Using Teamwork and Communication Skills to Monitor and Strengthen the Effectiveness of Undergraduate Aerospace Engineering Design Projects

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Abstract:
Earlier work in a 2nd year undergraduate engineering design course suggests that there is a strong correlation between poor written communication and poor design performance. Moreover, a correlation between poor teamwork and poor design performance has been noted. This paper reviews that work and proposes a model that explicitly teaches teamwork skills and uses written communication to develop team dialog around those skills. This model uses team communication deliverables to identify poorly functioning teams early in the process and suggests strategies to intervene with those teams when identified. Assessment plans for this model are described.

Introduction:

This paper presents work done in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT) in monitoring the effectiveness of undergraduate student design projects through the use of communication deliverables. We present early work that demonstrates a strong correlation between student teams' low written communication scores and subsequent poor design performance. Then, we describe an intervention model designed to strengthen communication ability and team performance and thus to influence design performance.

Background:
At the Department of Aeronautics and Astronautics at MIT, 2nd year engineering students are introduced to the principles of flight in a rigorous, two-semester course, Unified

Engineering (16.03). The first semester of the course covers fundamentals of fluid dynamics, propulsion, structures, signals and systems engineering. In the second semester, teams of students implement that knowledge by designing, constructing, and flying electric-propulsion, radio-controlled model aircraft. This progression is determined by the department's CDIO engineering education strategy (Conceive-Design-Implement-Operate) that integrates classroom teaching and active learning. [1, 2, 3, 4]

In addition, the CDIO strategy specifies learning objectives in written and oral communication practice. Thus students in Unified Engineering are required to document their team's goals, objectives, program plans, trade analyses, scheduling choices, and progress during the course of the second-semester aircraft design and flight project.

Early work:

In February 2003, fourteen teams (each composed of 5 students) were required to assemble, analyze, and fly a radio-controlled, electric-propulsion model aircraft, the Diversity Model Dragonfly. [5] Then, student teams were required to modify their aircraft for higher performance in the course competition scheduled later in the semester. Teams received points for their aircraft's flight performance based on rules set by the faculty. The Unified Engineering faculty asked the students to report on their team's progress by writing short reports in response to tasks established in System Problem Sets (SPS). The reports were team reports and were usually composed by one or two students based on contributions from other members of the 5-person team.

Earlier in the semester, the communications lecturer provided writing assignment guidance for engineering faculty and students through short lectures and resource materials. She also was available for conferences with students as they prepared their SPS. Engineering faculty and undergraduate TAs evaluated the SPS and assigned grades based on simple scoring rubrics.

However, in 2003, in a departure from previous years' practice, the Unified Engineering faculty decided to rigorously evaluate the written communication element of the SPS and to include it as part of the grade for the SPS. The technical element of the SPS was evaluated and graded by engineering faculty. The communications lecturer developed rubrics that focused on the basic communication elements of the SPS (Table 1), mapped the values on the rubric to the MIT grading standards (Table 2), and scored the SPS using those rubrics. She also added written comments re: the completeness and coherence of the writing. Data regarding communication elements was gathered from four SPS: 6, 7, 8a, and 8b. This data was then combined with the final competition flight scores of the teams' flight trials in early May (Table 3).

Table 1: Communication elements on SPS 6, 7, 8a and 8b

Communication skills	Document preparation skills
Short introduction that provides context	Cover sheet with appropriate identifying information
Ideas flow logically from sentence to sentence; from paragraph to paragraph; from section to section.	Page numbers
Language is grammatically correct; punctuation is correct; spelling is correct.	Labels on tables, figures, and equations.
Writing is concise, accurate, organized, and complete (e.g. all sections are present.)	

Table 2: Rubric grading as mapped to MIT grading standards

Grade	Description	Comment
5	Exceptionally good	Coverage and/or correctness of content demonstrates superior understanding of the subject matter, a foundation of extensive knowledge, an ability to skillfully use concepts.
4	Good performance	Coverage and/or correctness of content demonstrates a good understanding of the subject matter, capability of use of the relevant concepts.
3	Adequate	Coverage and/or correctness of content demonstrates adequate understanding of the subject matter, a foundation of extensive knowledge, an ability to apply the concepts in a relatively simple manner.

The communications elements scored on the rubrics were deliberately basic since this fast-paced course could not yield more time for in-depth communication instruction. However, faculty members felt strongly that communication skills are essential to effective and efficient engineering process and agreed that identifying and scoring these basic elements and including those scores in the final grade would help students focus on key skills that could then be refined in junior and senior level coursework.

But the faculty did not expect that some student teams would have such difficulty demonstrating these basic communication skills at a "good" or "exceptionally good" level. Nevertheless, as Table 3 shows, some teams received "adequate" or below adequate scores on several SPS.

Table 3 shows the scores for the fourteen teams on these particular SPS and correlates those scores against the competition rank of the teams. Note that in the top 50% of teams (scores above 200), there are 7 instances of communication scores that were "adequate" (3) or below. However, in the lower 50% of the teams (below 200 or did not finish (DNF)), there are 15 instances of scores that were "adequate" (3) or below. Thus, there appears to be a strong and quantifiable correlation between low communication scores and poor design performance. The reverse does not seem to be true: strong communication scores (4 or 5) do not correlate necessarily with successful design performances.

Engineering faculty also observed that the teams whose aircraft performed well in competition demonstrated strong technical understanding and good teamwork skills in addition to being able to articulate their work on the written SPS. On the less successful teams, faculty observed weak technical understanding and difficulty in achieving project milestones. Engineering faculty also observed that, in reflective memos written at the end of the term, students could describe the teamwork difficulties they had encountered even though they had not been able to remedy those during the term. Not surprisingly, the students who described the most teamwork difficulties tended to be on teams whose designs did not perform well.

Table 3: Correlation of competition scores with SPS communication scores

Competition Rank	Competition Score	SPS 6	SPS 7	SPS 8 a	SPS 8 b	Team name
1	925	3	3	4.5	4.5	Pukin' Dogs
2	613	3	4	3.5	4	Flying Fokkers
3	316.5	5	3	4.5	5	Chapter 11
4	290	3	2	4.5	4	Eggcellent
5	244	4	3	3.5	4	MotherGoose
6	215	4	4	5	4	Superfly
7	198	4	4	4	4	Fighting Falcons
8	197	5	3.5	4	4.5	X Pi Magnum
9	196	2.5	4	3.5	4	Afati Airplanes
10	139.5	2.5	2	3.5	3	Killer Clowns
11	112.5	4	5	4.5	4	Team Enterprise
12	.12	2	2	3	2.5	Wright Stuff
13	DNF	2	3	4	3.5	Flaming Monkeys
13	DNF	4	4	4.5	3.5	Argonauts

Discussion
While it is true that students can learn from failing as well as succeeding, faculty felt that for teams to have performed as poorly as several of the teams in the lower 50% of the competition was not an optimal learning experience, given the time and energy that the course had required. Thus, the faculty considered several possible explanations for the poor performance scores in the flight test as well as on the communication deliverables:
-   poor performance resulted from poor piloting abilities and/or lack of training on the part of one student;
-   poor performance resulted from material failure;
-   poor performance resulted from ineffective design choices;
-   poor performance resulted from team inefficiency on flight day;
-   poor communication scores resulted from one or two poor student writers;
-   poor communication was the result of lack of documentation, lack of substance and/or unclear critical thinking;
-   poor communication was the result of time pressure, not understanding the assignment, and/or not realizing that the communication element contributed to the grade.

After discussion, faculty determined that material failure was not a significant reason for poor performance in this particular competition. Faculty agreed that poor design choices,

team inefficiencies, and poor piloting abilities were likely causes of poor design performance and had some base in the ability of the team to work together to learn, to make choices, and to find and use resources. These difficulties manifest themselves in poorly written and disorganized communication deliverables.

Current work

The quantifiable correlation between poor communication skills and poor design performance could allow faculty to intervene in a dysfunctional design process and thus potentially to improve student learning. The multi-stage model described here uses written communication as a way to identify student teams who are having difficulties and also as part of the way to remedy those difficulties and assess continued progress. Yet it is not as simple as "teaching writing." Instead, the model relies on teaching key teamwork skills, helping students to articulate teamwork problems and offering strategies to strengthen team functioning and technical comprehension. Writing and information organization becomes an integral part of how strongly functioning teams communicate their design process to the faculty and to one another.

Multi-stage intervention model

First stage: Cornerstone teamwork skills

In the first stage of this model, the faculty explicitly (albeit briefly) teaches three key elements of teamwork: the task, the process of addressing that task, and the feeling that gathers around these elements on a team level as well as on an individual level. In addition, faculty teaches constructive ways to forestall work division difficulties and design process problems, two of the more common sources of team conflict.

Each student is asked to write a short memo about his/her strengths, weaknesses, expectations, skill sets and/or preferences re: team projects.

Communication faculty reads and responds briefly to individual writing.

Individual writing is shared (with student's explicit permission) within the team and faculty, thus forming a shared knowledge.

Faculty and TAs make queries about team function an explicit part of dialog with individual teams.

Student perception of team process is surveyed via a confidential, Web-based survey five times during the semester. The engineering and communication faculty has access to this data (although not to the identify of the respondent) as it is collected, allowing them to address general teamwork problems that surface during the course of the term.

Rationale for first stage:

Although there is an extensive body of knowledge about effective teamwork in industry and although educators regularly assign team projects, very little of this understanding about teamwork is explicitly taught to undergraduates. We think that, rather than merely expecting students to know how to work together on complex technical design projects, it would optimize design time if we clarified the relationship between effective design process and teamwork. The faculty thinks that making these concepts explicit makes it possible for individual student in the team as well as faculty to become knowledgeable about teamwork dynamics, to discuss them in common terms and, potentially, to resolve team conflicts when they arise. We note from the reflective assessment at the end of the semester that students are aware of some of these issues (albeit unevenly so) and interested in knowing more.

Administering an anonymous survey at five points in the term identifies difficulties within the larger class group and allows faculty and students to brainstorm ways to solve those difficulties using the strengths of the entire class rather than singling out a few individuals who have problems. Again, this shared (albeit brief) discussion keeps the profile of teamwork clearly in view and engages students as problem-solvers on their own teams.

Moreover, at the end of the term, the combined surveys allow faculty to correlate performance levels with students' perceptions of their team process.

Second stage: Identification of teams at risk

All SPS are scored not only for technical/design decisions, but also for communication elements. Communication scores are likely to target poorly functioning teams while technical/design scores identify teams who are struggling with critical thinking.

Rationale for second stage:

If the correlation described in earlier work holds true, then identifying teams who are at risk because of teamwork problems and/or design decisions is possible, and early identification is advisable. Because of the pace of the course, the pressures on the students, and the complexities of the task, difficulties in team functioning or design process usually become magnified rather than resolving themselves easily.

Third stage: Intervention with teams at risk

Having identified a team that seems to be functioning poorly, the faculty can intervene in one of several ways. First, faculty can ask a TA to meet briefly with the team to investigate more fully and report back to the faculty. Alternately, a faculty member can

meet with the team for further exploration. The goal of these meetings is to work with the entire team to identify the difficulties and to develop a plan.

If the team is functioning fairly strongly, then this may be all the intervention required. If, however, the team is more dysfunctional, a TA (graduate or undergraduate) may be assigned to work actively with the team for a short period of time to help strengthen it.

A team that has received an adequate or below adequate score on an SPS will consult with the communication lecturer as they draft their next SPS in order to look specifically at the written communication elements of the SPS.

Rationale for third stage:

Explicit teaching and writing about teamwork creates a shared vocabulary about the teamwork. Thus, addressing teamwork issues with dysfunctional team becomes more possible because students, faculty and TAs agree on key concepts. Lectures provide the vocabulary and theoretical knowledge to grapple with design problems.
Yet a team can become "stuck" because of poor team dynamics or because of lack of comprehension in technical material. Thus, it can be helpful to have an "outside" observer join the team to help re-focus its work. Student teams usually feel comfortable with TAs, and when this is possible, it is efficient to use TA resources rather than faculty. However, there are times when the expertise and authority of engineering faculty is necessary.

There is little time in the fast-paced course for revision of the SPS. However, learning how to organize and write technical material clearly is a culminating step in re-focusing team design process, and the ability to articulate necessary technical material reinforces the improved design process and the more effective teamwork as well as documenting technical comprehension. Thus, specific consultation with the communications lecturer not only sets standards for communication deliverables and allows students to receive specific instruction when needed, but it also insists on continued improvement in writing ability.

Assessment of the model:

Overall design performance: The overall desired outcome is to document improved team design performances in the competition. We will assess this, in part, by comparing competition scores for spring 2004 against competition scores for spring 2003.

Teamwork: Students will be assessing team process throughout the term, and this will culminate in final assessment at the term's end. Previously, students have assessed these elements in a reflective memo. However, the Web-based, confidential survey will provide measurements that can be more closely analyzed.

We will also ask TAs to assess teams to determine their perceptions of team process which we then be able to correlate with design performance.

We will continue to assess basic writing skills by using the rubric developed in spring 2003.

Lastly, we will assess this model by including new items on the departmental Web-based course evaluation form   at the end of the semester.

Summary

Earlier work indicates a correlation between poor written communication and poor design performance. Based on the working hypothesis that poor communication is often a result of a complex dynamic between dysfunctional teamwork and poor critical thinking about design choices, engineering and communication faculty propose a model that teaches key concepts of teamwork and encourages students to resolve team problems while always refining the technical elements of their designs. In this model, students also work with a communication lecturer to learn or to reinforce stronger writing and information organization strategies. On-going and confidential surveys provide student assessment of the success of the model as well as information about how team work and design process interact.

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We also want to recognize the valuable contributions of Todd Pittinsky, Ph.D. and Jeremiah Johnson, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts.

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