Using a First-Year Integrated Engineering Curriculum to Assess ABET EAC Program Outcome 3d: Ability to Function on Multidisciplinary Teams

Jenna Carpenter, David Hall, James Nelson
Louisiana Tech University, College of Engineering and Science, 2009

Abstract

One of many goals of our NSF-supported first-year Integrated Engineering Curriculum is to provide students with both instruction and opportunities to function on multi-disciplinary teams. During this year-long sequence of courses, students participate in eight multidisciplinary team-based projects. At the end of the year, a Design Expo is held during which student teams present their final projects. Students are evaluated on their projects, presentations and team skills by panels of external and internal evaluators. This paper provides an overview of 1) the content and structure of the curricular focus on multidisciplinary teams in the first-year sequence; 2) the assessment process for both evaluators and students; 3) the data collected and revisions to improve the process; and 4) the methods by which individual engineering programs incorporate this feedback into their assessment process to demonstrate fulfillment of ABET EAC's Program Outcome 3d: ability to function on multidisciplinary teams [1].

Introduction

Projects-based freshman engineering curricula began in the 1990's due in large part to the funding of the NSF Engineering Education Coalitions [2,3,4,5]. Most of these curricula are focused less on discipline-specific projects and more on the aspects of conceptual design and they include a variety of formats, such as studio courses, design courses focused on projects for external clients, to courses which emphasize topics like writing, ethics, team skills or graphics in addition to design.[6,7,8,9]. There is a significant amount of literature on the subject that shows many benefits of incorporating projects-based instruction with design early and often within engineering curricula [2-13]. For example, assessment results indicate that such courses increase retention rates, improve the quality of the senior capstone design experience and that students who completed these integrated curricula were better prepared for more advanced math and engineering courses [9,13].

The College of Engineering and Science at Louisiana Tech University began its first-year integrated, team-projects focused engineering curriculum in 1997. It has, over that time period, been supported by two major NSF grants. The year-long, six semester hour course sequence (ENGR 120 – 122) underwent a major revision in 2007 moving to a project-centered experience facilitated by a student-owned laboratory platform consisting of a laptop, software, a robot kit and a tool kit. This new version of our Integrated Engineering Curriculum, called *Living With the Lab*, has led to an increase in the quantity and level of difficulty of the engineering content while fostering an innovative spirit among student participants [15-20]. Each curriculum objective is mapped to one or more of the ten attributes of "The Engineer of 2020" [18,21] which serves as a set of guideposts for the curriculum. Assessment of course and curriculum outcomes is ongoing with promising initial results [22].

From the beginning, one of the goals of the curriculum has been to provide students with both instruction and opportunities to function on multi-disciplinary teams. All entering freshmen from the seven engineering degree programs in the College (approximately 500 students per year) must complete this first-year engineering sequence, consequently it provides an interdisciplinary engineering team environment. In addition to enhancing the learning environment, the use of multidisciplinary teams starting in the freshman year provides a unique opportunity to assess ABET's EAC Program Outcome 3d: ability to function on multidisciplinary teams.

Multidisciplinary Teams in the First-Year Integrated Engineering Curriculum

During the year-long sequence of courses, all freshman engineering majors participate in the same eight multidisciplinary team-based projects. The major projects include fabrication and testing of a centrifugal water pump (fall), fabrication of a "fishtank" system to provide closed-loop control of the salinity and temperature of a small volume of water (winter), and open-ended design of an innovative product (spring). The fishtank project comprises a number of smaller projects. The theme of the third course in the sequence is innovative product development. Student teams of four students conceive an idea for their own "smart product" based on a "bug list" [23] that they develop during the first half of the course. The complete list of projects is given below:

1) Fabrication and testing of a centrifugal water pump
2) Fabrication of a fishtank reservoir from PVC pipe and fittings
3) Fabrication and calibration of a conductivity sensor
4) Fabrication of a wooden fishtank platform
5) Fabrication and calibration of a resistance temperature detector (RTD)
6) Assembly and testing of a system providing closed-loop control of water temperature and salinity
7) Evaluation of the efficiency of a robot servo
8) Design and fabrication of an innovative "smart" product

At the end of the first-year, a freshman engineering Design Exposition is held during which all of the student teams make poster presentations and demonstrate their working prototypes to a panel of internal and external judges. In addition, students prepare a PowerPoint presentation which must include a detailed cost analysis, specifications for their product, segments of the program code, and the fabrication process. Students are graded not only on the functionality of their prototype, but also on their ability to present their product.

Figure 1 – Students prepare to "sell" their designs to the judges at the Design Exposition

The freshman engineering courses are taught in sections of 20 students (honors sections) or 40 students (non-honors sections). Students are placed in teams of 2 or 4 to complete the team homework assignments and team projects. Use of teams of two provides more individual accountability during certain aspects of the projects. Several times in the curriculum we transition from teams of 2 to teams of 4 to provide time to finish projects or presentations. Student teams are formed based on where students are sitting in the class-lab (furnished with tables accommodating 4 students in the center and surrounded by laboratory workbenches around the edge of the room). By the end of the first project, students expect that their seating location will determine their team composition. The freshman engineering courses are scheduled for two 2hour blocks each week, to facilitate the course format, which merges the lecture and lab components seamlessly into one course. There are a number of team homework assignments throughout the year. Multidisciplinary teams are incorporated into the projects-based focus, as follows:

Project 1 (pump project). Students work in teams of two for the fabrication and assembly portions of the project and in teams of four for the testing and presentation stages. As a team students spend approximately two hours on fabrication, two hours on assembly, three hours on testing/analysis, and three hours preparing their PowerPoint presentation.

Projects 2 - 6 (fishtank project). These projects are focused on the fabrication, calibration, assembly, and programming of a system that controls the temperature and salinity of a small volume of water. Student teams are again formed based on seating location. Student teams spend more time working together on these projects – around 25 hours. The reservoir project and the conductivity sensor fabrication and calibration project utilize teams of two students. The wooden fishtank platform, RTD fabrication and calibration, and fishtank assembly and control projects are completed using teams of four. The fishtank system requires students to put together all of the smaller components they have made in projects 1 – 5 to create a working system. Moving from teams of two to teams of four introduces an interesting dynamic where multiple teams combine and make decisions together. For example, the four-student teams must decide whose fishtank reservoir and conductivity sensor will be incorporated into the final project.

Project 7 (servo efficiency). A stand-alone project is incorporated into the third engineering class to support student understanding of forces and moments. Students, working in teams of 2, disassemble the servos that drive their robots, counting the number of teeth on the gears in the gearbox and measuring the RPMs of the servo output shaft. Students then measure the mechanical energy output of the servo as it lifts a weight as well as the electrical energy delivered to the DC servo motor. The servo efficiency project requires student to work in teams in class to determine the efficiency of their servos and complete a related team homework assignment.

Project 8 (design of smart product). The open-ended Innovative Product Design project requires a minimum of forty hours of team work. During this project, teams of four students participate in a variety of activities which include a team training component, including the following:

- the creation of a "bug" list to generate potential project ideas;
- a review of the "10 Faces of Innovation" [23] based on Tom Kelley's book <u>The Ten Faces of Innovation</u> [24, 25] which is designed to encourage students to appreciate the skills of others and realize that every person has something unique to contribute to the team;
- an IDEO video [26] which demonstrates an effectively functioning team; and
- formal brainstorming training[26] which covers team-relevant topics such as listening to others' ideas, as well as the fact that it is essential that ideas flow freely without passing judgment.

Students are taught that there will need to be "give and take" during the design process. There are multiple situations throughout the curriculum that must be faced as a team, including simple decisions such as what color to paint their fishtank platforms, who will pay for project supplies, how to debug computer programs, how to format presentations, and who will deliver of the various segments of the presentations (pump, fishtank, design). There are also significant decisions that must be made as a team, such as which "bug" to choose for their innovative product design and which design alternative to pursue toward a final prototype.

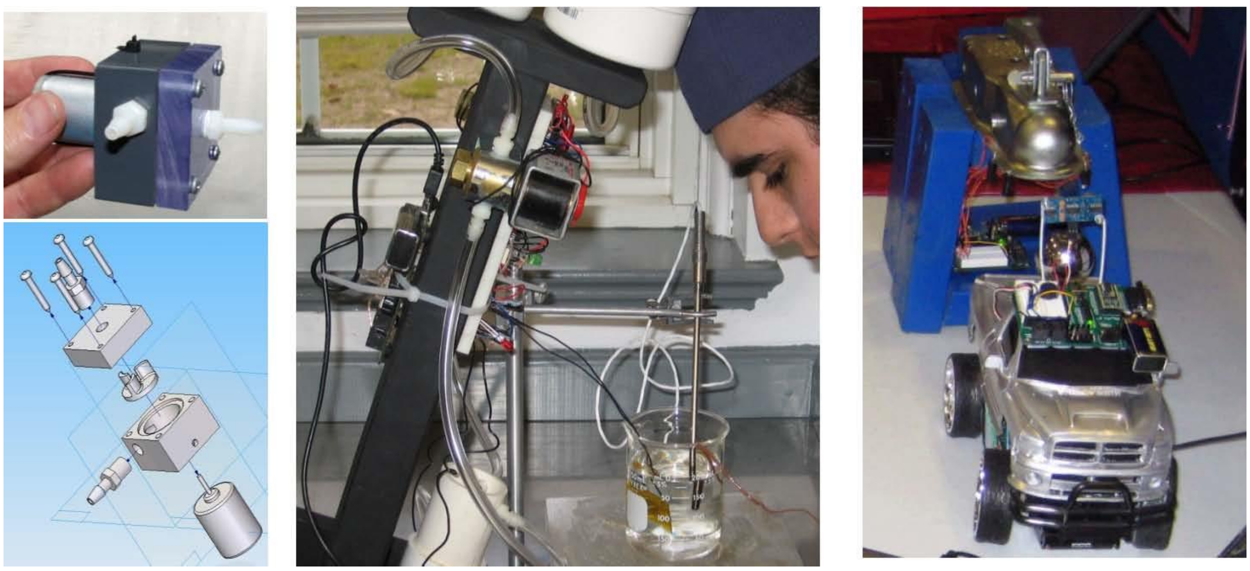

Figure 2 – Example projects, including the centrifugal pump (left), the fishtank (center), and a smart trailer hitch which provides an example of an innovative product (right)

Assessment of Ability to Function on Multidisciplinary Teams

As part of the year-end Design Expo, students are evaluated on their projects, presentations and team skills by panels of external and internal evaluators. The evaluation of team skills utilized here focuses on aspects of students' ability to function effectively on multidisciplinary teams that can be reasonably assessed by the external evaluators during student interviews. The assessment focuses on five areas of team function:

1) effectiveness of collaboration;
2) team communication skills;
3) ability to work together to convey ideas;
4) readiness to accept feedback; and
5) ability to use team decision-making processes in solving their problem.

The assessment instrument incorporated part of the work of the NSF-supported Foundation Coalition project [28] which uses Bloom's Taxonomy to develop and organize a set of learning objectives for ABET Outcome 3d: ability to function on multidisciplinary teams. Students also completed a self-evaluation of their team skills. The assessment instrument for this activity is similar to the one used for the evaluators and is taken from the Foundation Coalition project as well.

Data Analysis and Suggested Revisions

The evaluator assessment instrument of team function is given in Figure 3, and the data resulting from the instrument are given in Figure 4. In addition, evaluators are asked to indicate the number of engineering disciplines that were involved with the project. Figure 5 shows the evaluator feedback on this question, providing a direct measure of student experience in functioning on multidisciplinary teams.

ENGR 122 Evaluator Assessment of Student Ability to Function on MultiDisciplinary Teams

One of the goals of the ENGR 120-122 sequence is to provide instruction and opportunities for our students to function on multidisciplinary teams. To assist us in assessing the effectiveness of this instruction and the extent to which our students are able to apply this instruction, we need you to complete the questions below. Your candid evaluation is very important.

As they relate to functioning effectively on multidisciplinary teams, rate each of the statements below as follows:

1—strongly disagree, 2—generally disagree, 3—no opinion, 4—generally agree, 5—strongly agree

Collaboration 1. Students shared the responsibility of developing their product.	1 2 3 4 5
Team Communication 2. Team members respectfully listen to one another.	1 2 3 4 5
Team Communication / Influencing Others 3. Team members work together to clearly convey ideas.	1 2 3 4 5
Feedback 4. The team collectively accepted feedback from the judges.	1 2 3 4 5
Team Decision-Making 5. The team applied a systematic decision-making process to solve their "problem".	1 2 3 4 5
6. Please share any additional comments, observations or recommendations related to the team's functioning as a multidisciplinary team.	

Figure 3 – Evaluator Assessment of Multidisciplinary Teams

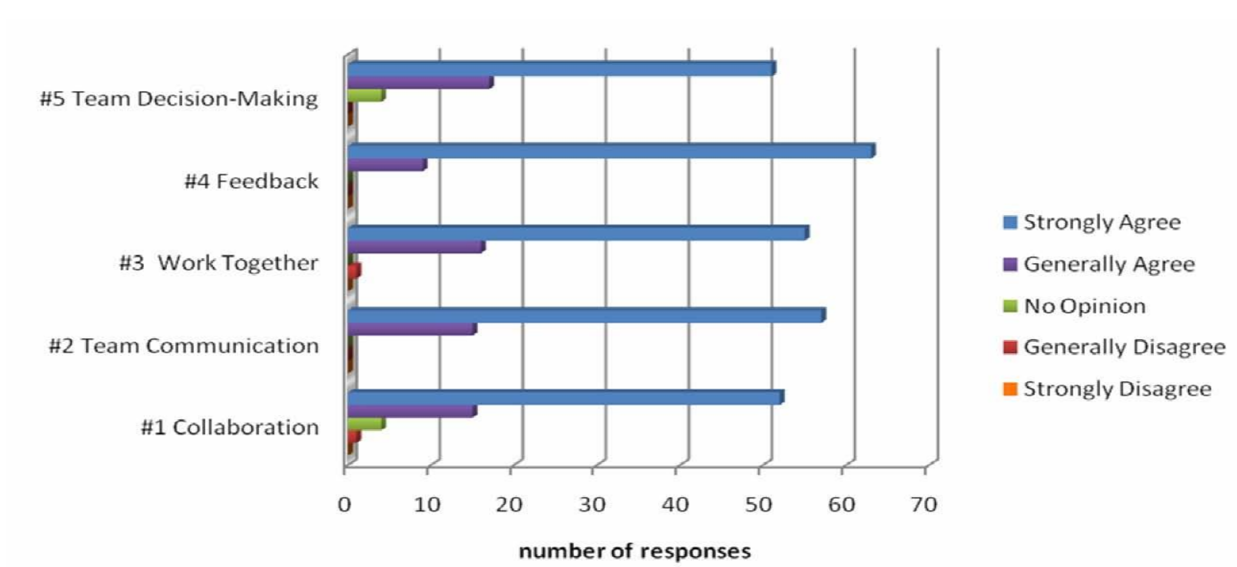

Figure 4 - Summary of Evaluator Assessment of Student Ability to Function Effectively on Multidisciplinary Teams

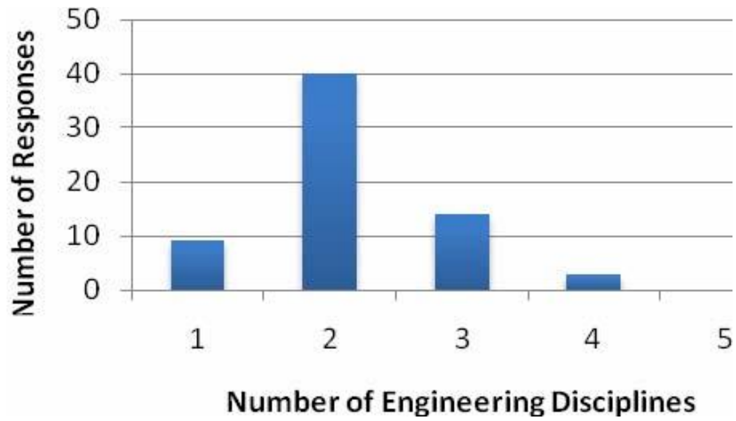

Figure 5 – Evaluator Assessment of Number of Disciplines Involved in ENGR 122 Projects

Lastly, evaluators have an opportunity to provide comments on student ability to function effectively on multidisciplinary teams. Verbatim evaluator comments are given in Figure 6.

Evaluator Comments on Student Ability to Function on Multidisciplinary Teams
Great
The team consists of 3 biomedical majors and 1 nanosystems major. All of them are females.
visuals were great -very well presented
impressive circuit and the demo worked -problem was well-addressed
visuals could use more color and larger fonts
very well-built, but could use a little more preparation for question sessions
almost forgot about treads, presentation could use more practice, but good ideas, well-built
great idea! could use more explanation of simple circuit
great idea and well-built
It is a good problem to fix and they seemed to explain their approach well.
Implemented IDEO process -terrific! Excellent presentation
great concept
appreciate the autonomy of vehicle; very well-prepared team

Figure 6 - Evaluator Comments on Student Ability to Function on Multidisciplinary Teams

The five areas of team function all received very high ratings, with average ratings between 4.5 and 5.0. The average number of engineering disciplines involved in the projects was two. Feedback from evaluators indicated that the wording of this question could be improved. Next year, plans include clarifying this question to include an additional question to determine the majors of the team members, as well as the number of disciplines involved. Overall, evaluator comments were very positive. At this time, no adjustments in content appear to be necessary. Tracking these data over a period of several years may reveal trends that will be of additional assistance in improving training on functioning in multidisciplinary teams.

In addition to collecting data from evaluators on the ability of students to effectively function on multidisciplinary teams, the students are asked to conduct a self-assessment of their ability to function as part of a multidisciplinary team on one of their last homework assignments. Again, this assessment instrument is based on the work of the NSF-supported Foundation Coalition project [28]. This self-assessment instrument is more in-depth than the evaluator instrument and focuses on three major areas: collaboration and conflict management; team communication; and team decision-making. Student must respond to four questions under each area. Figure 7 gives the student homework instructions and the survey instrument.

ENGR 122 Student Survey – Multidisciplinary Teams One of the goals of ENGR 120-122 is to provide instruction and opportunities for students to function on multidisciplinary teams. You have work together all year long on various projects (pump fabrication, pump testing, conductivity sensor, RTD project, fishtank project, servo project, smart product). Some of these projects have been with two-person teams, and some have been with teams of up to four people. By this point, you've probably been on teams that functioned very well, and on some teams that didn't function as well. In most cases, you have picked up on how to work as a team by actually working as a team. In ENGR 122, we presented the Ten Faces of Innovation to help you learn to appreciate the benefits and strengths of people who are different from you. To assess the overall effectiveness of your experience on teams and on the instruction that we provided to you on teams, please complete survey below. You are invited to submit this anonymously or include your name, as you desire. Your candid evaluation is very important.	
As they relate to functioning effectively on multi-disciplinary teams, rate each of the statements below as follows: **1-strongly disagree 2-generally disagree 3-no opinion 4-generally agree 5-strongly agree**	
Collaboration and Conflict Management	
Team Development	
1. I can apply basic principles of team development and interpersonal dynamics.	1 2 3 4 5
Interpersonal Style	
2. I recognize and can capitalize on individual difference in style and perspective.	1 2 3 4 5
Conflict Management	
3. I can apply principles of problem-based conflict management.	1 2 3 4 5
Participation	
4. I understand and am willing to be fully involved in team efforts.	1 2 3 4 5
Team Communication	
Active Listening	
5. I can convey understanding and use listening skills to move a conversation forward.	1 2 3 4 5
Feedback	
6. I can give and receive constructive criticism.	1 2 3 4 5
Influencing Others	
7. I can persuade others through well-reasoned use of facts and clear conveyance of ideas.	1 2 3 4 5
Sharing Information	
8. I can provide and review information in a timely manner.	1 2 3 4 5
Team Decision Making	
Defining a Problem	
9. As a member of a team I can help identify and articulate the problem to be solved.	1 2 3 4 5
Innovation and Idea Generation	
10. As a member of a team I can help generate creative and viable solutions.	1 2 3 4 5
Judgment and Using Facts	
11. As a member of a team I can help research conclusions based upon clear analysis of facts and ideas.	1 2 3 4 5
Reaching Consensus	
12. As a member of a team I can help ensure buy-in and commitment to decisions reached.	1 2 3 4 5
13. Please share any additional comments, observations or recommendations related to your instruction and experience of functioning on multidisciplinary teams.	

Figure 7 – Student Survey of Ability to Function Effectively on Multidisciplinary Teams

Figure 8 presents a summary of feedback provided by students. Student comments from Question 13 of the survey are given, verbatim, in Figure 9.

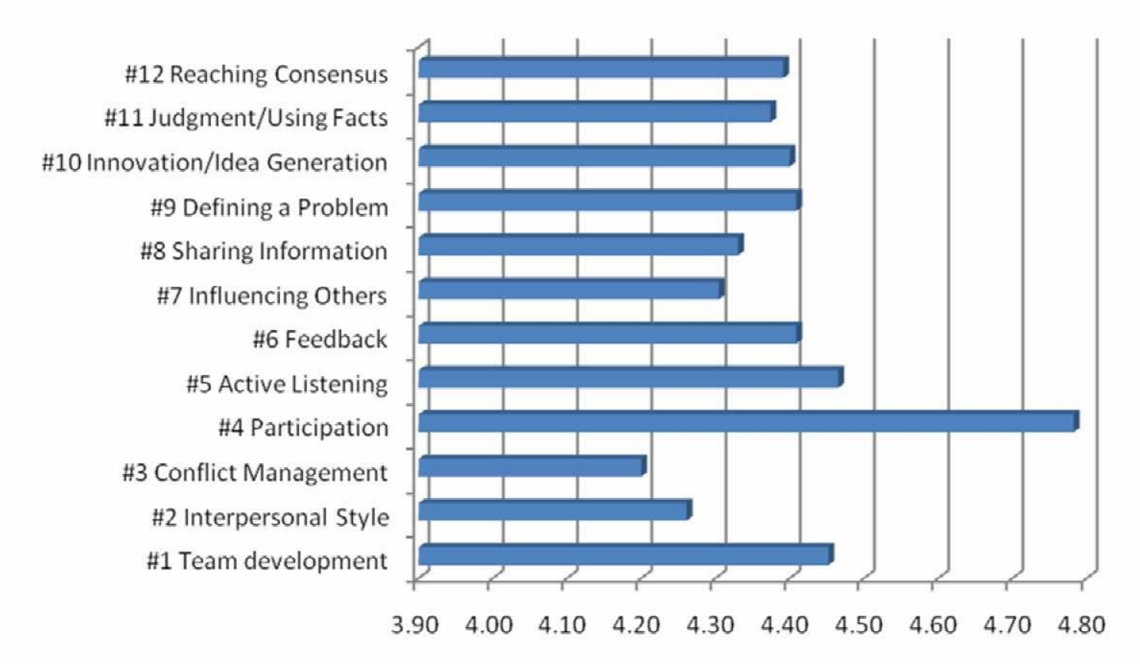

Figure 8 – Student Assessment of Multidisciplinary Teams (Scale of 1 to 5)

All student ratings fell between 4.2 and 4.8 on a 5-point Likert scale. The highest ranked item was participation. The lowest ranked items included conflict management, interpersonal style, and influencing others. The instructional material and activities relating to these items will be revisited to determine if there are ways to assist students in dealing more effectively with these issues. Student comments reveal that students viewed the experience as enjoyable and beneficial, in general. Problems were reported in the areas of conflict management, interpersonal style and influencing others, in concert with feedback from the other items on the survey.

The high ratings from Figures 4 and 8 show that both evaluators and students have positive feelings about the teamwork component of the first-year curriculum. It is important to note that teamwork skills are not a significant topic of discussion in the first two courses, although we do discuss the importance of working together and of each person doing their share of the work. The project work in these two courses provides multiple opportunities for students to work together and experience the positive and negative aspects of teamwork. Groups of students in the first course usually don't stay together during the second course since they register for different sections or don't continue to the second course for one reason or the other. Consequently, students get a chance to work with a number of two- and four-person groups during the year. We believe this is a positive element of our first-year experience. Many of the teams formed in the second course partially survive to the third course as strong friendships are formed. By the time students reach the third course, they are primed to receive and apply the "team instruction" content provided. Figure 8 shows that almost all students are strong participants in the project; the results make a case for adding a conflict management module to the course sequence.

Selected Student Comments on Ability to Function on Multidisciplinary Teams
Two people isn't enough for a group. It should be 4.
I believe that a good team consists of members who have a balance of strengths and weaknesses. It's important that students consider this when choosing a team.
Some people are just hard to work with. They don't want to show up and push more work on the ones that are actually trying.
The more people there are in a group, there is going to be a few people that work hard and then one or two that don't. Smaller groups are better.
From the freshman program, I have definitely learned a lot. I feel much more confident and comfortable with all the above from the survey.
I think giving incoming freshman the opportunity to work in teams is a wonderful feature of the new curriculum that helps build leadership skills.
Our instruction provided the background information needed to help us perform effectively in groups.
While working with teammates can be a rough job, it is a great experience that all freshman engineers need to experience.
I feel that the multidisciplinary work provides a chance to understand what lies inside each discipline.
Overall, I feel as though the ENGR 120-122 series has enshrined the concept of teamwork, and this can be applied anywhere in life. I can now study for all my classes in groups so that we can help each other when someone doesn't understand. This is something I was never able to do before now. I have also developed friendships with my classmates that are sure to last.
It was very difficult to work with unfamiliar people who were already well acquainted.
It is great to have people who are exceptional in a given area on your team, but that doesn't mean the other members cannot help in that area.
I have generally enjoyed the team projects throughout the year. Having a team-mate helps to solve problems that we have come across while working on our projects.
My work with multidisciplinary teams has gone very well.
My teammate and I worked well together playing to our strengths and avoiding our weaknesses. We worked efficiently and effectively.
I found this experience to be extremely valuable experience that will be used throughout my career as an engineer.
I liked working with a team.
I have found it difficult to motivate certain members to engage in team construction activities concerning our final project. 3 out of 4 participating is enough but it isn't a team -I hate to say it but I think she thinks that it’s the "boys" job to do all the dirty work while she does posters and other displays.

Figure 9 – Student Comments Related to Instruction and Experience of Functioning on Multidisciplinary Teams

Incorporation into Program Assessment for ABET’s Program Outcome 3d

All of our engineering programs have elected to incorporate the feedback from the assessment of multidisciplinary teams in the first-year curriculum as part of their evaluation of ABET EAC’s Program Outcome 3d: ability to function on multidisciplinary teams. Given that all freshmen must complete the first-year engineering curriculum, it provides an excellent opportunity to demonstrate a documented assessment of truly multidisciplinary teamwork. Our engineering programs are completing their most recent ABET reaccreditation cycle during the current academic year. Several examples of how programs are incorporating this assessment are summarized, below.

- Programs 1 and 2 assesses ABET Program Outcome 3d using both feedback from a senior exit interview assessment tool, which rates both effectiveness and importance of teamwork skills, as well as the average evaluator rating from the Evaluator Assessment of Multidisciplinary Teams survey instrument (average of responses to questions 1 – 5 in Figure 3).
- Program 3 utilizes the tool as a freshman assessment of teamwork skills, relying more strongly on feedback from their senior exit interview and capstone project evaluation to assess ABET Outcome 3d.
- Programs 4 and 5 use both the student and evaluator assessments as a supplemental assessment of freshman teamwork skills. They use additional tools, such as items from the Senior Exit Interview, Capstone Design project, Alumni Survey, and Employer Survey, to evaluate ABET Outcome 3d.
- Program 6 relies on the student and evaluator assessments to assess the teamwork skills of their students in the integrated freshman (and sophomore) engineering curricula, with more direct input from multiple senior-level courses and their senior design conference survey.

Conclusion

The College of Engineering and Science at Louisiana Tech University has implemented a project-based first-year experience to boost experiential learning and foster innovation. Students participating in this new curriculum participate in eight projects where they gain approximately 75 hours of experience working on multidisciplinary teams. The College has modified survey instruments developed by the NSF-supported Foundation Coalition project to assess ABET's EAC Program Outcome 3d: ability to function on multidisciplinary teams. The survey instruments are utilized at the freshman engineering Design Exposition held at the end of the freshman year. A survey to be completed by internal and external project evaluators was developed as well as a survey to be completed by student participants. The results from both of these assessment instruments are presented as along with verbatim comments from the evaluators and students. These assessment instruments are a strong component of the College's strategy for assessing ABET EAC Program Outcome 3d; the instruments are utilized by all engineering programs in the College.

Acknowledgement and Disclaimer

Partial support for this work was provided by the National Science Foundation's Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No.0618288. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Bibliography

1. *ABET Criteria for Evaluating Engineering Programs, Effective for Evaluations during the 20082009Accreditation Cycle*, http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20Criteria%2012-04-07.pdf

2. Richardson, J., Corleto, C., Froy, J., Imbrie, P.K., Parker, J., and R. Roedel, "Freshman Design Projects in the Foundation Coalition," *1998 Frontiers in Education Conference*, Tempe, Arizona, November 1998.

3. Hanesian, D., and A.J. Perna, "An Evolving Freshman Engineering Design Program – The NJIT Experience," *29th ASEE/IEEE Frontiers in Education Conference*, November 10-13, San Juan, Puerto Rico, 1999.

4. Weggel, R.J., Arms, V., Makufka, M., and J. Mitchell, “Engineering Design for Freshman,” prepared for Drexel University and the Gateway Coalition,” February, 1998.

5. Sheppard, S. and R. Jenison, “Examples of Freshman Design Education,” International Journal of Engineering Education, **13** (4), 1997, 248-261.

6. Carlson, L., Sullivan, J., Poole, S., and M. Picket-May, “Engineers as Entrepreneurs: Invention and Innovation in Design and Build Courses,” *29th ASEE/IEEE Frontiers in Education Conference*, San Juan, Puerto Rice, 1999.

7. ITL (Integrated Teaching Laboratory), University Colorado at Boulder, 2008, http://itll.colorado.edu/ITLL/.

8. Hein, G.L. and S.A. Sorby, “Engineering Explorations: Introducing First-Year Students to Engineering,” *31st ASEE/IEEE Frontiers in Education Conference*, Reno, Nevada, October 21.

9. Dym, C., Agogino, A., Eris, O., Frey, D., and L. Leifner, “Engineering Design Thinking, Teaching, and Learning,” *Journal of Engineering Education*, January 2005, 102-130.

10. Splitt, F.G., “Systemic Engineering Education Reform: A Grand Challenge,” The Bent of Tau Beta Pi, Spring 2003.

11. Felder, R.M., “Changing Times and Paradigms,” Chemical Engineering Education, **38** (1), 2004, 32-33.

12. Carlson, L.W., and J.F. Sullivan, “Hands-on Engineering: Learning by Doing in the Integrated Teaching and Learning Program,” International Journal of Engineering Education, **15** (1), 1999, 20-31.

13. Cropley, D.H. and A. J. Cropley, “Fostering Creativity in Engineering Undergraduates,” High Ability Studies, The Journal of the European Council for High Ability, Carfax Publishing, Taylor & Franic Ltd. UK, **11** (2), 2000, 207-219.

14. Nelson, J.D. and B. Schroder, “Establishing an Integrated Mathematics, Engineering, and Science Curriculum: Lessons Learned,” *Proceedings of the American Society of Engineering Education Meeting*, Albuquerque, New Mexico, 2001.

15. Hall, D.E., Hegab, H.E., Nelson, J.D. *Living WITH the Lab -A Freshman Curriculum to Boost Hands-on Learning, Student Confidence and Innovation*, 38th ASEE/IEEE Frontiers in Education Conference, October 2008.

16. Hegab, H.E., Hall, D.E. *Microfabrication of a Resistance Temperature Detector*, 38th ASEE/IEEE Frontiers in Education Conference, October 2008.

17. Swanbom, M.E., Hall, D.E., Crittenden, K.B. *Centrifugal Pump Design, Fabrication and Characterization: A Project-Driven Freshman Experience,* American Society for Engineering Education Annual Conference and Exposition, June 2008.

18. Hall, D.E., Cronk, S.R., Brackin, P.D., Barker, J.M., Crittenden, K.B. *Living with the Lab: A Curriculum to Prepare Freshman Students to Meet the Attributes of "The Engineer of 2020,"* American Society for Engineering Education Annual Conference and Exposition, June 2008.

19. Reed, A., Creekbaum, T.M., Matthew, E.D., Hall, D.E., Harbour, W.D. *Utilizing Robotics to Facilitate Project-Based Learning: A Student Perspective,* American Society for Engineering Education Annual Conference and Exposition, June 2008.

20. Hegab, H.E., Hall, D.E. *Increasing Experiential Learning in Freshman Engineering through a Microfabrication Project*, ASME International Mechanical Engineering Congress and Exposition, 2007.

21. National Academy of Engineering, “The Engineer of 2020.” The National Academies Press, Washington DC, 2004. www.nap.edu.

22. Brackin, P. and Sexton, S., 2008, “Robotics-Centered Curriculum: 2006-07 Annual Assessment Report.” Rose-Hulman Institute of Technology, 49 pages, 2008.

23. Hall, D.E., The 10 Faces of Innovation, ENGR 122 course notes, http://www2.latech.edu/~dehall/LWTL/ENGR122/notes/7_10_faces_of_Innovation.pdf

24. Kelley, T. with J. Littmann, The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate & Driving Creativity Throughout Your Organization, Doubleday Publishing, 2005.

25. Kelley, T./IDEO, The Ten Faces of Innovation, http://www.tenfacesofinnovation.com/?variable=8&customEasing=[object+Object]

26. abcNews, Deep Dive, Nightline episode aired on 7/13/99 featuring the IDEO design process, July 2008.

27. Hall, D.E., Brainstorming, ENGR 122 course notes, http://www2.latech.edu/~dehall/LWTL/ENGR122/notes/9_brainstorming.pdf

28. Shuman, L., Besterfield-Sacre, M.E., Wolfe, H., Atman, C.J., McGourty, J., Miller, R.L., Olds, B.M. Rogers, G., Foundation Coalition Outcome 3d an ability to function on multidisciplinary teams, http://www.foundationcoalition.org/home/keycomponents/assessment_eval/outcome_d.html.