

Engineering Teams: Individual or Group Sport?*

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This paper describes a study undertaken to explore the functional roles that engineering students take on project teams as they progress through the Mechanical Engineering program at the University of Maryland. The data gathered from the study exposed the pervasiveness of functional role specialization in project teams. Specialization may be turning engineering project teams into collections of individuals learning different topics.

Keywords: team; team notes; specialization; project teams

INTRODUCTION

ENGINEERING INSTRUCTORS instill fear and horror in their students by uttering this sentence: 'A significant portion of your grade will be determined by a course-long, team project.' Engineering student project teams can be collaborative, interdependent, and supportive learning networks that inspire participants to perform at a level equal to or above their prior individual bests. Ideally, engineering project teams encourage students to attempt tasks outside their academic comfort zone and support students as they learn new concepts and skills.

Unfortunately, most students have served time on a project team that never achieved a competent level of performance. Experiences of engineering students and educators unequivocally tell us that effective team performance is not a spontaneously occurring phenomenon. Scheduling a team project into a course does not automatically result in the creation of supportive learning networks that immediately and continually perform to the instructor's highest level of expectations. The selection or assignment of student roles on engineering project teams is important to understanding the educational experience.

Formal studies have uncovered the challenges to effective performance by engineering student teams. One representative and particularly relevant study was conducted with engineering student focus groups and faculty interviews at the University of Maryland, Morgan State University and Catholic University. The inquiry was conducted by a team of researchers (including this author) to inform the development of engineering student team training materials. This work was conducted under the project name BESTEAMS (Building

Engineering Student Team Effectiveness and Management Systems); BESTEAMS partners have included the University of Maryland, Morgan State University, Howard University, The United States Naval Academy and Catholic University. Engineering faculty members and students in the study confirmed that effective teamwork does not just happen and that little or no training is available to help students develop teamwork skills. Furthermore, students suggested that training in teamwork skills (e.g. conflict resolution and leadership) should begin in the first year.

A second study of engineering project teams at the University of Maryland discovered that students embrace specialization as a strategy to produce higher-quality team deliverables. Specialization means the intentional assignment of particular project task work roles to individuals who already show (or declare) proficiency in those skills. By dividing the tasks required to accomplish a project by functional area, the team may produce a strong product, but students' understanding may be limited to their area of contribution. This is the specialization model of teaming that is pervasive in industrial settings, where project completion is emphasized over learning.

In some classroom project situations, technical specialization by engineering discipline is necessary for the success of the effort (e.g. senior capstone courses or national competition project courses). However, widespread specialization throughout the undergraduate experience, especially in courses serving first- and second-year students, interferes with the learning goals of engineering education. Understanding specialization in teams will allow engineering educators to develop project structure and assessment strategies for course projects that maximize team strengths as informal learning communities and minimize team weaknesses.

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BACKGROUND OF TEAMWORK STUDIES IN ENGINEERING

Teamwork has been studied in a variety of fields, including business, human factors, education and psychology. Applying these perspectives to engineering teams, we see that there are two sets of roles that must be filled for a team to perform effectively. 'Teamwork' includes all the interactions among members, and 'task work' describes the individual assignments undertaken by team members that contribute to the team's goal. In the case of engineering design teams, task work is used to refer to the set of functional roles that students assume in order to complete a project. Functional roles in design teams include researcher, CAD modeler, analyst, machinist and technical writer.

The roles most often identified and studied in the engineering education literature are those characterizing non-technical activities and behaviors—in other words, the traditional teamwork process roles. However, teamwork process roles are not the set that students refer to when asked about the roles they take on a team, with the possible exception of a leader role. When queried on 'roles' that team members have on project teams, students identify task work roles (hereinafter referred to as functional roles). This suggests that students tend to interpret the team as a collection of individuals with specific assignments, which further supports the fact that students are specializing on their project teams. Specialization emphasizes the model of the project team as a sports team; sports teams are made of individuals playing clearly defined positions to achieve a common goal.

Recognition of specialization on student project teams occurred during a study by a group of investigators from the Colleges of Engineering and Education at the University of Maryland. The activity was a pilot study using focus group interviews with student team members to understand the behavior of students in selecting functional roles on project teams. The ongoing study is funded by the National Science Foundation under the grant number DUE-0243265. The researchers were interested in discovering which roles students recognized as necessary to engineering project teams and how individuals selected their roles. The data revealed a model of intentional specialization on project teams to produce good team deliverables and showed that the specialization increased as students progressed through their engineering courses. The Maryland functional role study is described in more detail in the next section.

Method: Maryland engineering team functional role study

To better understand student and faculty awareness of functional roles in engineering student teams, a group at the University of Maryland

conducted a pilot study using qualitative data collection. Data presented below includes compilation of results reported in two prior publications from the Proceedings of the American Society of Engineering Education Annual Conference and Exposition of 2004 and 2005. The 2004 publication compared first- and fourth-year student attitudes (27 participants) toward the existence of functional roles on teams. The second report from the Maryland study compared responses from five Mechanical Engineering student project teams (26 participants) from selected courses required by the curriculum during the 2003–2004 academic year. Teams highlighted in the second paper were two teams of freshman or transfer students taking Introduction to Engineering Design (ENES 100), one team of sophomores enrolled in Mechanics of Materials (ENES 220), one team of juniors enrolled in Statistical Methods for Product Engineering and Manufacturing (ENME 392) and one team of seniors taking Integrated Product and Process Design and Development, the capstone design experience (ENME 472). Analysis of responses from students in this collection of courses allowed the researchers to make observations on the awareness of functional roles by students as they progress through the curriculum.

There are several benefits to working with currently operating, intact teams in focus groups. The experiences are fresh. Teammates have a working relationship with each other that can encourage discussion. They can build on the comments of each other or present an alternate view. One potential drawback to focus group studies conducted with intact teams is that teammates may not be completely candid in their responses. To identify the degree to which study participants felt free to respond in the presence of their teammates, each participant filled out a simple, anonymous questionnaire. Twenty-three (23) of the 26 study participants recorded agreement or strong agreement to the statement, 'I did not withhold or edit my comments because my teammates were present.' Twenty-five (25) of the study participants agreed or strongly agreed with the statement, 'I felt comfortable during this conversation.' Another limitation of the present study is that the students interviewed represented a cross-section of students in the A. James Clark School of Engineering during the 2003–2004 academic year. This was not a longitudinal study that tracked the same set of students throughout their engineering education experience. As a result, we have the responses of different students in different courses, introducing variation among students into the factors influencing their responses.

The focus groups were facilitated by a graduate student and one of the principal investigators familiar with the engineering courses and jargon used by the participants. The same questions were used to elicit comments from each group. The facilitators actively solicited feedback from all

team members and asked for clarification as needed. The facilitators were also free to follow up on interesting issues raised by the participants even if they were not in the original protocol.

The focus group protocol included introductory questions about the team project and course context, as well as questions about team functioning, functional roles, process roles, and questions about mastery of engineering content. All questions were open-ended. Every effort was made to construct questions that did not influence responses. The initial questions refrained from suggesting roles to students (e.g., task work or teamwork). The more neutral term of 'function' was used. A few examples of the questions used to elicit information on the kinds of roles students take on teams are:

- What functions do you prefer to do when working on a team?
- Do you use the team experience as an opportunity to learn new skills? If not, why? If so, describe how or give examples.
- What are the special group process roles you like to take on project teams (e.g. leader, facilitator)? (This question was asked of the team only after they articulated what they consider to be functional roles assumed by members of their team.)

The focus group sessions were tape recorded, transcribed, and studied using content analysis software. Students used aliases during the conversation to maintain confidentiality. Each student received a \$20 gift certificate to the campus bookstore at the completion of the focus group.

To provide a different perspective on the questions, the investigators interviewed each of the five faculty members who were currently teaching the focus group participants. Faculty members were

asked to discuss the team project in their courses, describe a well-functioning team, and comment on themes raised by the student team from the corresponding course. Again, open-ended probes were used to elicit candid responses.

Results from engineering team functional role study

This paper highlights student and faculty attitudes toward functional role specialization (Table 1) and learning in project teams (Table 2). Students in the focus groups did not automatically associate queries about functional roles with task work. Only after some discussion with the facilitator did the students begin to describe the task work roles used on their teams. Interestingly, many teams recognized the role of leader as a functional role.

Study data revealed that students on engineering project teams divide their work load to efficiently achieve better project results. Self-reported interest or expertise was the primary determinant of task work assignments in the case of first- and second-year student teams. As students progressed into upper-level course projects, more emphasis was placed on performance based on prior team membership.

Students on all the teams studied hold the opinion that identifying task work strengths in individuals is a good strategy for project work. The responses in Table 1 indicate that team members link good project performance outcomes with the matching of team member and task skills. From their very first team experience, students know that specialization increases efficiency in project work. The realization and exploitation of functional role specialization increases with the number of team projects students encountered.

Table 1. Students recognized that specialization improves overall team product

| Course Year | Attitude Toward Specialization and Representative Comments#270 |
|-------------|---|
| First | Specialists enhance overall product 'It helps that a lot of our group had prior knowledge of things going into [the project] . . .we had someone who could already program, do the web page, do the wiring.' 'You can get each individual part done well with input from every other person who doesn't have that specialty.' |
| Second | Specialists enhance overall product 'Usually when you're on a team, you're like, well, what do you like to do? . . .This is what has to be done. So, if you like to do that, just go do it so we can get it done.' 'They [specialists] can make it, like, look like a professional product and finish it off. I don't know how it [having specialists] could be a disadvantage to the final product.' '[A specialist] provides, you know, hopefully you're doing this so that at least that one part of the project should be good.' |
| Third | Some specialization works well 'I think it helps to have—looking back—to have half the people on the team very specialized in either, you know, in something like, maybe they're really good at the conceptual work . . .or really skilled with doing like, computer design. And the other half it helps to have people that are very flexible.' 'It [being a specialist] is always going to be helpful.' |
| Fourth | Recognize need to specialize 'We started talking over the summer . . .and he said, 'I knew people who were really good at building stuff and designing' . . .I like the process stuff . . .we kind of just brought it together that way.' 'We know that three people here really know how to do engineering drawings and that's who we assign that to.' 'The roles fell into place. . . .we found people's strengths and you know how people work.' |

Table 2. Students recognized that specialization impacts individual learning

| Course Year | Specialization Has Effects on Learning and Representative Comments |
|-------------|--|
| First | Team members can learn from specialists 'This is a first where I've had a group where other people are specialized in that I can learn from a lot of people in the group.' |
| Second | Team members can learn from specialists 'If you are a specialist, it can be good because, one, hopefully the rest of your group can take a little bit away from, you know, your increased knowledge of the subject.' 'If you can cause an interaction or even perhaps not assign them to their area of specialty or have them as like a backup to help someone else specifically assigned to them, then the learning process would be augmented.' Specialization has costs 'A lot of times that [having specialists] could be a disadvantage, just because you don't get to learn the other things that are outside your specialty.' 'The disadvantage is the specialist has been taught in a specific manner, and to get to this point, they've already made so many assumptions. What if you don't want to make those assumptions?' |
| Third | Specialists gain valuable experience 'If you specialize you get good at it.' |
| Fourth | Specialization doesn't replace interaction on a team 'It's not like we all go off in a separate little corner to do it . . . I'm not in my own little world doing it . . . we get back together and all the different parts have to come back together.' 'This project is time-consuming, but other projects are also time-consuming. So the time constraint is definitely a problem [that affects how the project is approached].' Not everyone specializes (or learns) 'I consider myself a jack-of-all-trades because I know a little bit about a lot of things, but not an extreme amount about any of them.' |

Capitalizing on specialization in project teams becomes a strategy for team formation in upper level courses.

It may not be immediately clear that specialization on engineering student project teams has drawbacks. Table 2 summarizes students' attitudes about how specialization impacts learning in project teams.

Even in the first-year teams, students made the case that specialization strategies produce the best final product and offer novices a way to organize the team effort. Drawbacks to this 'divide and conquer' approach are not mentioned by first-year students. Some even claim that their learning is enhanced when specialists are identified.

The second-year course team clearly recognized that specialization can support or deter individual learning. Peer-to-peer learning may not occur if team members stick to their specialties. Conversely, specialists can be deployed in the service of the learning goals of all team members by sharing their experiences and teaching other team members. This latter benefit is realized only if there are built-in opportunities for sharing information within the team context. Since this coordination is rare, most students noted that the specialization strategy limits their learning. The third-year team acknowledged that specialization is a path toward learning. This also implies that you will not learn task work which you are not already inclined to try.

All fourth-year engineering students must participate on a capstone design team. A person's specialty figured prominently in whether or not someone was invited to join student-formed project teams. The team was designed to have a range of talents represented. Duties were divided along expertise lines with some effort to share

information and progress back to the larger team. Specializing was viewed as essential to completing the monumental task at hand. The project quality was paramount. All other goals for the course (e.g. learning to work in teams, developing a broad knowledge of a design process or learning field-specific design methods) were secondary.

Discussion of study results

The evidence of specialization on the project teams studied is very strong. Students contend that the team projects demand it. To excel in an engineering design project, everyone must contribute his or her talents. It is clear that many students develop specialties that they are repeatedly called upon to contribute to their teams. One fourth-year student described himself as a 'jack-of-all-trades,' but went on to disclose that he consistently performed the same functional role as in all his previous teams.

Students are sensitive to becoming specialists, particularly if they are not recognized as task work specialists. First-year students claimed that their initial roles in no way predict or limit future roles on project teams. No one in this study reported performing (or intending to perform) only one role throughout their college career, but the recurring patterns were clear.

Faculty members interviewed as part of this study acknowledged that specialization occurs on the project teams in their courses. The faculty members support specialization as an efficient approach to complete team project assignments. When asked how team projects serve course content learning, faculty in the second-, third-, and fourth-year courses confessed that they have no way of knowing if their learning goals for

individual students are being met through the project assignment.

Faculty members were not surprised to hear that their students ranked the quality of the team project deliverable above individual learning, but they felt perplexed about how to react. Developing team experiences for undergraduate students that simulate professional 'real-world' problems creates a natural tension with the obligation to teach course content and skills. Professional settings value efficiency and high quality and expect employees to be specialists (depth at the expense of breadth). Educators value content and conceptual mastery with an appropriate balance of depth and breadth.

Three observations can be made on the basis of this study. The first is to challenge the adoption of the industrial project team model in a classroom at all levels of the curriculum. Intensive team projects should be selectively placed within the curriculum. Student teams will not and cannot duplicate the diversity of experience, both in team process and functional expertise, of a team in an engineering firm. Given the distinctive demands of engineering project teams in a university context, the emphasis must be on student learning rather than efficiency or, perhaps, even overall product quality. Engineering educators should not be satisfied unless all students gain proficiency in all aspects of the subject matter addressed by a particular project. This calls for a return to both individual and team levels of assessment, even in project-intensive courses like capstone design.

A second observation is that students may specialize on teams by 'going off' to work on their parts of the project, but they must return for group decision-making. Engineering project teams are characterized by a high degree of interdependent decision-making. That is, team members may assume responsibility for a particular task in the project, but the decision-making process in engineering is so coupled that rarely can decisions be made by individual team members in isolation. It appears that the functional roles students recognize and assume in engineering project teams have limited autonomy. The pattern that emerges is one of functional specialization yielding to group decision-making. It is discussion after the specialist has presented options that can serve as a learning experience. Faculty members should adapt assignments to include reports on key decisions and provide teams with a protocol for how to use group decision-making discussions as learning activities.

A third observation is that there may be times when specialization is appropriate and encouraged. One could make the case that the senior capstone experience offers such an opportunity.

Faculty members using team project assignments in other courses should identify areas of project-enhancing specialization and actually assign specialists in these areas to teams. For example, Pro/ENGINEERING skills are useful in a third-year fluids class where teams are formed to create and analyze models of vehicles traveling at a high speed in air or water. At the same time, developing Pro/ENGINEERING skills is not a key learning outcome of the course. In this team project scenario, placing a Pro/ENGINEERING specialist on a team will allow members to focus on course learning objectives, not learning a new tool to support the project. Customizing team skill sets to allow focusing on critical course content is an effective strategy for faculty, but requires more deliberate intervention in team formation. First, faculty members must distinguish course learning outcomes that all students should achieve from skills that a subset of students will bring into the course. Then an instructor must devise a means to determine the skill set of each student in the course. Student information questionnaires can be designed to identify specialists in skills that will enhance team performance. Armed with skill profiles of students, the course instructor can build teams that include members with the appropriate project support skills. This eliminates the need for a student to make trade-offs between learning primary course content and developing project-enhancing skills. Skill specialists on a team can act as tutors for teammates.

CONCLUSION

The team project is commonly used in engineering courses as a means of creating a group-learning experience. Projects are embedded into course syllabi, but they do not guarantee individual student learning. Student specialists can work together to produce a great project without adequately learning all project elements. Educators have failed to notice that strategies students use to achieve good project outcomes may be undermining individual learning outcomes. Faculty members need guidance in how to structure and monitor the team experience to prevent it from becoming a set of individuals contributing pieces to a project. The engineering student project team is a rich and powerful learning network whose activities must be channeled to serve the educational needs of each individual team member.

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REFERENCES

1. A. Gibbs, Focus Groups, Social Research Update 19, conducted for the Department of Social Medicine at Bristol University (1997).
2. F. Rees, *Teamwork from Start to Finish*, Jossey-Bass, San Francisco (1997).
3. L. C. Schmidt, J. A. Schmidt, P. E. Smith, D. I. Bigio and J. B. Contardo, *BESTEAMS A Curriculum Guide for Faculty*, College House Enterprises, LLC, Knoxville, TN (2005).
4. P. Mead, D. Moore, M. Natishan, L. Schmidt, S. Brown, C. Lathan, I. Goswami and S. Mouring, Faculty and student views on engineering student team effectiveness, *Journal of Women and Minorities in Science and Engineering*, **5**, pp. 351–363 (1999).
5. M. E. Natishan, L. C. Schmidt and P. Mead, Student focus group results on student team performance issues, *Journal of Engineering Education*, **89**(1), pp. 269–272 (2000).
6. J. Brown Leonard, J. A. Schmidt, P. E. Smith and L. C. Schmidt, A pilot study of functional roles on engineering student teams, *Proceedings of the 2004 Society for Engineering Education Annual Conference and Exposition*, Salt Lake City, UT (2004).
7. J. Brown Leonard, L. C. Schmidt, P. E. Smith, J. A. and Schmidt, A pilot investigation of functional roles on engineering student teams: A developmental perspective, *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition*, Portland, OR (12–15 June 2005).
8. B. B. Morgan, Jr., A. S. Glickman, E. A. Woodard, A. Blaiwes and E. Salas, Measurement of team behaviors in a Navy environment (NTSC-TR-86-014), Naval Training Systems Center, Orlando, FL (1986).
9. D. P. Baker and E. Salas, Principles for measuring teamwork skills, *Human Factors*, **34**(4), pp. 469–475 (1992).
10. P. Johnson, Problem-based, cooperative learning in the engineering classroom, *Journal of Professional Issues in Engineering Education and Practice* (January 1999).
11. R. Knecht, Can peers be used to effectively assess teams? *Proceedings of the 2004 Society for Engineering Education Annual Conference and Exposition*, Salt Lake City, UT (2004).
12. J. McGourty, K. De Meuse, *The Team Developer: An Assessment and Skill Building Program*, John Wiley & Sons Press, New York (2000).

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