss their viewpoints and summarize them in a formal laboratory report related to the experiments they did in the laboratory. Formal cooperative groups lasted throughout the entire semester. The features of the formal cooperative groups are:

a) laboratory assignments are completed and handed in by teams
b) only names of participants are put on the final products
c) one grade per team

In the beginning of the semester, the students selected their formal cooperative groups themselves. The only limitation was that the groups could not be larger than four students.

It is important to keep in mind that students do not immediately cooperate as soon as they are put into groups. There are several basic elements any group needs to have in order to function.
According to Johnson, Johnson, and Holubec, these elements are:

a) structuring positive interdependence,
b) arranging face-to-face interaction,
c) structuring individual accountability,
d) teaching students the required small group skills, and
e) group processing.

a) Structuring positive interdependence
“Positive interdependence is successfully structured when group members perceive that they are linked with each other in a way that one cannot succeed unless everyone succeeds.” In order to facilitate positive interdependence, we structured group assignments such that each group member had a role. The roles, as we defined them, were calculators, analyzers, and formalizers. Furthermore, students in each group would rotate these tasks for different assignments. The calculator was primarily in charge of performing the calculations necessary for the laboratory assignment. The analyzer was guiding the group in answering the questions in the laboratory assignment. The formalizer, on the other hand, was the person primarily responsible in leading the group when the group was ready to put all their information together into a formal laboratory report. Figure 2 shows a sample of a laboratory handout we used.

Within the task division put forth in this manner, a group cannot succeed unless every group member participates. Furthermore, the overall success of the group (in terms of the grade the group gets) strongly depends on every group member doing their best. Furthermore, every member in the group, especially the formalizer, must interact with the others in order to, at least, determine how to link individual task pieces together. As a consequence, we believe the task division we put forth structures positive interdependence.

b) Arranging face-to-face interaction
“Students need to do real work together in which they promote each other’s success by sharing resources and helping, supporting, encouraging, and applauding each other’s efforts to achieve.” For each laboratory session, individual laboratory groups were assigned to a time schedule for making laboratory measurements. For example, group one would come in first to collect a portion of the required data; half an hour later, group two was expected to come to the laboratory etc. This enabled every student in the entire laboratory session for that particular day to participate in the experimentation.
Knowing that the students needed each other’s data to complete the assignment encouraged the students to be more careful in gathering their portion of the data. Furthermore, the sharing of data contributed not only to the success of the entire laboratory section but also to the success of each individual student.

c) Structuring individual accountability

“Two levels of accountability must be structured into cooperative lessons. The group must be accountable for achieving its goals and each member must be accountable for contributing his or her share of the work”.\textsuperscript{7,8} Especially in order to address the issue of individual accountability we instituted a mechanism by which students were asked to evaluate their group mates at the end of the term. As mentioned earlier, each group consisted of three to four students. If, in any group, there was one person who two of the three students or three of the four students (depending on the group size) identified as contributing significantly less work to the group than the rest of the group members, this person would get a –10% added to their overall laboratory grade. The person who is
identified as contributing significantly more work to the group, on the other hand, would get a +10% added to their overall laboratory grade. In order to establish group accountability, students were informed that in every group, the formalizer would obtain an additional 10% added to the overall laboratory assignment grade the group received. Since everybody was going to take their turn in becoming the formalizer, group members were encouraged to support each other’s efforts. Ideally, every member would do their share and the +/- 10% would not be applied. In fact, this was the case in nearly all the groups in the entire laboratory section.

d) Teaching students the required small group skills

“Cooperative learning is inherently more complex than competitive or individualistic learning because students have to engage simultaneously in task work (learning academic subject matter) and teamwork (functioning effectively as a group)...Social skills for effective cooperative work must be taught to students...” 7, 8. At the beginning of the semester, a three-hour laboratory period was dedicated to sharing the principles of cooperative learning with the students. During this time period students had the opportunity to ask questions and familiarize themselves with the concepts of cooperative learning and how it differed from competitive and individualistic learning types. We also put the class discussion on the web for students to refer to later on in the semester 9.

Introducing the principles of cooperation helped the students understand what kind of a working environment we wished to foster in the laboratory sections. In addition to this demonstration, some student groups needed more specific guidance as to how to function effectively as a group. In one group in particular, personal differences created some friction, which prevented the group from functioning properly. The instructor noticed that the problem was primarily communication. After creating some sessions in which students were able to talk about their differences, the functionality of the group increased again. Although the problem between two individuals was never resolved entirely, they were able to not let personal differences influence the efforts of the entire group in a negative manner.

e) Group processing

“Group processing exists when group members discuss how well they are achieving their goals and maintaining effective working relationships” 7,8. There were three Graduate Student Instructors (GSI) for the course. We all spread out our office hours in such a way that at any given day the students had the opportunity to speak with any GSI and/or the course instructor not only about lecture material but also about the performance of their group in general. Furthermore, the GSIs were monitoring the performance of the groups and had the option to intervene in the group’s work if they felt the need to do so. As mentioned before, there were cases where the instructor needed to intervene in order to maintain an effective working relationship between group members.

IV. Student Feedback

“If used properly, student feedback can help maintain student attention, elicit responses and
classroom discussion, and help organize the student’s thoughts\textsuperscript{10, 11}. In the fluid mechanics laboratory we used three different student feedback mechanisms: a) student ambassadors, b) laboratory surveys, and c) an end of course survey.

Two volunteers from each laboratory section were selected to become student ambassadors. A few times during the semester, the instructors would leave the class early. During the remaining class period, students, through the guidance of the student ambassadors, would discuss areas of further improvement or anything else the students felt the instructors need to be made aware of. Areas of further improvement included the questions being asked during demonstration sessions, the format of the formal laboratory handouts, the manner in which material was presented in the laboratory sections etc. The goal of this exercise was to help students brainstorm for problems and solutions rather than listing complaints only. In one of the laboratory sections, for example, the instructor was not giving complete answers to discussion questions they asked. The thought was, that by doing so, the students would think some more about the question and see the instructor during office hours for a more detailed answer. The students did not like this approach. Instead of just complaining about this (for example by saying that the instructor was not good or that the discussion was unclear) they suggested the following: “We would appreciate if you could give the whole answer to the discussion question before you move on to the next topic”.

In order to address more specific issues involving individual laboratory exercises, such as whether we were able to demonstrate certain fluid mechanics related principles to students in as an effective manner as we had hoped, we conducted a total of four laboratory surveys. In those surveys, students were asked to grade questions about the subjects they learned and the effectiveness of the laboratory exercise in the following manner:

- 1 = no added value beyond that obtained in lecture
- 2 = some added educational value
- 3 = definite added educational value
- 4 = very useful learning experience

Figure 3 shows a sample survey utilized for this purpose.

Finally, at the end of the semester, we conducted a survey to get an idea of which of the labs students thought were most effective in conveying principles of fluid mechanics and if there were any areas of improvement. A sample of this survey is given in Figure 4. We also compared the results of this survey with a similar one administered to students in the fall of 1999 when the CEAL structure was not present.
VI) Survey Results and Lessons Learned

Were we effective in giving our students the necessary skills to succeed? Did our students see the course as a valuable experience? We may not be able to fully answer these questions, however, the results of the student feedback we gathered shed some light on the answers to these questions.

Overall, a majority of our students (more than 50%) believed that the laboratory exercises presented through the concept of CEAL added definite educational value beyond that obtained in the class (a grading score of 3 and higher, as mentioned in the student feedback section of this paper). Only two students among all the survey participants (56 students total) believed that the laboratory sessions for which surveys were administered added no value beyond that obtained from the lecture. A more interesting result is that the surveys collected during the first half of the semester indicated that 62% out of 53 survey participants believed that laboratory exercises added a definite educational value beyond that obtained in the lecture. At the end of the semester, this ratio increased to 80%. One conclusion may be that there was an initial resistance to CEAL in the beginning but as students exposed themselves more to the concept, they found important value in

Figure 3: Sample Laboratory Survey
it. However, we would like to view this result with some caution because the final course survey we handed out indicated that the laboratory exercises in the second half of the semester were more favored by students than in the first half of the semester.

Additionally, when asked how much of what they learned was acquired through discussion/collaboration with their group partners, approximately 57% of our students marked 60% and higher. In our view, this is an important result indicating the value of cooperation in the comprehension of material of our student body.

At the end of the 1999 academic semester, we administered a questionnaire to the students in the course, which was intended to determine the student’s perceptions of the laboratory sessions. The questionnaire was simple in design; in addition to some general questions, we asked the students to indicate their three most favorite lab sessions as well as their three least favorites. The original intention was to use this input to re-think the structure of individual lab sessions. What we found
was that the students preferred the demonstration sessions by a significant amount (69 percent of the most favorite sessions were indicated to be demonstration sessions). We used this information to restructure the measurement laboratories along the lines outlined in this paper as most of the cooperative efforts were implemented in the measurement labs. At the end of the 2000 academic semester, we decided to re-administer the same questionnaire to see if there were any changes in the student responses. The students again preferred the demonstration sessions, but this time only at a rate of 58 percent of the most favorite sessions. This comparison is imprecise since we did make changes to individual sessions, but these were primarily to the demonstration sessions. Another measure of the "least favorite" sessions showed little change from year to year with a 1999 rate of 69 percent of the least favorite sessions indicated to be laboratory measurement sessions decreasing only slightly to 63 percent in the 2000 course. Nevertheless, we take both of these shifts as indicative in a shift in the student’s approval of the measurement laboratories and the associated cooperative learning approach. To consolidate this view, we would like to present an excerpt from a letter a student wrote to Prof. Wright at the end of the semester. For the sake of anonymity, the name of the student has not been mentioned here.

…”You have been a great teacher and I really enjoyed Fluids 325. I know I may not have made a great impact on your class, but it certainly made one on me. It [the class material] was a definite challenge, but you and the GSI’s were of so much help and you made it interesting, and made us think during labs…these are things that other CEE classes are definitely lacking.

Traditional end-of-semester course evaluations included a number of questions relating to the effectiveness of the laboratory section in the overall course structure. On every laboratory related question asked in this evaluation, significantly more satisfaction was indicated in the 2000 course as compared to the 1999 course. In particular, a question asking "I gained valuable experience in working in teams in this course" received an increase in median score of 0.15 between the two years; this appears to be an increase of about 15 percent in the relative score compared to other courses taught at the University that asked the same question.

In retrospect, however, we feel that we should have put more emphasis on the fifth element of cooperative learning, namely group processing (as mentioned in section III of this paper). The way we administered group processing was by the instructors monitoring the working relationships between group members. This monitoring was limited to the times when the instructors were either in the laboratory sections with the students or when students approached the instructor with problems. What ended up happening was that toward the end of the semester, when exam periods came around, students used the task divisions between groups as a convenient way to subdivide work. Consequently, they did not need to meet as regularly as they did before. If we had a structure in place in which group members met in regular time intervals to discuss working relationships within the group, they would have been able to use this time to finalize a better plan to meet with each other in order to get the work done. They further would have realized that
continuing to work in a group would have decreased the time and effort each individual member needed to put into the final report.

In summary, this paper provided an outline and description of a fluid mechanics laboratory course that was offered in the fall of 2000. It also introduced the concept of CEAL (Cooperative and Experimental Learning Initiative), which was implemented as part of the course. As a consequence, principles of fluid mechanics were introduced to junior level engineering students in a format where they had a chance to do actual experiments and see visual demonstrations of principles learned in class, and where they shared, listened, and created results themselves in a cooperative group environment. Overall, we believe these exercises increased an understanding of principles related to fluid mechanics.

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