ASSESSING COMMUNICATION MODES IN DESIGN PROJECT TEAMS

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Abstract *---This paper reports an assessment study of communication modes and content used by engineering students in a special project-course. The course topic, Robotics for Theater, focused on the planning and construction of a robot from scratch, to support theatric production as actor and prop. Our intention was to challenge teaming and innovative design skills, identified as key areas for engineering education by industry and the National Science Foundation, and analyze communication modes and content.*

Our assessment tools included questionnaires, journals, and students' expressions of their views on the communication and learning processes. Web and video protocol analysis, pioneered by Leifer and others, were not presently suitable because of the unique nature of our institutional environment, which does not require distance learning. In fact, our study could be used by other institutions as an example of tailoring generic methods appropriately to their unique learning environments.

Analysis of the case study of the Robotics for Theater project revealed: 1. Resource mobilization was fostered by the role of the advisor as information facilitator and "weak tie" in the network, and also by the frequent informal contacts among the students in the team. 2. Innovation was fostered by intra-team trust. The strong friendship and teaming experience of the group were critical for effective team dynamics. 3. Probably due to time constraints, the field of theater did not become a fundamental reference of the project, contrary to plans. 4. Time constraints and technical difficulties in implementation inhibited progress. 5. Informal meetings were crucial in the progression of design and implementation.

As a result of our summative (analyzing rather than steering the learning process) study we propose a formative (feedback for improving learning) protocol, which includes use of a website as a project development locus for students and window into the development process for instructors. Additionally, instructors will analyze videotapes of selected student meetings to assess communication processes. This protocol is to be applied to other engineering classes to improve the quality of teaching/learning via feedback.

The roles of the website include intranet for communication, archive for product definition, repository for student design journals, monthly report library, resource pointer, and design workspace. By putting the results of informal meetings out in view, students can assess the entire project at all times and instructors can monitor progress and communication/teaming processes.

INTRODUCTION

The explosion of information technologies during the past decade has revolutionized the practice of engineering, which, quite naturally, drives requirements for changes in engineering education. Two key areas for change identified at the national level by industry, government and schools are 1) Teaming and 2) Design. The information technologies provide new tools for communication in the former and development in the latter. That is, distance learning, video conferencing, e-mail, and intranets provide a new medium for shrinking space and time in cooperative teams. Databases and CAD systems provide error-free archives and design baselines instantly accessible for the product.

The information technologies also provide a useful window into the team and design process for analysis and tuning of the teaching process. Educators can tap in to the stream of messages and designs, measuring the kinds of activities in progress, and find and correct problems in the curriculum. Larry Leifer pioneered such techniques, among others at Stanford University[1]. Leifer electronically instrumented the communications streams between team members, analyzing their activities to assess the educational process and disseminate the results. The original intent of his study was to develop methods to bridge the gap between professional practice and education with joint industry-academic product focused projects.

An important discovery from this and other studies was that **team engineering is a social activity.** While any team effort of course requires social interaction, awareness and training of this aspect had been largely ignored in engineering education, which instead emphasized technical content.

The discovery of the importance of the social element led to deeper examinations of its nature via protocol analysis. Atman, Bursic, and Lozito applied this technique to the verbalization of a student in a design project, coding sentences into categories which included Problem Definition, Information Gathering, Generate Ideas, Analysis etc[2].

Button and Dourish discuss formally the methods and application of protocol analysis in terms of ethnomethodology, i.e. treating engineering communication as utterances by an alien culture to be objectively analyzed by the anthropologist for the purpose of improving the culture, i.e. increasing engineering design productivity[3].

In an interesting study which focused entirely on the social interactions devoid of technical content, Bereton,

[1] *The Robotics Renaissance Group:* The Cooper Union for the Advancement of Science and Art

Cannon, Mabogunje and Leifer analyze the protocols of videotaped conversation in a design team, coding the results in terms of focus and transition[4]. The former is a locking in of a design decision, which often requires assertion of authority based either on merit or power. For smooth teaming, this must be accompanied by persuasion, smoothing the feelings of the loser, and formal registration of the decision. Transition, on the other hand, requires cooperation, exposure of self to risk, and requests for help. The authors note that students are rarely trained in the use of such group dynamic techniques and manners. The authors of the paper at hand observe from their professional experience that the most successful team leaders in industry are superb at these social skills.

The work cited above describes studies which examine the communication associated with teaming and design. The purpose of the studies was to understand and improve skills in these two areas which industry deems of central importance, and hitherto neglected in engineering education. Our purpose is to learn from these examples, and apply communications assessment tools to the improvement of undergraduate engineering education. Every institution has unique characteristics, rendering universal methodologies inapplicable. Thus, we have selected and adapted some of the tools described above, and applied them to a pilot study. From the results of this study we propose a somewhat more general methodology for future courses, encouraging others to tailor their methods accordingly.

CASE STUDY

For a case study, we wished to assess the communication within a coherent team on a well-defined but creative project which challenged the team members and provided ample need for communication. The project should be a focused design with challenging technical requirements.

Just prior to the start of our study, Professor Adrianne Wortzel, who has authored and directed theatrical productions involving robotics and live Web media at Cooper Union, Lehman College, and international venues, approached the department with a proposal for technical collaboration for robotics and theater. This resulted in a special project course, ME363, in the Fall of 1998, followed by ME364 and EID111, "Robotic Visions and Theater" taught in the Spring of 1999.

The case study was based on a design team of students who worked in all three of these courses, adapting and developing robotics platforms for theatrical performance.

ME363 is a special topics course for juniors and seniors with a firm technical background in Mechanical Engineering behind them. In the fall of 1998 the project consisted of adapting the control system of one of Adrianne Wortzel's robots, which had manual remote control via radio link, to remote control from a computer program which triggered the radio link. This was to be the first step in a long-term goal to provide web control panels for robots, enabling theatrical directors and choreographers with the ability to control robots without having programming skills.

The technical goals, while superficially simple, required programming, digital-analog circuit design, RF noise isolation, and driver level software. Gain tuning, impedance matching, and all the unwritten interference problems between digital and analog circuitry cropped up unexpectedly and had to be solved for a working demo. These problems challenged the students' technical knowledge, problem solving skills, and ability to recruit help when beyond their experience (e.g. RF interference). Professors Weiman and Wortzel provided guidance for the course at the requirements level. Technical direction and week-to-week feedback was provided by Professor Wei and consultant Ericson Mar, a recent graduate and robotics expert. An assessment for the course was designed and implemented by Gerardo del Cerro, Director of Assessment at the Cooper Union School of Engineering.

The course met once a week for three hours, providing intense interpersonal communication and project work. Other components of labor were provided individually by students during the intervening days.

A web site was used as a repository for design decisions, technical information, and journal entries narrating the design process. The end result of this project was a working demo successfully showing the integrated functioning of the components.

ME364 followed in the next semester, using the same team (described in the next section). In this course, the knowledge learned by the team was applied to the design of a from-scratch robot, using the HandyBoard (68CH11 based) robot control package from MIT. A body, displays, control system, and remote video were designed and built by the team. The user interface for the ME363 robot was based on key-commands from QBASIC. The ME364 interface was higher level, based on a Visual Basic form with command buttons for direction, speed and state. The architecture and interface were more advanced than the ME363 robot and required considerable digging for components, interfacing, and programming. Ericson Mar provided a crucial role in guidance towards resources and the www was a major source of information.

The EID111 course only peripherally involved the team for ME364, but nevertheless provided a bridge and application context for the robot project.

The robotics team consisted of three juniors and one senior, all ME majors. They had worked for at least two years together on courses and projects and were aware of each other's particular characteristics. The working profile of these students bears some discourse because of its impact on the methods of communication. All commuted to school from nearby neighborhoods, and did not live on campus. Most worked part-time, and did not use e-mail from home. Thus, their time at campus was scheduled, and significant communication was face-to-face, i.e. this was not a distance learning nor intranet experience.

A Summative Assessment Of The Robotics-For-Theatre Project

The objective of the assessment of this project was mainly *summative* and experimental. It was planned so that we could gather information about the work of the team at different levels. The purpose was to develop a protocol for assessment of similar projects in the future. Thus different methods for collecting information were developed and implemented, and the data analyzed (see below). The *formative* dimension of assessment was not stressed, although it is the thrust of the designed protocol for use in future projects. For instance, the use of a website as an archive and bulletin board was new to this course, and was not used primarily as a source of development, but rather as a destination of reports. There were no means for intranet privacy, and students rarely used the site from off campus. Therefore, the situation was not appropriate for the kind of "electronic instrumentation" cited by Leifer[5].

Due to the experimental and summative nature of this pilot assessment, the assessment objectives were not explicitly formulated at the outset of the project, nor were they incorporated into the overall structure and development of the Robotics project. The assessment plan was designed and implemented by Gerardo del Cerro, Director of Assessment at the Cooper Union School of Engineering. The specification of objectives, the design of assessment instruments, the process of data collection and preliminary analysis took place during the Spring of 1999, and towards the end of the project. A second phase of the assessment developed during the Summer of 1999, and consisted of weekly meetings for discussion of results and design of the assessment protocol presented in this report. Profs. Chih-Shing Wei and Carl Weiman, and Consultant Ericson Mar, in the Mechanical Engineering Department, fully participated in this phase. Similarly, this report is the result of the collaboration among all the authors.

As an ethnographer and participant-observer, the work of the assessor developed in parallel to the work of the team, although for a relatively brief period of time. The assessor was present in the weekly working meetings of the team scheduled between February and April 1999. The assessor became familiar with the members of the project and with the general direction of their work. During this first phase of the assessment, the specific purpose was to document interactions among the various members of the team in order to meaningfully track the course, content, and types of information flows. Observation sessions were complemented with semi-structured, informal interviews and direct questions to the members of the team.

Ethnographic observation of the work of the team was indeed critical for a meaningful formulation of a *situated* assessment plan[6]. Nevertheless, the assessment results presented in this report do not constitute so much an assessor's ethnography as *an ethnography by the team itself*, however guided by specific questions and however modest in purpose. Communication flows within innovating teams are hard to track by participant-observers unless the ethnography encompasses the full duration of the team project itself. Whenever possible, the ideal situation is to have the team members record such flows, as well as other pertinent information for assessment. We asked the team members of the Robotics-for-Theater project to do just that. Through individual self-assessment, the multiplicity of perspectives inherent to all collective endeavors is not distorted. The final questionnaire (see below) was prepared and administered to the team members after the completion of the project.

The assessment plan was formulated according to the following working assumptions:

a. **Learning is a network-like process**, not an individual gain in one´s own stock of knowledge. Learning is then a purposive (there is a clear means-ends sequence), and context-bound exercise which consists of a) juxtaposition and interconnection of concepts and ideas relevant to the context of teamwork, b) diffusion of such concepts, ideas, and their interconnection, c) ability to communicate them, a prerequisite for a successful diffusion, d) ability to resolve potential conflicts among competing ideas or proposals

b. **Team projects foster innovation**. The challenge of this project is to produce innovation by incorporating wider circles, emergent relations, and weak ties into an open-ended task with multiple solutions. Innovation is a function, among other things, of the number of ideas and concepts that get to be discussed. The wider the circle, and the more and more varied the sources of information, the more likely is innovation to be achieved. Unlike diffusion of information as it may proceed in intellectual circles, what we are dealing with is *identification of sources of innovation in language* and use of such sources in the design (learning) process. It's not so much diffusion of information from a core of experts, but rather the use of information (resource mobilization) by a group of innovators. The main indicator of innovation/creativity in team design contexts, based on a scientific study, is number of noun phrases[7].

c. **Creativity, and the possibility of innovation (successful conceptual design), may be a function of**: 1. Size: Number of sources of information. 2. Heterogeneity: Variety of sources of innovation. 3. Density: Close and intense face-to face interaction among participants may be extremely important for the success of the project. 4. Time: internal and external constraints due to deadlines, commitments to clients, dependence on suppliers, dynamics of team interaction etc. 5. Successful interaction among team members, that is, effective application of skills such as consensus building, conflict resolution, assessment of alternatives etc. 6. Ability of team to learn: if we define learning as a network process (see a, above), then the ability to learn is closely related to the ability to mobilize resources, adopt and adapt ideas, and to use information throughout all steps in the design process. The value of assessment lies upon the fact that learning may be facilitated by the implementation of feedback mechanisms based on collection and storage of relevant information produced during the development of the project.

d. **Gathering data about the members of the team helps to measure innovation** and learning. Data about the team members works as a baseline, or initial point for comparison. A Team Profile may be an effective way to store such data. These data would provide us with important information on: a) the type of networks of the team members (occupation of family members, major of friends...), b) their educational background (class, GPA, and GPA major, robotics courses taken, design courses taken, formal communication skills courses taken, oral presentation training, written communication skills, concept-generation training, elective courses taken in college), c) their professional/industry experience in design, d) their sources of information for the project, e) their learning styles (via MBTI results).

e. **Task clarification and product definition are critical in conceptual design**. The specific needs of the client are not always clear. There may be a statement of the task by the client, which should be recorded and stored. However, divergences, clarifications, specifications, unanticipated problems should be expected, and are to be discussed -and resolved- through ongoing interaction. Therefore, another important piece of information that should be recorded periodically is a statement of the task and the product *as interpreted by each team member at different points during the development of the project*. Manipulation of the definition of a concept may influence a concept-creation process. And here we need to establish a typology of design steps. Robie suggests four steps: task clarification, conceptual design, redesign, detail design[8].

It seems clear that the client will need to be brought in for discussion on task clarification. Thus, we strongly stress the need to pursue *maximization of contacts with the customer*. In the context of a project-course, the ideal scenario would involve industry partners as clients. Other possibilities include advisors and professors playing the role of "the client." In any case, the students should be aware of the "discursive" nature of open-ended design engineering projects, and should be prepared to collect, store, analyze, and react upon the information on *product definition via communication* which is typically generated during the development of an innovative project.

f. **Analysis of team dynamics**. Despite individual info-storage and face-to-face interactions, team dynamics and performance are worthy of assessment. Taping some of the sessions would be recommended. Ethnography, content analysis (with an appropriate software), conversational analysis, ethnomethodology are ways to analyze the information. Additionally, records of statements by each member of the team summarizing weekly team dynamics would help the goal of student self-assessment. Some guidelines for such statements could be: a) List main topics of discussion throughout the project, b) Identify the main discrepancies that occurred, the actors involved, and the mode in which were resolved, c) Identify the alternatives brought in for discussion and how one was selected,

g. **Measuring motivation**. Knowledge, experience and motivation seem to have an effect on team performance. A way of measuring motivation would be by asking the team members: a) to list fields of interest for future employment, b) to rate 8 design tasks, c) to write a statement on initial motivation and expectations for the project

h. **The current process of socio-economic and educational restructuring features a clear convergence** of work methods, processes and objectives among R & D settings, industry and academia. ABET is aware of this trend, and schools, Cooper Union included, are making efforts to cope with the changing socio-economic reality (see Table 1). Schools of engineering educate students who for the most part will work in corporate environments. In addition, schools are socially embedded institutions, and have an obligation to remain open to contemporary trends in order to fulfill their mission. We believe that projects such as Robotics-for-Theater contribute to this endeavor.

The above assessment assumptions were reformulated and included in the assessment instrument. The in-depth questions finally asked to the team members were the following:

1. **We would like to know more about your innovation process.** We would like that you

select two ideas, a successful one, and one that was never applied to the robot. Could you track back the origin and development of these ideas? Please make sure that you mention and explain:

the sources of information used; the recipients of the information; the types of information/ideas obtained, retained, or transformed; the decisions and actions taken; the agents deciding and/or taking action; the means of action used for implementation; and the constraints bearing on each step.

2**. What have you learned from your participation in this project?** Please rate from 1(lowest) to 5 (highest). Also give one example (and a brief explanation) of each of the following:

a-Familiarity with problems inherent *in your future profession*

b-Substantive knowledge relevant to these problems (what the problems are; why they happen)

c-Process knowledge relevant to these problems (how they develop in practice and how to solve them)

d-To develop problem formulation and problem solving skills

e-To develop implementation (how to) skills

f-To develop skills to lead and facilitate collaborative problem solving

g-To develop skills to manage emotional aspects of leadership

h-To develop and demonstrate proficiency in independent thinking and learning

I- To understand the interdisciplinary nature of engineering projects

Table 1: The Robotics-for-Theatre project and the broader industry context

ROBOTICS NET-TEAM		THE HORIZONTAL CORPORATION[9]
.Flexibility .Coordination: avoiding articulation errors .Feedback: corrective actions, in-time learning .Resource mobilization: spin-offs and close contact with core .Trust	ABET CRITERIA (a-k): The engineering student as an emerging professional	.Process .Flat hierarchy .Teamwork .Assessment .Rewards based on performance .Maximization of contacts with suppliers and clients .Information training and retraining of employees at all levels

3. **What means of communication did you use most commonly?**
Which contributed most to the number of good ideas or useful tips in the development of the project? Which were crucial? Which were useless?
-formal meeting
-informal meetings
-written memos
-e-mail
-chance encounter in the halls
-going to libraries
-surfing the web
-frequenting exhibitions

4. **Your robot was designed to be an actor in theatre.** What did you have to learn from the field of theatre in order to successfully design your robot? What did you learn from other fields other than engineering and robotics design?

THE PROPOSED PROTOCOL

The student projects studied in the pilot program will assume the format of client-based product development and delivery. A preferred scenario would involve industrial partners who sponsor and participate in specific product prototyping projects. In this ideal case, a technical representative of each industrial partner would be the *client* to the student team working on the industrial partner's project. Building such an industrial alliance is an ongoing effort of the Department. For the pilot program, an emulated setting will be adopted during the 1999-2000 academic year in which the instructors or advisors of these student projects also play the role of the *client*.

The ways and means for transporting information among members of a product development team and its client have a major impact on the outcome of the development effort. An objective of the proposed pilot program is to analyze this transport of information for the purpose of assessing and enhancing the students learning experience. A set of communications protocol will be implemented to enable better understanding of the information flow among students engaged in a common engineering design and manufacture project. Two key elements of this proposed protocol are Web-based archiving of communications among the students and instructors, and videotaping of selected student team discussion sessions.

The proposed assessment protocol will address the following issues:

1. **Resource mobilization for creative problem solving.** A Web-based team portfolio will be established to track the progress of each student project. It will feature a Product Definition section where definition and specification of the product, formulated by the student designers and their client, are recorded. It will also feature a Resource Mobilization section for periodic gathering and analysis of how students access and utilize information for creative problem solving. The sources of information, as well as their relevance to the problem solving process, will be recorded. A timeline for the resource mobilization process will be maintained to facilitate the students' own evaluation of how timing of discovery of information propels the flow of the problem solving process. The client of the product development effort will monitor this archive of resource mobilization, and provide feedback to the student designers to either reaffirm or redirect the flow of information.

2. **Innovation and creativity**. The team portfolio will feature a Project Profile section where information utilization and student initiatives are recorded. This provision will facilitate the instructor's assessment of the students' use of technology, as well as their general problem solving skills. Each student designer is expected to demonstrate his or her abilities to design as well as to analyze and interpret data, to identify, formulate, and solve engineering problems, and to design a system, component, or process to meet desired needs. In addition, emphasis will be placed on assessment of the students' understanding of professional and ethical responsibility, and the need for life-long learning.

3. **Interdisciplinary requirements**. The team portfolio will feature an Interdisciplinary Elements section to highlight the interdisciplinary characteristics of the project. Recruitment of students from non-mechanical engineering disciplines to participate in the student projects will be a priority during the initial team formation. Students will be encouraged to identify specific elements of the product development process that they perceive to be interdisciplinary.

4. **Teamwork.** The team portfolio will feature a Teamwork section to track the birth and growth of team design concepts, product components and modules, and general interactions among the student designers. Videotaping of selected student meetings will be used to aid in the assessment of the students' teamwork competencies such as conflict resolution, consensus achievement, effective oral communications, and leadership. Each student will assess the other team members.

5. **Communications.** A Communications section will be featured in the team portfolio to provide a depository for student communications and feedback, minutes of meetings, and student presentations. Monthly review/assessment meetings will be held to identify blockage points of information flow, and to continuously improve the communication channels affecting the advancement of the product development process.

6. **Management/Leadership**. Each member of the team will rotate as a leader of the group, and will have periodic responsibility for managing the development of the project. The team leader will be responsible for periodically reviewing the ongoing assessment data and will give feedback to the group.

A detailed implementation matrix for integrating assessment into project courses similar to the ones studied in this pilot program is presented below.

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Assessment Protocol Implementation Matrix

OUTCOMES	STRATEGIES AND ACTIONS	ASSESSMENT METHODS	FEEDBACK PROCEDURES
RESOURCE MOBILIZATION FOR CREATIVE PROBLEM-SOLVING -To identify sources of information and ideas used by the students -To assess students' effectiveness in gathering information relevant to the project -To improve students' research and documentation skills	Storage, analysis and classification of information-source usage: .by number of sources .by type of source (variety) .by time spent in information- collection .by whether the source/idea was used or discarded by the team	-Development of a web-based form/diary that students fill out on an on-going basis -Review of patterns of information-collection before and after feedback, and throughout the development of the project	Periodic review meetings with students .to discuss patterns observed in the information stored and analyzed .to exchange information-collection strategies among team members -Students write reactions to feedback sessions
INTERDISCIPLINARITY -To improve students' appreciation of interdisciplinary skills and knowledge	-Storage, analysis and classification of information-source usage -Subjective statement on the value of interdisciplinary skills for engineers --to be written at the beginning and at the end of the project	-Web-based student diary/form: analysis focuses on **variety** of sources of information -Probing on sources of information used: *what have you learned this week from disciplines other than your own?* -External review of assessment data -Comparison between beginning and end-of-project statements (amount of information included in statements/essays, attitudes towards interdisciplinarity)	-Ongoing project diary review -Written external review of assessment data on interdisciplinary skills is incorporated into project diary -Comparisons between essays written at the beginning and at the end of the project is incorporated into project diary
TEAMWORK -To develop students' awareness and competency as effective teamworkers	Videotaping 3 student-team working sessions at the beginning, mid, and end of the project.	Performance assessment: Peer and faculty assessment during review/feedback session using **teamwork outcomes guidelines**.	-Review/feedback session; the session itself is videotaped or recorded. -Each student writes a reaction statement which is included in the web project diary.
COMMUNICATION SKILLS -To enhance students' communication skills	-Videotaping 3 student-team working sessions at the beginning, mid, and end of the project. -Written statement on project task -Transcription and content analysis of working sessions	Performance assessment: -Peer, faculty, and industry assessment during review/ feedback session using **communication outcomes guidelines**. -Joint discussion of subjective understanding of task -Ethnographies of students at work	-Review/feedback session; the session itself is videotaped or recorded. -Each student writes a reaction statement which is included in the web project diary.
TECH-TOOLS INCORPORATION -To assess the impact of tech-tools incorporation in teaching and upon the students' learning (specifically teamwork and communication skills)	-Set-up an e-mail suggestion box -Probe students on the usefulness of techtools used during the project. -Encourage the use of the internet as a design aid -Encourage the use of the internet for product availability searches for DFM (Design for Manufacturability) -Introduce CAD practices -Familiarize students with engineering instruments -Obtain tutorial CD-ROMs to complement software collection	-Instructor reviews the suggestion box on an ongoing basis. -Include use of internet as an indicator for resource mobilization (# of searches). -Review of statements by students on usefulness of techtools used during the project.	-Instructor is responsible for fixing problems and adjusting the techtool support system based on students' feedback. -Ongoing project diary review. -Ongoing review of Internet resources available

MANAGEMENT/LEADERSHIP -To develop the students' ability to manage, lead, and effect change.	-Each member of the team rotates as leader of the group. -The group leader will be responsible for reviewing the assessment data stored, and for assessing and informing the team about the ongoing patterns of information gathering and	Performance assessment: -Peer, faculty, and industry assessment during review/feedback session using **leadership outcomes guidelines**	-Review/feedback session; the session itself is videotaped or recorded. -Each student/leader writes a reaction statement which is included in the web project diary. -The group leader gives periodic feedback to the team on ongoing performance, based on assessment data stored.