MULTI-LEVEL DESIGN TEAMS: A SUCCESS STORY?

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Abstract – *A study of student team evolution, performance, and student satisfaction was completed in a novel, vertically integrated, Materials Science and Engineering design course that included mixed sophomore, junior, and senior teams. This course explored a new learning model where students at different grade levels worked together to solve small design problems. The course included simple analysis oriented quizzes and team-based design projects. Each team had members spanning grade levels. In addition, teams were given guidelines for team functioning and recordkeeping, and evaluated on performance in these areas. The impact of the vertically integrated student team experiences was evaluated by means of a questionnaire administered before and after the experience. Questionnaire responses were evaluated and statistically significant results are reported.*

Introduction

The importance of engineering undergraduate's experience in design and their ability to function as a member of a team is at the forefront of engineering education today. Much attention has been and continues to be given to collaborative learning in the engineering classroom with more and more emphasis on students working in teams to do homework problems and class projects. The success of this more collaborative classroom is presented throughout literature [1-3]. Additionally, much attention is given to the importance of the incorporation of design into the undergraduate curriculum. Often, the design experience is added as a 'capstone-type' course in which knowledge gained in prior courses is tied together with the design process by means of a real-world final project [4]. The importance of the design experience and its incorporation into engineering curricula is heavily influenced by industry as well as by the Accreditation Board for Engineering and Technology (ABET) [4].

Collaborative learning occurs when students work in teams to accomplish a common goal while maintaining positive interdependence and individual accountability [3]. The process of collaboration must include face-to-face interaction, teaming skills, goal setting, and team assessment [3]. Although this method has been shown time and time again to be extremely effective as a teaching methodology in college engineering courses [3], it provides the additional benefit in that students must learn to function as a team, a skill critically needed when entering the workforce as practicing engineers. As design experiences are necessary to prepare the student for the practice of engineering, and since most practicing engineers work in multilevel/multidisciplinary teams, it seems natural that the best preparation is to merge the two.

Focus on the incorporation of design and teaming throughout the curriculum stems from dissatisfaction in industry with graduates who are insufficiently prepared to tackle even simple problems that are new or unfamiliar. Although graduates have the necessary intellectual tools for solving problems, they are often ill-prepared to apply these tools in situations that vary, even slightly, from previous experience. Additionally, graduates often have poorly developed team skills. The advantage of asking teams to solve simple design problems is that such problems have no immediately obvious answer, and there is no explicit roadmap given for their solution. Students are forced to work together, drawing upon their experiences in prior classes and their varying expertise, to restate the problem so it can be solved with the tools at hand.

The ABET Engineering Criteria 2000 general criteria for basic level engineering programs is consistent with demands from industry. ABET requires that engineering programs demonstrate that graduates are able to "design a system, component, or process to meet desired needs and an ability to function on multi-disciplinary teams" [5]. Additionally, ABET recognizes that design cannot be taught in one course; it is an experience that must grow with the student's development [5].

A course involving multi-level design teams provides an opportunity to better meet the demands of industry and ABET and in the process, better prepare the students. This paper focuses on the initial offering of a new course entitled *Vertically Integrated Design*. It explores a new learning model in which students at different grade levels work together on teams to solve design problems. The students are required to take this course each fall semester of their sophomore, junior, and senior years.

Background

The course was organized with the following key aspects in mind:

- Design projects were stated in realistic terms so that the students had to hone the problem statement into something solvable. This was intended to simulate a real world situation in which their supervisor is not likely to state an unambiguous, well defined problem identifying the table in

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which all the relevant data are located. The problems were designed to take a little insight to solve and required students to extend their experience.

In all cases the problems posed were "word problems," well defined, and easily solved. Students inevitably viewed these problems as ill-defined and unsolvable. This was because all problems required the student to look at something from a new direction. To illustrate, rather than ask the students to "report the temperature, resistance, and power generated at 12 volts by a 1mm diameter, 1 meter long platinum wire," they were asked to "design a filament to generate 100 watts at 1550C in an oxidizing atmosphere using a 12 volt power supply". The first problem requires the direct application of three simple equations while the second requires rearrangement of the same equations. The problems were designed to be easily completed within one week. Since our curriculum includes a capstone design course during the final semester of the senior year, "mini-design" problems allowed us to cover a greater breadth of material with assignments involving polymers, metals, ceramics, and electronic materials.

- Each team had one senior, one junior, and one or two sophomores. Senior members generally were expected (but not required) to assume overall project responsibility and delegate appropriate components to juniors and sophomores. This supervisor/subordinate management situation is similar to what students will see in engineering practice. Teams that consist of students in different levels of a curriculum have been shown to be successful both for the seniors, gaining experience in realistic management situations, and for sophomores, having the benefit of seeing what is to come in terms of academics and careers [6]. Additionally, the structure of the teams, with students at different levels and experience, was designed to foster an environment in which students are learning from students.
- Perhaps the most fundamental goal of the course was to transfer responsibility for learning from the faculty to the student. Responsibility for arranging meeting times to work on problems was transferred from the faculty to the teams. Responsibility for evaluation was, in part, transferred from the faculty to the teams. Responsibility for making sure the problem was fully understood was also transferred to the students. As stated earlier, all problems posed were complete and precise. However, all problems were presented orally to the students, who were responsible for recording and understanding them. Students were encouraged to ask for clarification, auxiliary data, hints on how to approach solutions, *etc*, but it was the student's responsibility to arrive at a clear understanding of the problem. Problems were not purposely made obscure or tricky; they were simply realistically stated word problems.

Course Organization

The course included 58 students. Two faculty members organized and taught the course. Nineteen student teams consisting of 1 senior, 1 junior, and 1 or 2 sophomores were randomly chosen. These teams remained intact until midterm when new teams were formed. Each design project was to be completed in one week and was often augmented for a second week.

Although the students had prior experience working in teams in other classes, instruction on working in teams was provided in terms of member roles, conducting meetings, and delegation and follow-up. For example, for each project, the teams were expected to assign a project leader, record-keeper, and convener. Although the senior member of the team was expected to assume leadership there were opportunities for sophomores and juniors to seize the role as well. Record-keeping was required in a 'team record book.' In this book, all team activities were to be recorded including meeting minutes and project solutions.

There was concern for typical student team problems such as 'hitchhiking,' where a student does not contribute to the project but does reap the benefit of the grade, or a senior leader just completing the whole project on her or his own. To minimize the occurrence of these problems, the teams were required to document their activities in the team record book. There were requirements that the record book include meeting dates, times and duration, attendance, roles, individual assignments within the team with deadlines, follow-up on previous assignments, and presentations by individuals in the team to other members of the team. In addition, for the initial meeting on a new project, an action plan defining the problem and offering a plan on how to tackle it was also required. The instructors stressed that 'who did what' had to be clearly documented.

The primary evaluation of the teams was by grading the design problem solutions. As stated, these solutions were written up in the team record books. The instructor could look for balance in effort among members and get a feel for the relative contributions from sophomores, juniors, and seniors. In addition to the evaluation of all problem solutions, the teams' record books were occasionally reviewed to insure they included all requirements. A further check on participation was accomplished by requiring presentation of problem solutions by three teams for each project. The students did not know which team or which team member would present until a random drawing at the beginning of the class period. This notion of random presentation was meant to insure that team members felt a responsibility to the other members of their team to participate in and understand the project solutions. Additionally, this encouraged teams to make sure that all members understood the problem and solution [3].

The primary evaluation of individuals in the course was accomplished through the use of short quizzes (4 questions) each week. These quizzes consisted of short answer questions related to concepts used in the design as well as one simple basic materials question. All students took the same quiz so questions reflecting either the design problem

concepts or materials related concepts from introductory level courses were asked.

The design problems assigned to the students covered all four materials specialization areas: polymers, ceramics, metals, and electronic materials. The presentation of the assignments to the students was such that there was no clear strategy to solve the problem in the problem statement; however, appropriate solution strategies were presented with the problem description. The students would have to meet in their teams and collaborate to form a problem statement. Since the sophomores had not had many materials courses and the juniors were limited in their experience, concepts that were necessary to solve the problem were presented to the students. For example, for design of a furnace, the students were taught simple concepts in heat flow.

The desired outcome of the course was that the students would gain experience, confidence, team skills, and problem-solving skills in developing materials engineering designs for devices, parts, processes, and/or systems. Course assessment was accomplished by analysis of the individual performance of the students on the quizzes and evaluation of the team record books. Additionally, a survey consisting of questions related to overall experiences in teams was given to the students at the beginning of the course. This survey was administered again at the end of the course and the students were instructed to answer the questions based on the vertically integrated course alone.

Results

Individual Performance on Quizzes

The results of the weekly quizzes indicated that on average, most of the students did quite well. A histogram plot, provided in Figure 1, shows the results for each of the 5-point quizzes. In the plot, sophomore, junior, and senior results are shown separately. The overall averages with standard deviations shown for all quizzes for sophomores, juniors, and seniors are shown in Figure 2. Clearly there was no significant difference between the quiz scores by class.

Team Record Books

The team record books were reviewed periodically for team participation and for the requirements mentioned previously. It is difficult to present quantitative data based on these record books. However, a count on the number of teams completing each requirement resulted in Figure 3.
In figure 3, the criteria being judged was:

1. Are meeting dates, times, and duration recorded?
2. Is attendance recorded?
3. Are roles defined?
4. Is there a meeting agenda?
5. Is there an action plan with a proposed schedule?
6. Are individual assignments given with deadlines?
7. Is there follow-up on the individual assignments?
8. Did each member report to the rest of the team?
9. Did the group include the project write-up?
10. Was there an assessment on how the team felt they functioned as a group?

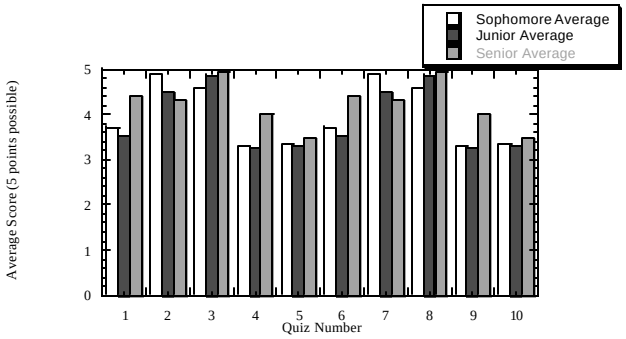

Figure 1: Histogram of averages for each individual quiz

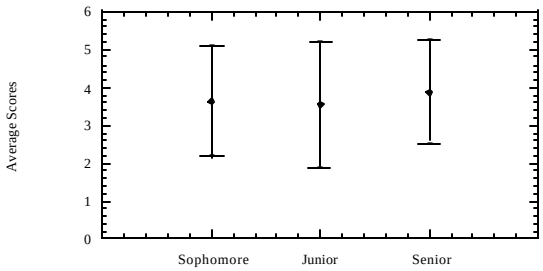

Figure 2: Overall quiz averages for sophomores, juniors, and seniors

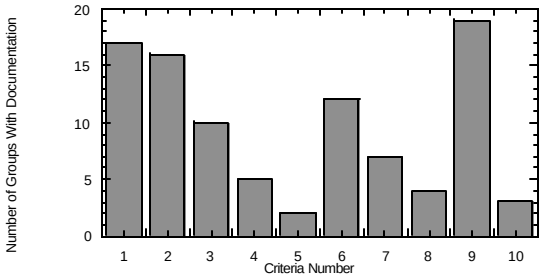

Figure 3: Group functioning criteria met in team record books

Results of Survey

The students in the course were asked to answer questions both at the start of the course, based on prior team experiences, and at the end of the course, based on team experience in this course only. The following figures are frequencies (shown as percentages) of responses to some of the questions. The survey contained over 40 questions so only the results pertinent to this experiment are shown. Both the 'before' response and 'after' response are shown in the

same figure. The 'before' response is represented by a clear box and the 'after' response with a shaded box.

Questions Related to Team Functioning. Numerous questions on the survey dealt with how the team functioned. Key topics we were interested in included whether all members were participating and whether members were meeting deadlines. Participation by all members was important, as there was concern that the seniors would do most of the work, leaving the less experienced students behind. Figures 4, 5, and 6 are related to these areas.

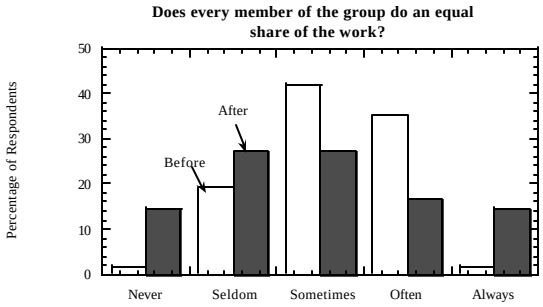

Figure 4: Response to whether all team members do an equal share of the work.

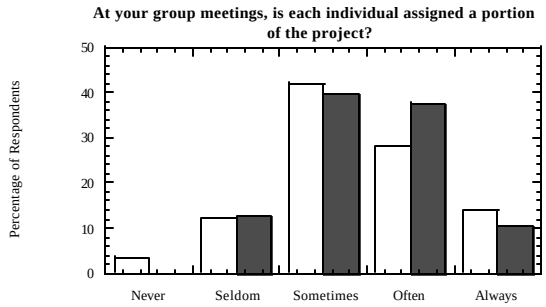

Figure 5: Response to whether team members are each assigned a portion of the project.

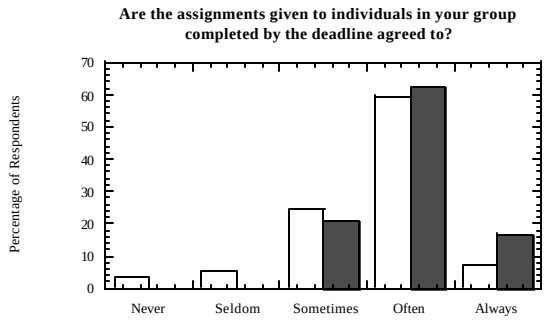

Figure6: Response to whether team members meet team deadlines on individual assignments.

Student Experience. Another concern with the multi-level teams was how the seniors would respond to working with the students that aren't at the same level as they are. For example, would the seniors just 'take over' the project and complete it on their own? Would they just parcel out insignificant tasks to the younger students and not give them the opportunity to learn all the material? Similarly, we wondered if sophomores would feel that they couldn't contribute in a meaningful way and would thus not have a good teaming experience. Figures 7, 8, and 9 represent the results related to students' experience and satisfaction.

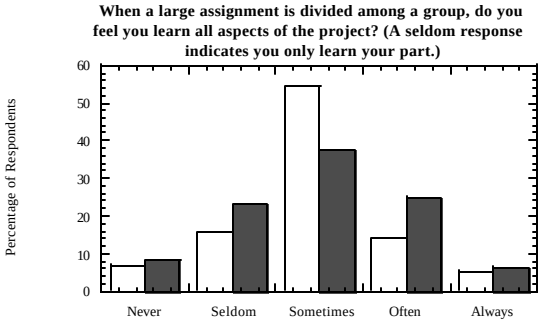

Figure 7:Response to whether the students feel they learn all aspects of the project.

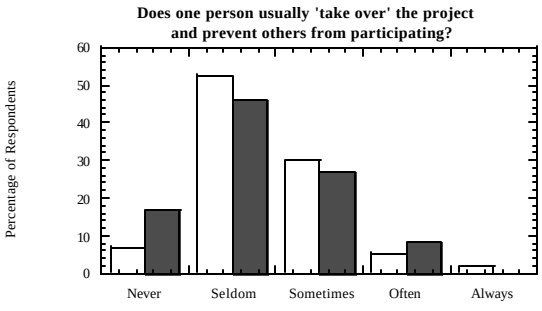

Figure 8: Response to whether the students feel that one member does most of the project.

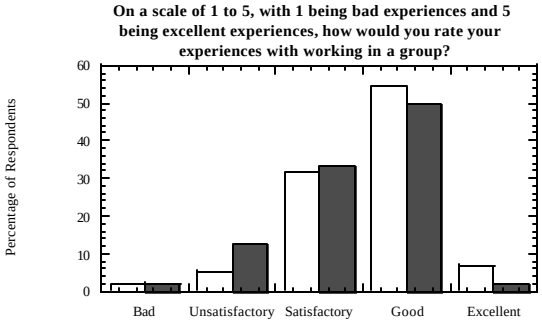

Figure 9: Response to rating of group experience.

Student Comments. The students were also asked to comment on their experience in the course. Typical comments are given below.

One thing I like about the course:

- Group work helps underclassmen
- Working with other members of the materials department, gaining knowledge from each individual's experience
- Good for practice at working in groups with different levels of knowledge
- I get to work with upperclassmen on projects. It gives me a good idea of what is coming up for me in future classes and what it will be like once I graduate and get a job.
- Getting to work with smart people who know stuff about materials engineering
- Teaches us how to do group work
- I think the vertically integrated aspect is an excellent idea. It is a good way to teach underclassmen how to work as a team. Teamwork is like balancing a checkbook in that everyone is expected to know how to do it, but no one teaches you. This allows upperclassmen to teach others how to work in a team.

One thing that could be improved in the course:

- Sometimes the problem statement is not very clear.
- Need projects more related to sophomores
- The sophomores have not completed many materials courses so I find myself doing all the work and then teaching them.
- Inexperience of underclassmen makes some projects more time consuming/burdensome for seniors.
- Have a more specific question/project
- Better defined problems
- Maybe handouts of what exactly is expected – include write-up and what's necessary for procedure steps.

Discussion

The quiz scores for the students provided interesting information. The overall averages and standard deviations in Figure 2 show that there is no statistical difference among the different grade levels. These results indicate that the sophomores were able to compete at the same level as the juniors and seniors for the material tested in the course. Furthermore, since the students were being tested over concepts utilized in the design project, these results are consistent with the inexperienced students gaining at least a conceptual knowledge equivalent to the more experienced students.

The use and evaluation of the team record books was primarily to verify that the students were all participating in the team activities. However, we were also interested in how the teams functioned and whether or not they used the suggestions provided on team management. The results of the record books evaluations indicated that the students did a good job of project write-ups, meeting dates, and attendance, with all teams completing the documentation. However, when it came to meeting minutes including the agenda, individual assignments, follow-up, and defined roles, there were in some cases fewer than half of the teams completing documentation. Finally, in the case of individual reports to the team, team assessment, and project action plans, there were only a few teams that complied.

The purpose of the team record book requirements was to provide the teams with management tools. Students are not always comfortable following-up on other students whether they are at the same level or not. The use of the criteria for the notebooks was intended to make it easier for team leaders to function as leaders, delegating through individual assignments and following-up on those assignments. Additionally, it was thought that if students knew that the instructors were going to follow-up on participation they would be more likely to take responsibility for their part. Although the number of teams that portioned out individual assignments was promising, the extent of follow-up on those assignments and reports by individuals to the groups was disappointing.

The survey results comparing the 'before' experiences with the experience in this course provided more insight into the group dynamics. For example, Figure 4, which gives the students' opinions as to whether all members of the team did an equal share of the work, indicates variation among teams. Those responding *never* and those responding *always* both increased rather significantly. The increase in the *always* response is encouraging as there was great concern that the seniors would do the majority of the work. However, the increase in the *never* responses were bolstered by the increase in the *seldom* responses. Additionally, Figure 8 which shows the responses to whether one person takes over the project indicates the same type of variation among teams with increases in *never* and *always*. These increases are likely due to seniors doing the majority of the projects which is further supported by some of the student comments.

The reponses to the question regarding individual assignments, presented in Figure 5, show that in this course, students divided the project into individual portions slightly more than they have in past teaming experience. However, the numbers are not significantly different. For the completion of individual assignments by the team deadline, shown in Figure 6, the student responses suggest slightly more responsibility being taken. There are no *never* or *seldom* responses based on experience in this course. This may be attributed to the leadership of the seniors or to the record book requirements. Both the assignment and follow up of individual assignments is important in that the students need to feel a sense of responsibility to their team.

A major concern in the course was the question of whether the sophomores would be able to understand concepts that they may not have seen prior to this course. This would be further complicated if they were only given small roles in the project such as typing up the report or making presentation slides. The quiz results indicated that they did participate. This is also intimately related to the students' individual reports to their team. For large projects,

there is not always time for each team member to participate in all parts of the solution. By reporting findings at team meetings, it was thought that the students could teach one another. Figure 7 shows the reponse to whether the students felt they learned all aspects of the project. According to this figure, as well as the record book result, only a portion of the teams accomplished this. This is not consistent with the quiz results, where scores indicated that the students did gain an understanding of the projects.

In addition to team functioning and dynamics, the students' satisfaction with their teaming experience was also important. If they didn't enjoy working in teams, the team experience was not likely to be positive. Figure 9 shows the student ratings of the team experience. Comparing the before response to the after response shows very little difference. There is a slight increase in low ratings and slight decrease in high ratings. Most students rated their experience as positive or satisfactory. This is actually quite surprising in that we received much more negative feedback from anectodal and other measurment instruments. The survey data presented here indicates that we met many of our pedological goals; however, the students didn't like the experience.

The student comments helped in the assessment of both the teaming and the design experience. The students tended to respond favorably to the teaming aspects, with sophomore indicating that they felt working with the juniors and seniors was extremely beneficial. Some sophomores expressed concern that they weren't contributing as much and wanted projects more related to their level in the curriculum. Also, there were some complaints by seniors that they were doing all of the work while at the same time were teaching the sophomores. The juniors were in between and probably had the best experience.

It should be noted that the teams did quite well on the design problems. However, much student dissatisfaction revolved around problem definition. The students wanted an unambiguously stated problem which was in itself a clear roadmap to the solution. This was not the purpose of the course. The whole point of the projects that were assigned was to force the students to see things on another level: the real world. This was the most difficult aspect to communicate to the students.

Conclusions

This course explored a new learning model in which students at different grade levels worked in teams to solve design problems. From the student perspective, the review of this model was mixed, with positive and negative ratings related to the vertically integrated teams. However, the positives far outweigh the negatives. Most of the negative aspects of the teaming are related to problems typical in all teams, i.e. members not participating, one member doing all the work, members with different knowledge bases. These types of problems will also be present when the students enter the workforce. However, there are some key changes that can be made to alleviate these problems. First, when creating the design projects, considerable thought must be given to the sophomores' contribution. The projects must be designed with elements in which the sophomores and juniors can offer expertise. This will give them a better experience as they will feel they are making a more significant contribution. Additionally, this will ease some of pressure on the seniors. Second, there must be more time spent teaching the students, especially the seniors, about team skills. Since engineering students do not typically take courses in management, this type of course may be their only chance to experience it.

Sophomores *always* thought they were at a disadvantage on quizzes, in problems, in presentation skills, *etc*. even though this was not the case. Sophomore performance often exceeded that of upperclassmen. Participants assumed that upperclassmen were better prepared and would outperform underclassmen. This was just not true.

Student feedback on the design aspect of this course was negative. They desired a tightly defined problem statement including a probem-solving procedure. This was not the objective of the course. It is clear that a better job must be done in communicating expectations to the students and in explaining the course goals. Better articulation of the course's goals and presentation of actual results to the students should do much to mitigate student difficulty in accepting the responsibilities the course thrusts on them.

This was the initial offering of the vertically integrated design course. With students enrolling in the course three consecutive fall semesters, it is extremely important that the course provide new information and experiences each semester. To accomplish this, a rotation of ~ 60 different mini design problems will be used so that students are given different experiences each time. Furthermore, the course will be carefuly evaluated to insure the students needs are being met. We expect that both student perceptions of the course and the course itself will evolve as experience is gained.

References

[1] Mourtos, N., "The Nuts and Bolts of Cooperative Learning in Engineering," *Journal of Engineering Education*, January 1997, 35-37.

[2] Johnson, D.W., and Johnson, R.T., *Learning Together and Alone: Cooperation, Competition, and Individualistic Learning 3rd Edition*, Allyn and Bacon, 1991.

[3] Felder, R., and Brent, R., "Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs," ERIC Document Reproduction Service, ED 377038 (1994).

[4] Dutson, A., Todd, R.H., Magleby, S.P., and Sorensen, C.D., " A Review of Literature on Teaching Engineering Design through Project-oriented Capstone Courses," *Journal of Engineering Education*, January, 1997, pp. 17-25.

[5] ABET: http://www.abet.org

[6] Tao, B.Y., "Senior/Sophomore Co-Class Instruction: Teaching Interpersonal Management Skills in Engineering," *Journal of Engineering Education*, Vol 82, No. 2, April 1993 pp 126-129.