Using writing to enhance collaborative learning in engineering courses

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Abstract: Many educators use collaborative learning in engineering courses. After detailing our efforts to employ collaborative efforts in our classrooms, we argue that these efforts can be enhanced and augmented by the thorough integration of writing. We give specific classroom examples of our recent efforts toward this end in three engineering courses—circuit analysis, solid state devices, and senior design. We explore writing in general terms as a process that allows collaborative learning to be more efficient and effective. We argue the use of writing, both as a learning tool and as a means of communication, can result in a qualitative improvement in collaborative efforts, that it is useful for addressing problems of students with a variety of learning styles, and that it is a flexible learning tool in developing critical thinking. Writing can be used to allow students adverse to group work and those who communicate poorly to participate more fully in collaborative activities. Frequent use of writing in engineering courses can both deepen students’ understanding of technical content and allow us to include topics which contribute breadth. All the while, writing allows students to develop a variety of skills vital for professional success.

Introduction

Collaborative learning is widely used in classrooms today. It engages students, involves them in knowledge construction, and gives them responsibility for their own learning. It helps to develop critical thinking. It closely parallels real-world activities and broadens the individual student’s perspective. As they are allowed to work together, students become actively involved in learning, and we, as educators, gain a powerful educational tool. Our thesis here is that the writing process can be used to enhance collaborative learning efforts. When integrated with collaborative strategies, writing can help achieve many fundamental educational goals. As a learning tool, writing is uniquely valuable, and it has long been recognized that writing is a vital component of engineering education.[1,2] We shall argue here that writing has pivotal role to play in our efforts to incorporate collaborative learning into engineering curricula.

Classroom observations

Research presents solid reasons for educators to employ collaboration in the classroom. We shall detail here some strategies used in three engineering classes—in solid state devices, in electrical circuit analysis, and a capstone senior design course. Nearly all the approaches here are known and have been reported upon by other workers in the field.[3,4] We shall discuss those we employed and how we use writing to enhance them.

Collaborative Structure

The class on solid state devices was composed of junior and senior electrical engineering students, the class on electrical circuit analysis was composed of sophomore electrical engineering students, and the third class, a senior design capstone course, was composed of an interdisciplinary group of mechanical and electrical engineering students.

In the solid state devices class, teams of three were designated by drawing numbers from a hat. The class assignments included homework, quizzes, exams, and a writing portfolio. From the start of class, it was emphasized that teamwork was encouraged in homework and writing assignments. To be sure that each student is held accountable for homework and writing assignments, the exams and frequent quizzes required individual work. In this way, low achievers were identified so that steps could then be taken to improve their performance. Members of each team were given a stake in their teammates’ performance by awarding bonus points based on team performance. For the writing portfolio, quizzes, and exams, a 5% bonus was given to each team member of teams whose members all scored above 75%. For scores above 80%, a 6% bonus was given; above 85%, a 7% bonus; and above 90%, an 8% bonus was awarded.

Awarding bonus points is a common classroom strategy that is remarkably efficient and effective. It provides an incentive for team members to help one another, placing peer pressure on all students to perform well. Most educators likely have made the observation that those
students with less native talent, who must work hardest to succeed, are often precisely the ones who expend the least effort. Thus, in many classrooms, those least able are also those expending the least effort. Collaborative learning strategies can help put an end to this waste of potential in our students and ensure that all more fully realize their potential. And, as time progresses, teams develop a group identity and pride that make assignments interesting and fun.

The same strategies were employed in the electrical circuit analysis course. One difference between this course and the solid state devices course, besides each team having four members, was that this course had an integrated lab component. In lab, students worked in the same groups as in class and submitted a common report for which they were given a common grade. To ensure individual accountability for laboratory work, quizzes over material covered during the previous week were administered at the beginning of most laboratory classes. Laboratory work significantly enhanced group interdependence in this class when compared to the solid state devices course. In most laboratory work, the students really do become interdependent. Each performs functions that are vitally important to the group’s success. This team-building, cultivated in the lab, transferred in visible ways to enhance students’ collaborative work in the classroom. In courses without a laboratory component, as in the solid state devices class, such transport is not possible.

The senior design capstone course evolved from a strong desire among the faculty in the mechanical engineering department at VMI to provide their seniors with a real-world design experience. Industry executives are invited to submit actual projects they would like to pursue. The engineering faculty then chooses appropriate ones from the list, and students sign-up for projects according to their interest. At the beginning of each project, each student group travels to the industrial site to meet with the industry partner. In cooperation with industry officials, the students define the project scope and desired outcomes. Throughout each project, the student group has actual responsibility for the project, and the student group leader is responsible for making sure each member of the project team actively contributes to the group’s success. The supervising faculty member receives frequent written progress reports, and each group member is responsible to their group leader for reports investigating specific topics. Upon completion, a written report is prepared for the industry partner, and students give a formal, professional presentation at the industrial site based on the findings detailed in their report. The industrial partner and faculty advisor have equal weight in determining the grade given to the group.

Specific examples of how writing enhanced collaboration and furthered overall educational goals in these courses

The results of these classroom efforts were mixed. Some students benefited from writing far more than others. The reader will likely not be surprised when we report that some of our students did not consider writing important and questioned its usefulness. Such students naturally did not receive the full benefits available from the use of writing. On the other hand, the many students who invested writing with importance did receive the rich and substantial benefits available.

We observed three primary benefits. First, writing results in enhanced group discussions and allows important topics to be better understood by students. Second, writing gives the instructor a powerful assessment tool that is quite useful in gauging whether students really understand a given topic. Third, we observed that a synergy develops between writing and collaborative learning when students are asked to review each other’s writing.

Early in the solid state devices class, students were asked to write on the physical operation of electron tubes, specifically the diode and triode. The operation of these electron tubes are, in many ways, analogous to the operation of semiconductor diodes and transistors. Electron tubes are perhaps simpler to understand qualitatively than their solid state counterparts, and, through the detailed discussion required when writing their papers, these students likely developed a solid foundation for further study when we began to study solid state devices. Later papers and exam essay questions on solid state diodes and transistors further reinforced their physical “feel” for the devices. The physical understanding of device operation is far more important and useful than an understanding gained solely through familiarity with its mathematical model. Moreover, such a physical understanding is vitally important when, in their more advanced analytical and experimental work, they have need to understand and predict the limitations of its model. In class, we observed that group discussions of device operation focused more on the physical operations of the devices and less on merely finding the “solution” to the mathematical model. When compared to past classes, it seemed that a higher percentage of students were able to tie device behavior to the physical mechanisms giving rise to the behavior. We take this as evidence, anecdotal evidence to be sure, that these students had gained a more mature understanding than would have been possible had we not combined writing with collaborative strategies in the class.

As an example from the circuits course, students were asked, in one assignment, to report on the problems and challenges present in battery technology—in its improvement and in the recycling of batteries. During and after this writing assignment, these students held several
informed discussions on the various related issues, both in group discussions in class and in informal discussions outside the classroom. Through this assignment these students gained a more sophisticated understanding of batteries than is usual in an introductory circuits course. It allowed the inclusion of an important, current, and relevant topic in their engineering education to which they might well not have otherwise been exposed. And, all the while they were involved in this study, their basic communication skills were being developed.

The senior capstone design course required close collaboration on the part of the students throughout the entire semester. The team included students from both mechanical and electrical engineering. There was real interdependence in the project as it was too large for any individual—the work had to be split among team members. The group had to succeed for any individual to succeed. The team leader decided how each member could most effectively contribute to overall group success. An integral part of this effort was the writing required throughout the project. The group members often communicated via email, and the frequent progress reports to their faculty advisors and industrial clients often required them to work and write frequently together. The writing component in this course, especially, may have been the most important factor in ensuring effective collaboration. Each student had to write in order to inform the others on the team of their progress, and the overall team progress had to be reported to their advisors and industrial client. Without writing being thoroughly integrated in the course, the team could not have been successful. The model followed in this course seems to us to accurately mirror the work in which many, perhaps most, engineers engage in each day in their professional work.

Another way that writing enhances collaborative learning and overall educational goals is through its power as an assessment tool. Writing provides a uniquely penetrating probe into thinking processes. As such, it can provide strong evidence of the presence, or absence, of mature and creative thought. In both the circuit analysis class and in the solid state devices class, student writing often uncovered poorly understood points. For example, in the circuits class, it was quickly learned that many in the class did not immediately understand, among other things, sinusoidal steady-state analysis. Many of these same students could mechanically follow the procedures in certain problems in phasor analysis to obtain the correct solution. But, by having them write on the topic, it was often revealed that they had little real understanding. Most topics in science and engineering rely on previous learning. By the modest use of writing—a paragraph here, a page there—we can make certain that important misapprehensions are not carried too far. That is, through the use of short writing assignments, we have an efficient assessment tool that can continuously monitor student understanding as they progress through our engineering programs. Moreover, by coupling writing as a learning tool to group work, we feel that we are able to effectively reach a higher percentage of students than would otherwise be possible. By assessing their understanding through writing assignments, we can, precisely and efficiently, identify and correct errors in student thinking. In subsequent group work, these students can then amplify our efforts by transferring their knowledge to the rest of their group. The mutual help between students in an important factor in the construction of knowledge in collaborative learning. The process of discovery through writing can allow students, when they meet as a group, to participate in an informed discussion. Our students often attest to the fact that without these writing assignments their understanding of the course material would have lacked a crucial depth. A student in a circuit analysis class who has only the most rudimentary understanding of the meaning of a transfer function might, for example, be asked to write a short description of the meaning of transfer functions prior to collaborative activities. In discussions on transfer functions, each group member then would be able to both contribute more meaningfully to group discussions and to benefit more fully from the comments of others during such a discussion. Group work is enhanced when each member of the group has personally struggled with the topic through the process of discovery available through writing.

In addition to this, we feel writing is particularly valuable in an educational environment where computer tools are widely employed since these tools can mask a student’s lack of understanding. For example, in a systems analysis class, students often rely on computers to perform, say, convolution, or they perform the operation by hand, often in a quite mechanical fashion. Whether they truly understand the meaning of convolution may well remain unknown to their instructor. Perhaps they are following some recipe, and they treat convolution as just another step in the recipe. If we ask them to write on convolution, however, we can quickly learn whether they truly understand convolution, that it is an application of superposition.

Finally, writing can enhance collaborative efforts by having students peer-review other students’ work. We have seen indications that a synergy can develop between writing and collaborative learning when students are asked to peer-review their writing. In the courses reported upon here, even though we encouraged students to review each other’s work, they were required to do so just two or three times during the semester. Having seen indications of the remarkable results that may result from this tool, however, we plan to employ it to a greater extent in our future classes. Having students peer-review gives student writers a real audience and invests their writing with importance. Many
students seem more willing to submit shoddy work to their professor than to their peers. By a gentle application of peer pressure, students can be encouraged to become more diligent in their work.

Through peer-reviews, group members can gain detailed access to each other’s thoughts. Poor writers gain immediately through having a pattern to follow in their own writing, and all see the issues from another’s perspective. Peer-reviewing is also valuable for the experience of editing it provide students. It is often easier to see weaknesses in someone else’s work than one’s own. In general, students can gain editorial experience that is certain to prove useful when analyzing their own work.

Students who write best are often different from those who perform best on analytical homework, quizzes, and exams. Collaborative work promotes a valuable awareness among students that they all have different strengths and that this diversity makes the group stronger. This is an important life lesson for students to learn while in school. Through peer-review, new respect and appreciation is accorded those who write well by other members of the group. This acts to more evenly balance the power relationships within the group and enhances group interdependence.

How writing can help in achieving some of the important goals of collaborative learning

It is vital that each student learns to conduct an internal dialogue, to become a reflective thinker. Long ago, John Dewey emphasized the importance of reflective thinking as an educational goal.[5] He argued that students should be asked to reason and think for themselves. It prevents students from being passive, waiting to receive wisdom from their professor or to be stimulated by television. It encourages them to act for themselves, to rely on themselves and others in their group. The writing process can also serve as an important training tool for the mind—perhaps, in the end, an even more important one. Happily, we can have both collaborative learning and writing. In fact, as we argue here, they work best when used together.

Writers are active agents, engaged in thinking for themselves. When writing, what is to be related must first be made clear to oneself. The writer is forced to develop a comprehensive, logically constructed, and connected discussion. Research in writing across the curriculum during the last twenty years has revealed clear evidence that writing is a uniquely effective tool for promoting learning.[6,7] Quite simply, by utilizing writing in more of our classrooms, we encourage action and thought on the part of our students.

Others have pointed to the need for reflective thinking in engineering education. Donald Schön argues persuasively that the educational preparation professionals receive is largely training in some type of rational technique, that they are not always allowed to develop critical thinking skills.[8] He writes:

But, as we have come to see with increasing clarity over the last twenty years or so years, the problems of real-world practice do not present themselves to practitioners as well-formed structures. Indeed, they tend not to present themselves as problems at all but as messy, indeterminate situations. Civil engineers, for example, know how to build roads suited to the conditions of particular sites and specifications. They draw on their knowledge of soil conditions, materials, and construction technologies to define grades, surfaces, or dimensions. When they must decide what road to build, however, or whether to build it at all, their problem is not solvable by the application of technical knowledge, not even by the sophisticated techniques of decision theory. They face complex and ill-defined mixtures of topographical, financial, economic, environmental, and political factors. (Italics in the original)

Like Dewey, Schön points to the need for engineers who have developed the capacity for reflective thought, ones capable of thinking what they are doing while they are doing it. That is, in practice, engineers need to be able to adjust their techniques and strategies continuously, based on the difference of the present state of a design versus the desired final one. Writing can play a role here in at least two ways. Writers are forced to think comprehensively and to link thoughts in sequence. The vast majority of writers also extensively rewrite and revise their work. The habits developed when writing—thinking comprehensively, expecting to rework the initial results, and knowing there is no one “correct answer”—are indispensable in educating the reflective practitioner.

Researchers have demonstrated the ways in which writing can address the needs of students with different cognitive styles, i.e., various natural inclinations for processing and then expressing knowledge. Kolb has shown the difference among students he labels “convergers,” who seek direct routes in problem-solving; those he calls “divergers,” who enjoy more creative approaches, such as mapping and brainstorming; “assimilators,” who enjoy building new knowledge by
collecting and processing that from other sources; and finally, “accommodators,” who enjoy basic trial-and-error approaches to learning.[9] Writing assignments, particularly those involving collaborative work, are ideally suited to match the fullest range of student needs.[10] As Bean argues, “Through strategies that promote active learning, teachers hope to make students more engaged and inquisitive learners...”[11] Writing is one of the best available means for encouraging students' involvement with course material.

Discussion

Engineering education must, by its nature and heritage, be closely linked to results and measurable outcomes. One crucial skill the engineering student must develop and possess is the ability to think critically. The ability to think, maturely and independently, is vital for success. Without critical thinking skills, it is difficult to see how students can possess many of the outcomes called for in Criteria 3 of ABET 2000.

Our challenge, then, is to employ the most effective tools to achieve this end. We believe most engineering courses should incorporate writing in some fashion. We believe that, when students are asked to write about what they are studying, the subject matter being studied is more thoroughly and more deeply comprehended. Student might be able to move such knowledge across disciplinary and subject boundaries. The present efforts in curricular integration largely have this as their object—giving the student the ability to transport knowledge and techniques across disciplinary and subject boundaries.[12] The goal is for the student to gain a number of flexible and powerful ideas which can be used as a tool in diverse areas.

Modern theories of knowledge point to the fact that language and our ability for thought cannot be separated, that they are interdependent.[13] Vygotsky, in the 1930s, studied how we use language as a tool in the construction of knowledge.[14] Language is a symbolic system and is used by our minds to accomplish tasks and to think thoughts that would otherwise be impossible. We are symbol manipulators. Our ability to think clearly and well is contingent upon the symbols available to us. The meanings associated with language permit us to think sequentially and in manageable chunks. Confirming the relationship between thought and word requires only a moment's reflection. For a few moments, try to think—without words, without inner speech. The result, while perhaps pleasant, likely does not include a logically-connected sequence of thoughts. This idea, that language is a vital tool allowing our minds to think efficiently, is also emphasized in more recent work in the theory of knowledge.[15,16] Another writer, Hamann, states: “Even if I were as eloquent as Demosthenes, I would merely have to repeat a single maxim three times: reason is language, λόγος. This is the bone that I gnaw on and on it I will gnaw myself to death.”[17] That language is inseparable from thought is therefore seen not to be new. Nor is it unique with the Greeks. Just as in ancient Greek, where logos denotes both reason and language, so to in ancient Egyptian there is a single word for the two concepts.[18] Our point here is that language is the primary symbolic system in general use and that it should be seen to be of central utility in efforts to develop the ability of our students to reason. Indeed, many researchers doubt whether language or the human mind could have developed independently. They argue that, in a real sense, our identity as self-conscious reasoning beings is dependent upon having access to, and effectively using, language.

To incorporate writing in engineering courses effectively, however, requires careful planning, imagination, and hard work. The individual instructor must be convinced of the utility of writing and be committed to its introduction. We have encountered resistance from some engineering students to the use of writing in engineering classes.[19] The instructor must be firm and be committed to a long-term effort if the introduction of writing into engineering courses is to be successful. Both the assignment of writing and its grading is time consuming. In previous Frontiers of Education Conferences, others have presented efficient ways to minimize this burden while still obtaining the pedagogic benefits of writing.[20,21] We agree with these researchers who suggest that student conferences are an effective and efficient tool in the evaluation and grading of student papers.

Institutional support is important as well. The administration must be supportive of efforts to integrate writing into the curriculum, and faculty must be convinced the effort is worthwhile. Perhaps most important is that the effort must be sustained and steady—quick results are unlikely. The importance of writing must become part of the fabric of our curricula, not concentrated in only a few courses but rather extensively utilized in most. At VMI, we have begun efforts aimed to more thoroughly integrate writing into the curriculum. A Writing Across the Curriculum committee has been reconstituted, bringing together faculty members from most disciplines. The committee is charged with the role of advocate, and conducts regular meetings and workshops to discuss and learn about the effective use of writing in all disciplines. A writing center, staffed with composition professionals, has been established to assist faculty in helping students with the writing process, and we shall soon introduce required writing intensive courses into our core curriculum.
Conclusions

We are working to incorporate collaborative learning into our classrooms. We are convinced, as many others are, that students' experiences and outcomes are enhanced through collaborative efforts. In collaborative learning, our role as educators is to ensure that our students are actively involved in learning. The argument presented in this paper has been that writing can be employed to enhance and to augment collaborative learning efforts. Writing is a powerful educational tool that can and should be utilized in most engineering courses. Writing encourages critical thinking on the part of the student while improving the ability of students to communicate. The technical competence of our students is raised, not lowered, by the thorough integration of writing in engineering courses.

Perhaps most importantly, writing is a central intellectual tool to aid in life-long learning. Writing provides a uniquely valuable mode of learning, and if we ignore this tool, as is presently done in many engineering courses, our students are deprived of a central intellectual experience. Indeed, for many of our students, the process of knowledge discovery during writing may be the most important skill they gain during their entire collegiate career.

References