Capstone Design in the Earth Engineering Sciences: Case Study of a 10-Year Interdisciplinary Program

Jennifer L. Miskimins,
John B. Curtis,
Thomas Davis,
Maximillian Peeters
Colorado School of Mines

Introduction

The capstone design course entitled Multidisciplinary Petroleum Design has been in existence at the Colorado School of Mines (CSM) for ten years. Since its inception in 1993, approximately 400 students have passed through the class. The class comprises students from three disciplines including the Petroleum Engineering (PE), Geology and Geological Engineering (GE), and Geophysical Engineering (GP) Departments. The course is unique since no other university in the United States offers this combination of disciplines in a senior design course. Even though the course is one of a kind for the disciplines it addresses, several of the difficulties encountered in the course are believed to be universal to capstone courses that address earth engineering topics.

Multidisciplinary Petroleum Design is taken over a period of 15 weeks in the final semester of the senior year. The course is required for PE undergraduate students. GE and GP undergraduate students are also required to take a senior capstone design course, but the Multidisciplinary Petroleum Design is one of three options for these two disciplines. In addition to undergraduate students, graduate students pursuing a Masters of Science, a Masters of Engineering, or a Professional Masters degree occasionally enroll in the course. These graduate students generally make up less than five percent of the class population.

The class has experienced success both from an accreditation standpoint and from an industry viewpoint. However, significant issues regarding development, assessment, and the most effective format still exist. Considerable hurdles are still present including the deficiency of team skills development prior to the course, "language" barriers between the different disciplines, and the inability to employ three-dimensional thought processes. This paper outlines the course development, format, assessment techniques, and difficulties encountered. This information may help other schools with similar earth engineering programs and aid in multidisciplinary course curricula development throughout engineering and science programs.

The Need for Capstone Courses

Capstone design courses are vital components of undergraduate engineering curricula. Under Criterion 4 of the General Criteria for Basic Level Programs, the Accreditation Board for

Engineering and Technology (ABET) requires that "Students…be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work…."[1] In numerous curricula, this major design experience is reserved for the last semester of the final year of the undergraduate program, while in other curricula, the course can span an entire year of the final undergraduate experience.

In addition to being mandated by ABET, industry representatives of potential employers think highly of capstone courses. This support is demonstrated by assistance for such courses through provision of projects and direct monetary support. Additionally, it has been our experience at CSM that industry advisory committee members from the three subject disciplines support and encourage the development of the capstone experience. Advisory committee members from the three participating CSM departments, who are also potential employers, provide consistent encouragement for the continued development and improvement of the capstone course discussed in this paper. Interviews of recruiters from a variety of employers echo the support for the capstone courses importance and significance. This interest likely arises from studies that have shown direct monetary benefits realized through teamwork across the PE, GE, and GP disciplines.[2,3,4]

The truest test of the need for capstone design courses and Multidisciplinary Petroleum Design may come from alumni of the course themselves. An alumni survey taken in the PE Department in 2002 indicated that former PE students spend approximately 50% of their time working in team settings and 41% of their time working in multidisciplinary team settings. Additionally, 53% of those surveyed have taken an industry short course on the topic of teams or teamwork since graduation from CSM.[5] These percentages suggest that students should have the opportunity to practice teamwork skills in a "non-threatening" environment prior to graduation.

History of Course Development

As indicated by the title of this paper, the subject course, Multidisciplinary Petroleum Design, is celebrating a decade of existence. The idea for the course originally came from a multidisciplinary team research project undertaken by CSM faculty for the United States Department of Energy.[2] This project realized an incremental benefit of $20 million discounted at 10% and showed the power of a multidisciplinary approach. The results of this project also endorsed calls in the early 1990's that suggested engineering curricula needed to be improved in the area of engineering design and teamwork processes.[6] When the requirements of ABET were modified to include capstone design courses, CSM felt strongly that programs of this kind would benefit its graduates and make them more valuable to future employers. In addition to discipline specific design courses, CSM strongly supported the creation of multidisciplinary design courses between its various curriculum offerings. Thompson and Prestridge provide a description of the initial outline of Multidisciplinary Petroleum Design from 1993.[7] Since that time, the course has undergone numerous modifications as would be expected of a course of this type.

During their first two years at CSM, all students take two semester-long EPICS (Engineering Practices Introductory Course Sequence) courses.[6] These nationally-recognized courses provide instruction and practice in open-ended problem solving, technical oral and written communication, and team processes. The EPICS courses provide a basis for advanced design courses such as Multidisciplinary Petroleum Design that are taken later in the course sequence.

The Multidisciplinary Petroleum Design course has always been a one semester (15 weeks) course. However, the format during these 15 weeks has changed considerably during the last ten years. These changes include varying the amount of instruction (non-project work) time at the start of the course between one and five weeks. The number of projects assigned during the class has also been varied. Anywhere from one to four projects have been attempted. These variations have shown that one project for the entire semester is too long and does not have enough variety for the students (they become bored); whereas, four (or more) projects are too many because the teams do not have enough time to learn to function together. A final variation for the class has been the number of team members assigned to each team. Anywhere from three to six team members have been assigned. Experience indicates that less than four team members requires too much work for the class format and timing, while more than six members allows certain team members to "free ride" and not participate fully in the project development.

Current Course Format

The current Multidisciplinary Petroleum Design arrangement has evolved to the following format. During the first two weeks of the semester, students are instructed in general subjects such as teamwork skills, brainstorming, and multiple working hypotheses. Following this introductory instruction period, the students work on two projects, each of which lasts approximately 6 ½ weeks. The two projects are separated by a one-week spring term break. The class meets for five hours during the week (one two-hour period and one three-hour period).

The initial two-week instruction period has proved useful to remind the students about team skills. There is significant literature available that addresses numerous team skills, so in order to make it manageable, we focus on the following eight skills: back-up behavior, communication, team coordination, effort supplied to the project, inter-team feedback, technical knowledge, leadership, and team orientation.[8] The students are exposed to these skills during their EPICS courses, but we have found that most students need a reminder of the specific skills and the associated definitions. Also, although the students have used these skills in EPICS and other courses, this senior design class is the first time they will use these skills on a major project specific to their disciplines.

Also during the initial instruction period, the students are presented the idea of self-directed work teams (SDWT's) which are characterized by:

1. A limited life,
2. Are usually heterogeneous because of the diverse needs of the project,
3. Have a limited time frame to solve a specific problem,
4. Have members that may not know each other and their capabilities,
5. Must perform non-routine work, and
6. Have a mix of autonomy (self-directed) and dependence (client).[9]

The students are exposed to the SDWT concepts since they aptly describe the types of teams the students will be working on during the following 13 weeks.

Finally, during the instruction period, the students are reminded of such ideas as brainstorming and multiple working hypotheses. Again, although the students have been exposed to brainstorming in other courses such as EPICS, we have found that reminding them of this technique is beneficial to the subject course. The idea of multiple working hypotheses is generally new to the majority of the students, therefore, they are provided and required to read the 1931 paper by T.C. Chamberlain on how multiple working hypotheses relate to geologic situations.[10]

Following the instruction period, the students are provided the data sets for the first project. The data sets are provided to CSM by various companies. It is not uncommon for an alumnus, who has taken the class, to arrange for a new data set to be donated to the school. The data sets contain a myriad of raw data from the chosen field or project. The data sets are rotated from year to year with different problem statements provided each year. During any given year, all teams are given identical data sets and work on the same problem statement. The problem statements are commonly developed to provide an air of competition between teams.

The teams each contain 4-6 members and are assigned by the faculty. This allows for a fair distribution of the three disciplines between teams. Since the course is required for the PE students, the teams generally contain a high percentage of PE majors. We attempt to have one GE and one GP student on each team with the remaining team members being PE's.

Once the teams are provided the data sets and the problem statement, they are given significant class time to work on their projects. There is little formal instruction from this point on during the remaining 13 weeks of the class. The faculty members act as consultants, with additional faculty members from all three disciplines' staffs providing supplementary consulting as needed for various expertises. The teams submit mid-project reports and presentations approximately three weeks into the project and final project reports and presentations at the end of the six and one-half weeks.

The first project is completed the week before the spring break to provide a clean separation point between projects. The second project format is identical to the first project. For the second project, the students work with entirely different team members (if it is feasible based on the number of students enrolled in the class and their disciplines). The data sets and problem statement for the second project are designed to provide entirely different scenarios from the first project to encourage the development of different skills and knowledge.

Assessment Techniques

As with all capstone design courses, assessment and evaluation of the course is critical. A triangulation approach consisting of six techniques is used and includes: 1) peer evaluations, 2) faculty observations, 3) team presentations, 4) team reports, 5) individual interviews, and 6) individual quizzes.

Peer evaluations which measure the eight team skills (back-up behavior, communication, team coordination, effort supplied to the project, inter-team feedback, technical knowledge, leadership, and team orientation) are used twice during each of the two projects. The peer evaluations rate each of the eight team skills on a scale of 1 to 5. The students are shown both the average of what their teammates rate them in each category and how they rate themselves. The peer evaluations are not used in the calculation of the team or individual grades, but they do provide an indication of the functionality of the team and the individual team members.[8,11,12]

During the course, faculty observations play a large role in assessing both the teams and the individual team members. During any given semester, there are usually eight to ten teams working on each of the two projects. With a faculty of four and two additional teaching assistants, the faculty-to-team ratio is generally less than two. This allows individual observation of each team including the functionality of the team and the contribution of the individual team members. As faculty, we strive to make these observations unobtrusive to the teams as they work on their projects but find that the observations are critical to the evaluation process.

Team presentations and written reports are given at mid-project and end-of-project. The mid-project presentations and reports are not graded but are instead used entirely for feedback purposes. The end-of-project presentations and reports are graded and account for a significant portion of the teams' and individuals' grades for the class. To evaluate the individual team members, the teams are required to provide a listing of who worked on which portions of the project.

Finally, both individual interviews and individual quizzes are used for student evaluation. The quizzes are given twice during each project and are structured to assess learning between the three disciplines.[12] The individual interviews are not conducted for assessment of student learning but are instead used for assessment of the overall class format and appraisal. The individual interviews are time-consuming and therefore are not used every year.

In addition to assessing the course and the students currently enrolled, graduates of the three participating programs are also polled for their post-graduate views of the capstone design experience. This part of the assessment has two components. First, alumni surveys[5] are conducted annually for the petroleum engineering department. These surveys have an overall theme for that year, such as lifelong learning or assessment of a certain curriculum issue, but they always have an underlying ABET element with interdisciplinary components. Frequently, the questions are worded to directly address the subject capstone course, how the graduates viewed the course while they were taking it, and how the graduates view the course at present. The surveys are conducted anonymously, but the year of graduation is tracked. This allows a timeline to be established for any responses and comments regarding the course.

The second post-graduate assessment is less formal but perhaps more informative. The alumni base for all three departments is very active and direct contact with formal students is frequent. This contact generally takes place at alumni functions associated with professional functions such as the annual international meetings of the Society of Petroleum Engineers, the Society of Exploration Geophysicists, and the American Association for Petroleum Geologists. Former students frequently comment about the benefits of the capstone design experience, how it helped prepare them for industry, and how they believe it is a critical component of their undergraduate education.

For both types of post-graduate assessment, one trend is very similar and quite informative (as well as humorous). While taking the course, the students do not care for the course and believe it is "too much work" and the teams "negatively affect their grades." However, most alumni praise the course and express their appreciation for how the course prepared them for professional practice. These commendations from alumni generally start appearing around four or five years after graduation. We can only draw the conclusion that it takes that long for the shock of the class to wear off.

Difficulties Encountered

As with any capstone design program of this type, there are several difficulties that are encountered each semester. Although steps have been taken to eliminate as many problems as possible during the ten-year development of this course, some issues are still present and steps are being taken to evaluate and improve them as needed.

The first difficulty stems from the fact that PE students are required to take the course while GE and GP students have a choice between three different capstone design courses. Due to this requirement, the Multidisciplinary Petroleum Design course generally has a higher enrollment of PE students than of GE or GP students. This can be detrimental if there are too few GE and GP students to place at least one student of each discipline on each team. At the same time, this ratio may provide a fairly realistic profile of the discipline structure the students will encounter when they enter the industry ranks. Even if this is the case, the students have a hard time understanding why Team A gets the services of a GP while Team G does not and this can factor into attitudes about the class.

Another difficulty that is perhaps discipline specific appears to stem from proficiency of the students to "think three-dimensionally" or "non-linearly."[13] From observation of numerous students and teams, a lack of the ability to think in three dimensions appears to be more prevalent in the PE students versus the GE and GP students. This ability of the GE and GP students likely comes from the fact that they receive more field and visualization-type training than the PE students. Steps are being taken to remedy this in the PE curriculum. Also, further, more measurable studies are being evaluated which may help solidify these observations and will lead to improvements in instructional techniques both in this class and other required classes.

A lack of understanding of team skills can also play a role in the course. Although students receive significant team skill instruction in earlier courses (EPICS), they do not always have the opportunity to practice these skills throughout their undergraduate careers and can be out of practice when they take their senior capstone design course. In this mode, they sometimes do not understand how the pieces of a major project fit together in a "beehive" fashion, but rather they try to force fit an "assembly line" approach. Additionally, these students are groomed to act as individuals in their other, more traditional lecture classes where they often compete for grades. The students have a difficult time switching their mentalities between these competitive individually-graded classes and a design class which requires them to work together for the common good of all. Students must learn that they can't take on the entire project by themselves, but must rely on teammates.

“Language barriers” can also prohibit full team functionality. By this, we mean language barriers between different disciplines. At an undergraduate senior level, the students are just beginning to understand their own discipline’s specific terminology. There can be a huge learning curve for the students from the three subject disciplines to learn one another’s language. However, this does appear to encourage peer learning between team members.[12,14]

The final difficulty, and the least scientific, appears to be caused by “senioritis.” Since most of the students that are taking this course will graduate at its conclusion and since most of these students already have employment secured after graduation, a significant portion of them approach the class with an “I only need to pass” attitude. This approach may not be observed during the first project, but after that project is complete, the grades for it are secured, and spring break has just concluded, efforts toward the second project are significantly lower. This drop in effort is difficult to overcome without giving undue weight to the second project.

Conclusions

Capstone design courses provide significant benefits for undergraduate students. They offer students the opportunity to practice team skills and project presentation skills in a non-threatening environment prior to graduation and employment. The Multidisciplinary Petroleum Design course offered at CSM for the last ten years provides such an opportunity to students in the three disciplines of petroleum engineering, geophysical engineering, and geological engineering.

Even after numerous adaptations during the past ten years, the subject course is still evolving and providing a learning environment for the faculty members on the subject of engineering education. Several difficulties are still encountered including non-ideal ratios of the participating disciplines and the need to overcome these deficits, a lack of student understanding of team skills and practice of these skills, discipline-oriented variations in how the students undertake and view the projects, and discipline-specific “language barriers.” Although frustrating at times for both the faculty and students, these difficulties provide an excellent opportunity to observe team interaction and to work to overcome any associated problems.

Acknowledgements

Although the authors of this paper are the current instructors for the subject course, several other people have been involved during its development and instruction throughout the past ten years. Although they are too numerous to mention individually, the authors gratefully acknowledge their input and contributions to the course. A special thank you goes to the late Robert Thompson. Without him, this course would not be at the level it is today.

Bibliography

1. ABET, "ABET Criteria for Accrediting Engineering Programs (Effective for Evaluations During the 2004-2005 Accreditation Cycle)," (Maryland: Accreditation Board for Engineering and Technology, Inc., 2002).

2. R. S. Thompson, C.W. Van Kirk, R.D. Benson, T.L. Davis, R.M. Graves, and R.M. Slatt, "SPE 36771: Incremental Benefits of a Team Approach to Reservoir Management, " (paper presented at the 1996 Society of Petroleum Engineers 71st Annual Technical Conference and Exhibition, Denver, Colorado, October 6-9 1996).
3. J.H. Sutton and R. S. Thompson, "SPE 37968: The Incremental Benefit of a Multidisciplinary Approach to Field Development: A Case Study, " (paper presented at the 1997 Society of Petroleum Engineers Hydrocarbon Economics and Evaluation Symposium, Dallas, Texas, March 16-18 1997).
4. E.L. Bigelow, "Reservoir description and management: The impact of multidisciplinary integration," *The Leading Edge* 13, no. 11 (1994): 1123-1127.
5. Colorado School of Mines Petroleum Engineering Department Alumni Survey, conducted in-house 2002.
6. Ronald L. Miller and Barbara M. Olds, "A Model Curriculum for a Capstone Course in Multidisciplinary Engineering Design, " *Journal of Engineering Education* (October 1994): 1-6.
7. Robert S. Thompson and Andrew L. Prestridge, "Integrated Engineering Design by Design" (paper presented at the ASEE Gulf-Southwest Section Annual Meeting, Austin, Texas, 1993).
8. Robert S. Thompson, "Reliability, Validity, and Bias in Peer Evaluations of Self-Directed Interdependent Work Teams" (paper presented at the ASEE Annual Technical Conference and Exhibition, Albuquerque, New Mexico, June 24-27, 2001).
9. Connie Gersick and Mary Lou Davis-Sacks, "Summary: Task Forces, " in *Groups that work (and those that don't)*, ed. J. Richard Hackman (San Francisco: Jossey-Bass Inc., 1990), 146-153.
10. T.C. Chamberlain, "The method of multiple working hypothesis," *Journal of Geology*, no. 39 (1931): 155-165.
11. Robert S. Thompson, "A Repeated Measures Design for Assessment of Critical Team Skills in Multidisciplinary Teams, " (paper presented at the ASEE Annual Conference and Exhibition, St. Louis, Missouri, June 18-21, 2000).
12. Jennifer L. Miskimins, "Peer Learning: Observation of the Cluster Effect in Multidisciplinary Team Settings," (paper presented at the ASEE Annual Conference and Exhibition, Montreal, Quebec, Canada, June 16-19, 2002).
13. M.D.Piburn, S.J Reynolds, D.E.Leedy, C.M.McAuliffe, J.P.Birk, and J.K.Johnson. "The Hidden Earth: Visualization of Geologic Features and their Subsurface Geometry." (paper presented at the National Association for Research in Science Teaching, New Orleans, Louisiana, 2002) p. 1-48.
14. Cynthia R. Haller, Victoria J. Gallagher, Tracey L. Weldon, Richard M. Felder, "Dynamics of Peer Education in Cooperative Learning Workgroups," *Journal of Engineering Education* (2000): 285-293.

JENNIFER L. MISKIMINS

Jennifer L. Miskimins is an Assistant Professor in Petroleum Engineering at the Colorado School of Mines. Jennifer received her B.S. degree in petroleum engineering from the Montana College of Mineral Science and Technology and her M.S. and Ph.D. degrees in petroleum engineering from the Colorado School of Mines.

JOHN B. CURTIS

John B. Curtis is an Associate Professor in the Geology and Geological Engineering Department at the Colorado School of Mines. He received B.A. and M.S. degrees in geology from Miami University and a Ph.D. in geology from The Ohio State University.

THOMAS DAVIS

Thomas Davis is a Professor in Geophysical Engineering at the Colorado School of Mines. Tom helped found an integrated, team-taught graduate course at CSM starting in 1980. The success of that course led to two other graduate level integrated exploration and development courses in 1984. These courses continue to flourish and have a direct bearing on education and research at CSM.

MAXIMILLIAN PEETERS

Maximillian Peeters is a Professor in Petrophysics and Borehole Geophysics at the Colorado School of Mines.