



# The Value of Transdisciplinary Collaboration in Robotics Education and Research

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**T**his paper suggests that transdisciplinarity is rising as a powerful epistemic strategy for research in technology-related fields such as engineering. Though this topic has been approached from a philosophical perspective, we know little about the actual shape that transdisciplinarity might take in research and action. How is transdisciplinarity operationalized in research and professional practice? As a case study, we report an assessment study of communication modes and content used by engineering students in a special project-course, *Robotics for Theater*, focused on the planning and construction of a robot from scratch, to support theatric production as actor and prop. Our assessment tools were based on ethnographic research and included questionnaires, journals, and students' expressions of their views on the communication and learning processes. Analysis of the case study of the *Robotics for Theater* project revealed that: 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.

**Keywords:** Transdisciplinary collaboration, robotics education, ethnographic research.

## 1 Introduction

This paper suggests that transdisciplinarity is rising as a powerful epistemic strategy for research in technology-related fields such as engineering. Though this topic has been approached from a philosophical perspective, we know little about the actual shape that transdisciplinarity might take in research and action. How is transdisciplinarity operationalized in research and professional practice? During the last decade, transdisciplinarity has become the focus of important theoretical contributions. More recently, innovative research strategies and methods tackling complex objects and contexts have been presented at academic conferences and seminars. One aim of this paper is to present a case study of transdisciplinarity, which will not only improve our understanding of this approach but also illustrate how it can be operationalized in concrete ventures as it fleshes out our next technological futures.

While architecture and planning seem to be fertile domains for transdisciplinary contributions (because of their very nature as multidisciplinary disciplines involving both the natural and social sciences, and action-oriented practices aimed at transforming the built and natural environment), little is known about the shaping of technological futures involving collaborations between engineers and social scientists. This paper outlines a framework for transdisciplinary collaboration which is applied to the Robotics-for-Theater project, a transdisciplinary project made possible with NSF funding and developed at The Cooper Union for the Advancement of Science and Art in New York City.

This paper presents the development and results of an assessment conducted on the Robotics-for-Theatre project, an educational initiative developed at the Cooper Union School of Engineering under the auspices of the Gateway Engineering Education Coalition of the National Science Foundation.

The purpose of the assessment was *summative*: we wanted to gather information about a team of students who developed a robot for theatrical performance in order to develop a protocol for assessment of similar future projects. In order to gather the information, a number of assessment instruments were designed and implemented. Students were asked to track ideas that were successfully applied to the robot, and ideas that were not. They were asked about the means of communication used during the development of the project. They were also asked to express their views on the learning process on a number of issues ranging from communication skills, to teamwork, to interdisciplinarity. The analysis of students' responses has allowed us to design a new assessment protocol.

Unlike the summative assessment performed, the proposed protocol is fundamentally *formative*: it has been designed to be a part of the overall design of engineering projects from the outset, and it specifies feedback loops for continuous improvement that should be implemented during the development of the projects. If successfully implemented, we believe the protocol can be an effective way to track and improve the learning by engineering students at Cooper Union in a number of dimensions or learning outcomes. A successful implementation will require full collaboration among all parties involved in each project, especially faculty and students, the main players and beneficiaries of assessment practices.

This paper is divided into six sections. Section 1 provides an overall background of the relevant literature and the research problem addressed here. Section 2 presents our case study, the Robotics-for-Theatre Project, in the context of the engineering curriculum at Cooper Union. Section 3, entitled "A Summative Assessment for the Robotics-for-Theatre Project" discusses the assumptions underlying the assessment plan designed and implemented. Section 4 is devoted to presenting the main results of our research, including a section on validity and reliability. Section 5 devoted to future work, presents our proposed assessment protocol for innovative, open-ended engineering projects. Section 6 summarizes the value of transdisciplinary collaboration.

## 2 Background

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 (Siller, Palmquist, Zimmerman, 1998) [1]. 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. Leifer electronically instrumented the communications streams between team members, analyzing their activities to assess the educational process and disseminate the results (Leifer, 1997) [2]. 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 critically 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 (1996) [3] 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. Button and Dourish (1998) [4] discuss formally on 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 (increasing engineering design productivity).

In an interesting study which focused entirely on the social interactions devoid of technical content, Bereton, Cannon, Mabogunje and Leifer (1997) [2] analyze the protocols of videotaped conversation in a design team, coding the results in terms of focus and transition. 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.

There are in fact a number of other programs operating on these premises. A good example is provided by the Cranfield University in UK's Decision Engineering Centre, which, as part of a study, provides an ICT (information and communications technology) based infrastructure to share data, information and knowledge for competitive industrial design. One of the goals of the study is to prove that by developing ontological representations of knowledge and using standard languages for knowledge-sharing, the design process becomes more efficient. The principle at work here borrows from some of the same studies that the Cooper Union regarded for its Robotics-for-Theatre assessment protocol, such as Leifer's push for an electronic communication stream and Button and Dourish's theory of protocol analysis.

More recently, a 2005 article in the Journal of Engineering Education entitled "Assessment in Engineering Education: Evolution, Approaches and Future Collaborations," describes conversational analysis, observation, and ethnographic studies as "promising techniques that have been rarely reported in engineering education." (Miller, Moskal and Olds, 2005) [5]. The promise of an ethnographic approach remains that it makes work visible' and highlights the process of innovation. In the words of Ball and Ormerod, ethnographic assessments are appropriate to design because, "in design contexts it is apparent that the goals of research tend to be more applied in nature, such as attempting to understand design *behaviors* in order to make design productivity more effective (e.g., through computer-based support or changes to existing organisational practices)" (Ball and Ormerod, 2000) [6].

Also in 2005, J.M Thom and M.A. Kimble-Thom conducted a widespread literature review and presented findings in their paper "Academic and Industrial Perspectives on Capstone Course Content and the Accompanying Metrics." The literature review pertained to academic perspectives on engineering design capstones, and the authors also conducted interviews with members of industry and observed students participating in several design programs. Based on this research, the Thoms conclude that there is no dominant best practice for design course assessment. Like many others commenting on the situation, they recommend choosing protocol that best fits the school's goals and resources. What-

ever the protocol, they strongly encourage schools to be specific about desired student outcomes, which should be based on ABET standards, and the exact means by which students will be held accountable to these standards. The fear is that open-ended design projects lead to subjective grading. We believe The Cooper Union has done well to not only base course goals on ABET standards but also document which curriculum elements and assessment methods relate to which standard. The problem is that with qualitative measures, it is difficult to know what a sufficient response entails. For the purpose of converting qualitative measures into student grades, schools such as the Milwaukee School of Engineering address this problem with rubrics. Rubrics, however, are unnecessary to many of The Cooper Union's assessment measures because the focus is on investigating the learning process rather than evaluating students. Objective student evaluation measures, of course, do still exist.

The Thoms highlight a recurrent problem in that many design course students appear to struggle with knowledge synthesis. They do not look past engineering for ideas, do not seek help until problems arise, and generally act according to a "knowledge garnering paradigm," which excludes planning and foresight. The Cooper Union's assessment protocol addresses these concerns by asking students to state explicitly what they learn from other disciplines as they work on the project and by providing regular consultation with faculty outside of a troubleshooting capacity, requiring students to outline and review changes in product conceptions, and allowing each member to serve as team leader. An example of the results obtainable by the school's assessment protocol is provided by student responses to team profile and end-of-course questionnaires as well as faculty comments and observations from the pilot program.

### 3 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 Adrienne 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, followed by ME364 and EID111, "Robotic Visions and Theater." 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.

#### 3.1 Description of Project-Course

ME363 is a special topics course for upper classes with a firm technical background in Mechanical Engineering behind them. The project consisted of adapting the control system of one of Adrienne Wortzel's robots, which had been 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 and Professor 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, 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.

### 3.2 Robotics Team Profile

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.

The assessment plan for this project included a brief questionnaire designed to address these issues. By responding to the questionnaire, the team members gave us important information which can help *to track the external networks and therefore to uncover the dynamics of resource mobilization* which takes place during the development of innovative, open-ended projects such as the Robotics-for-Theatre. The Team Profile resulting from the responses of the team members to the questionnaire is included below.

### 3.3 The Cooper Union Context

The publications cited in the Background and References sections describe studies conducted at large institutions with sufficient engineering populations for statistically representative results and sufficient re-

sources to conduct in-depth analysis. Cooper Union, on the other hand, is a small institution and resources for this project were limited. Protocol analysis of videotapes and electronic metering of network communications were out of the question for this pilot study. The latter was not much of a loss; our compact campus and personal interactions between students diminish the need for distance learning. In fact, the size and quality of the school offer unique opportunities for efficiency and quick response. We encourage other universities to exploit their own unique characteristics in tuning their studies in engineering education assessment. Below we describe our characteristics.

Cooper Union has a nationally renowned School of Art, an internationally famous School of Architecture, and a top-flight undergraduate School of Engineering. Our small size, culture of intellectual curiosity, and tradition of integrating research and practical experience with education provide an excellent backdrop for adapting exemplary educational materials in innovative ways.

Cooper Union offers bachelors degrees in art and architecture, and bachelors and masters degrees in engineering (see Table 1). Admitted on merit alone, all 900 students receive full-tuition scholarships. About 40% of our students were born outside the U.S., and a similar percentage needs financial aid beyond the full-tuition scholarships. For over 150 years, Cooper Union has been a means of social mobility for a multicultural, largely urban student population whose members are often first in their family to attend college.

The School of Engineering offers chemical, civil, electrical, and mechanical engineering degrees, plus a general engineering BS degree and studies in cross-disciplinary fields such as biomedical, environmental, materials, and manufacturing engineering. Teresa Dahlberg, one of the nation's first woman dean of engineering, leads the school's 31 full-time and 53 adjunct faculty. In 2013, *U.S. News & World Report* ranked the School of Engineering first among U.S. undergraduate engineering schools; and *Time Magazine/Princeton Review* ranks it as the nation's third most selective school, tied with West Point.

In fact, our robotics team consisted of three females and one male, from a variety of ethnic backgrounds.

**Table 1:** The Cooper Union at a glance

Cooper Union Demographics	Enrollment	Women	African American & Latino-American, and Native American	Asian-American
Engineering	470	30%*	10%	34%
Art	280	45%	25%	16%
Architecture	155	43%	15%	21%

\*Almost double the national average for schools of engineering.

## 4 A Summative Assessment for the Robotics-for-Theater 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 (1997) [2].

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 and Professor 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 2011, and towards the end of the project. A second phase of the assessment developed during the Summer of 2011, 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 Depart-

ment, fully participated in this phase. Similarly, this report is the result of the collaboration among the four 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 2011. 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 (Suchman, 1987) [7]. 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 was prepared and administered to the team members after the completion of the project.

## 4.1 Assessment Principles

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 (see Leifer, 1997, 1998) [2].
- (c) **Creativity, and the possibility of innovation (successful conceptual design), may be a function of:** a. **Size:** Number of sources of information; b. **Heterogeneity:** Variety of sources of innovation; c. **Density:** Close and intense face-to-face interaction among participants may be extremely important for the success of the project; d. **Time:** internal and external constraints due to deadlines, commitments to clients, dependence on suppliers, dynamics of team interaction etc.; e. **Successful interaction** among team members, that is, effective application of skills such as consensus building, conflict resolution, assessment of alternatives etc.; f. **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 (Robie, 1991, p. 101f) [8]. And here we need to establish a typology of design steps. Robie (1991, p. 187) [8] suggests 4 steps: 1. task clarification; 2. conceptual design; 3.

**Table 2:** The Robotics-for-Theatre project and the broader industry context

ROBOTICS NET-TEAM	ABET CRITERIA (a-k): The engineering student as an emerging professional	THE HORIZONTAL CORPORATION (from Castells, 1996)
.Flexibility .Coordination: avoiding articulation errors .Feedback: corrective actions, in-time learning .Resource mobilization: spin-offs and close contact with core .Trust		.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

redesign; 4.detail design

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 of individual info-storage, 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 (from Robie, 1991) [8]; 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 2). 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.

## 4.2 Assessment Results: Tracking and Measuring Team Progress

As mentioned earlier, ethnographic observation of the work of the team was indeed critical for a meaningful formulation of a situated assessment plan (Suchman, 1987) [7]. Communication flows within innovative 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 assessment results presented below 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.

### Main findings:

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. Resource mobilization was inhibited by intra-team trust and friendship, and by time constraints affecting the development of the project.
2. Innovation was fostered by intra-team trust, advising, and informal meetings. It was inhibited by technical difficulties encountered along the way, and by time constraints.
3. Interaction with client shows gaps along the way. Probably due to time constraints, the field of theatre did not become a fundamental reference of the project, unlike it had been planned. Students seem not to have learned much from or about theater.
4. Team dynamics was effective, although on occasion the division of labor separated the team excessively. Frequent informal meetings and contacts, the time-intensive nature of the project, and the trust ensured by friendship among the students helped teamwork.
5. Intensive intra-team communication via informal meetings made a difference in an innovative, time-intensive project like the Robotics-for-Theater.

The course of the student's product development was ripe with many opportunities to observe various forms of interaction. The client-based product development strategy of education involves many aspects

of teamwork and design methods. This approach is similar to Stanford University's established principle for assessing engineering education called Product Based Learning, "a problem oriented, project organized learning activity that produces a product for an outsider" (Leifer, 1997) [2]. The observations were analyzed to produce useful conclusions on the communication modes leading to the formulation of the protocol.

**Resource mobilization for creative problem-solving.** As mentioned earlier, one of the major changes in engineering practice is the widespread adoption information technology. The internet has offered product development engineers increased productivity through a global knowledge base and asynchronous communications capabilities. As Brudiansky well put it, "the entire focus is on collaboration, exchanging ideas freely, and thoroughly documenting and presenting results" (Brudiansky, 1999) [9]. And the web constantly plays a major role in Stanford University's Product Based Learning Programs (Leifer, 1997) [2].

One of the roles of the advisor was to expose the students to the wealth of information on the internet pertaining to robotics and introduce the concept of interaction with professional topic groups on the internet. Students frequented the Handy Board web site for info and tips pertaining to the design of their robot as well as information on the Handy Board itself. They searched the archives for user contributed source code that they could modify and reuse. They were able to ftp and use the latest versions of the relevant manuals, schematics etc. Also, a major advantage stemmed from the use of the Handy Board e-mail forum, where many questions were answered and tips were attained. As mentioned in the student surveys, ideas and social interaction from these external sources helped the project along.

Traditional methods of design were not neglected. Many catalogs and product specification sources were given for the students to use. However, this provision countered the internet-based learning objective in one student. It was mentioned in one survey that web searches for parts were fruitless compared to catalog-based searches. What didn't the student realize was the fact that the good majority of the catalogs were accumulated through internet searches in a past project. Perhaps in the future this can be remedied by indicating the origins or steps

that led to the obtaining of the material and providing more unique opportunities to include internet searches as part of the development.

**Innovation and creativity.** A feature of American education is its strong focus on innovation. It is believed that this has provided the American technologists with the willingness to take the risks necessary to create new industries based on technology (Grose, 1999) [10]. To encourage creativity, projects are often open-ended like those found in Miami University's Design and Manufacturing Laboratory (Moller, et. al. 1999) [11] where students develop different approaches so solve a particular problem.

During the Robotics for Theater Project, the students went through periods of brainstorming and collaboration to design the product for their client. This produced many ideas to analyze and choose from. Through this approach, similar to the efforts of Leifer, the student's created a "product that embodies their knowledge" and used hands-on experience that "fused theory and practice" (Leifer, 1997) [2]. It was found that the advisor played a key role in providing the technical guidance that helped lead them to more robust designs. Though the advisor was careful not to produce solutions for the students, an action which would counter the original efforts.

The randomness and spontaneity of the solution formation coupled with the frequent informal interaction by the students produced a difficult scenario for tracking the origins of particular solutions. Post-assessment of the design yielded ambiguous paths from beginning to concept to manufacture. It is suggested that periodic logs of design decisions would help remedy this problem.

**Interdisciplinarity.** The chosen robotics project, being of a mechatronic nature, provided an opportunity for the students to experience the interdisciplinary nature of engineering projects. This case also included a non-technical influence, which was the client. As in real-world engineering projects, the product is often for a non-technical application. Associated with this is the need to interact across disciplines: both technical and non-technical.

The methods used for interdisciplinary interaction were internet-based and person-to-person communication. A significant contributor to the success of the project was through the use of the web, not only for reference as mentioned previously, but also for tapping into the various human resources in the

world. Students were able to consult with professors, professionals, robotics hobbyists, and other students of various skill-sets, experience and field specialties who frequent the Handy Board email list. Personal interaction with an interdisciplinary mix of professor and students were critical in filling in the gaps throughout the mechatronic design. The advisor also served as an interdisciplinary source of information. One drawback experienced was the small amount of client interaction apparent throughout the course of the project. For the future, client interaction should be stressed more to ensure that the student's recognize the importance of meeting the needs from a non-engineering point of view.

**Teamwork.** The strategies for guiding teamwork included the encouragement of the division of tasks and the formulation of concurrent engineering practices. These principles are the foundation of modern engineering practices in industry and as Yazdani et. al. indicate, the trend is continually toward these ideals, where sequential engineering is being replaced by various forms of refined concurrent engineering (Yazdani et. al., 1999) [12].

Though during formal meetings, much of team interaction consisted of brainstorming and collaboration, a significant portion of teamwork occurred outside of the meetings. It was indicated repeatedly in the surveys that this informal discourse was a major contributor to the success of the project. Similar findings on product development courses are supported by Leifer, who wrote, "a significant portion of teamwork occurs in parallel, outside of meeting rooms" (Leifer, 1997) [2].

Teamwork helped distribute the load of work as well as harness the various individual skills of each member. Some of the students possessed the manual talent required for the actual construction the robot's mechanical parts. Another had the software and computer hardware skills that helped the team incorporate the computer and Handy Board in the design. And another had internet technology knowledge. All worked in parallel, performing their own tasks. This division, however, tended to separate the team members leading each party to be delved in his/her own aspect of the project. Neither party was familiar with each other's work. This resulted in communication problems when the individual accomplishments were ultimately joined to form the whole robot. It should be emphasized that product success requires the continual communication of

achievements and knowledge gained between members of the team.

**Communication.** A main objective of any project development course is to provide "opportunities to develop enhanced oral and written communication skills, learning contexts that provide experience working in teams, and increased use of design projects throughout the curriculum", characteristics which conform to the three most emphasized areas of the ABET 2000 theme (Siller, et. al., 1998) [1]. Participation in internet email forums was integrated into the project to develop written communication skills. Informal meetings were encouraged to enable interpersonal communications and relations. Meetings were held to enable interaction with the advisor along various topics of robotics engineering.

With the use of the internet, the students had opportunities to learn (through practice) written communication skills for web interaction with other interdisciplinary and multi-cultural students, professors and professionals in robotics. The asynchrony of email forces students to learn how to get the point through in an efficient and effective manner since there is no room for ambiguity. Ambiguity may delay response time and in the worse case, may not trigger a response at all. Siller et. al. support these notions in his literature (Siller et. al, 1998) [1].

Repeatedly mentioned in the surveys was that formal and informal meetings contributed a major part to the accomplishments of the project. Formal meetings enabled the organization and preparation of question and answer sessions through personal contact. Visual as well as verbal methods were used to disseminate information. Sketches were used to facilitate visually descriptive communication. Similar circumstances were evident in informal meetings as well.

Though, assessment difficulties stem from the informal interaction prevalent especially since this was the communication most frequently used. No method was established to track the informal gatherings of group members. These gatherings were often random occurrences that sprung from the need to address immediate unforeseen issues. Team members also interacted with external persons including those through the internet. Perhaps, in future projects, the students periodic logging of project activities would record these interactions.

## 5 Evaluation, Validity and Reliability

Based on our own findings, we determined to analyze the validity and reliability of the results and the extent to which they are useful to the school's assessment purposes. While it is generally easier to examine the reliability and validity of quantitative measures, it is still possible to analyze qualitative results in this way, based on the suggestions of Guba and Lincoln (1981) [13] and other experts in social research methodology.

Generalizability is applied by researchers in an academic setting. It can be defined as the extension of research findings and conclusions from a study conducted on a sample population to the population at large. While the dependability of this extension is not absolute, it is statistically probable. Because sound generalizability requires data on large populations, quantitative research – experimental for instance – provides the best foundation for producing broad generalizability. The larger the sample population, the more one can generalize the results. For example, a comprehensive study of the role computers play in the writing process might reveal that it is statistically probable that students who do most of their composing on a computer will move chunks of text around more than students who do not compose on a computer.

Transferability is applied by the *readers* of research. Although generalizability usually applies only to certain types of quantitative methods, transferability can apply in varying degrees to most types of research. Unlike generalizability, transferability does not involve broad claims, but invites readers of research to make connections between elements of a study and their own experience. For instance, teachers at the high school level might selectively apply to their own classrooms results from a study demonstrating that heuristic writing exercises help students at the college level.

Generalizability and transferability are important elements of any research methodology, but they are not mutually exclusive: generalizability, to varying degrees, rests on the transferability of research findings. It is important for researchers to understand the implications of these twin aspects of research before designing a study. Researchers who intend to make a generalizable claim must carefully examine the variables involved in the study. Among

these are the sample of the population used and the mechanisms behind formulating a causal model. Furthermore, if researchers desire to make the results of their study transferable to another context, they must keep a detailed account of the environment surrounding their research, and include a rich description of that environment in their final report. Armed with the knowledge that the sample population was large and varied, as well as with detailed information about the study itself, readers of research can more confidently generalize and transfer the findings to other situations.

**Credibility** is a measure of how much trust can be placed in responses provided by students and faculty through questionnaires and interviews. High credibility is inherent in the school's assessment methods of team member profiling, group observation, and faculty assessment, but there is potential for low credibility of responses on peer teamwork assessments and the end-of-course questionnaire. While peer assessment of team dynamics is essential, such a measure is always in danger of low credibility because differences in student perceptions and motives could lead to disparities that are difficult for faculty to rectify. In The Cooper Union's case, however, faculty/team interaction was so frequent that faculty did have a good working idea of team dynamics. Furthermore, since peer teamwork assessments were not used for grading, there was little motivation to skew responses. In the future, the school can maintain the credibility of peer teamwork assessments by continuing a high level of faculty/team interaction and by establishing a vocabulary so that students apply the same standards to each other. In regards to the end-of-course questionnaire, the specificity of most of the questions serves to reduce aberrant interpretations and forces students to support answers with concrete examples. As with peer teamwork assessments, constant interaction with the team allowed faculty to anticipate and validate responses to most of these questions. In the future, reliance on web-based portfolios will allow for more frequent feedback and validation of student reports by faculty, thus creating more credibility.

In a similar vein, **Confirmability** refers to the extent to which assessment results can be corroborated by others. The school's pilot report is sufficiently confirmable, as the report errs on the side of quoting large portions of student and faculty responses. The point of the lengthy quotations is to establish the full

context of the pilot for the purposes of ethnographic study. The result is that little data is filtered, so it is easy for third parties to understand how the school derives its conclusions and to appreciate that plenty of material is available in its original format. The measures with the lowest inherent confirmability are interviews and direct observation, though transcription and videotaping go a long way in addressing these problems.

**Rigor** refers to the complexity or sophistication of the assessment methodologies, thereby reflecting the quality of results. Sufficiently rigorous assessment measures require faculty to demonstrate that measures are based on intensive planning and that they are capable of handling qualitative results and applying them in a course. In regards to the Robotics-for-Theatre pilot, assessment measures appear to have been well-planned. It is clear from several tables included in the report that certain ABET standards were targeted prior to the creation of the course, and the report's outline of assessment principles reveals how the protocol is based on theory. Where the report lacks rigor is that not much is said about how faculty are supposed to analyze results and relate them to course goals. There is no mention of rubrics or a final grading structure. Still, this is an area where The Cooper Union is allowed to deviate from other schools because of its resources. The detailed analysis provided by Dr. del Cerro in the pilot report proves sufficiently that the few responsible for assessment of these courses have well-defined notions of what students ought to demonstrate. A process that would be too time-consuming and idiosyncratic to pull off at other schools fits well into The Cooper Union's intimate environment. Standards may need to be more clearly defined if the program is expanded.

**Transferability** refers to the extent to which similar results would occur in different settings. Transferability is related to the measure of dependability (the extent to which results are repeatable in a common setting), as assessment results should be guaranteed dependable before they are compared to other contexts. This is problematic for the school since the pilot report only includes assessment results from one study. In order to ensure that the assessment protocol is transferable (and credible), it would be beneficial to conduct additional pilots and/or to compare pilot results with the results of subsequent

design course assessments. It is also possible to gauge the dependability of the school's assessment results by comparison to results of similar studies at other schools, particularly if the students and schools have similar characteristics, but such comparisons are difficult to make on qualitative measures, as each school has its own priorities and phrasings. In this case, the most important component of transferability is **applicability**, or the extent to which results can be used to affect future courses through curriculum restructuring. In other words, do assessment results help the school make the course better? According to The Foundation Coalition, successful assessment schemes require three components: "a statement of educational goals, multiple measures of achievement of the goals, and use of the resulting information to improve the educational process." The University of Detroit Mercy's process of applying assessment results to course structure is similar to that of The Cooper Union. During a pilot design course at Detroit Mercy, instructors found through student surveys and in-class observation that uncertainty on behalf of students as to what was expected of them in assignments and projects was holding up the learning process. In response, the school created checklists to be used for presentations with more detailed criteria. Because of the overall assessment protocol's high internal utility, it is likely that a similar protocol could be applied to courses in other departments at the school. Capstone and cornerstone courses are common in a variety of disciplines, including architecture, art, communications, and business, and that the use of electronic portfolios is increasingly popular in design fields. Emphasis on teamwork, innovation, and design is appropriate for any of these fields; the difference would come in the structuring of outcome goals. Because the limited information available about design courses in these fields is applicable to The Cooper Union environment, pilot studies are the best recommendation.

Changes in the engineering education paradigm mean there are no hard and fast answers to the question of how to evaluate students. Each method has its merits and problems, but it is commonly repeated that the ideal depends on the school. Nonetheless, there is sufficient proof that formative, qualitative, and web-based assessments are normal features of the Higher Ed landscape. The main drawback to these styles is that they require time and patience, but at the Cooper Union, it seems appropriate to

have an assessment model that takes advantage of the school's intimate environment, in which faculty members are able to interact and monitor students much more carefully than they could at other schools. It is possible to streamline the assessment process through quantified measures, but some information will be lost. As long as faculty members involved in the program continue to feel that student learning in the design course outweighs the costs of administering the current assessment protocol there is no compelling reason to make major changes, especially since minor adjustments are inherent in the system.

## 6 The Proposed Protocol

The student projects studied in the pilot program assumed 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. This model has been successfully implemented by Prof. Leifer at Stanford University, through a graduate-level project course (Leifer, 1997) [2]. Building such an industrial alliance is an ongoing effort of the Department. For the pilot program, an emulated setting was adopted during the 2011-2012 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.

## 7 Future Work

The proposed communications 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.

## 8 Conclusion: The Value of Transdisciplinary Collaboration

Transdisciplinarity connotes a research strategy that crosses many disciplinary boundaries to create a holistic approach. It applies to research efforts focused on problems that cross the boundaries of two or more disciplines, such as research on effective information systems for biomedical research, and can refer to concepts or methods that were originally developed by one discipline, but are now used by several others, such as ethnography, a field research method originally developed in anthropology but now widely used by other disciplines.

When the very nature of a problem is under dispute, transdisciplinarity can help determine the most relevant problems and research questions involved. A first type of question concerns the cause of the present problems and their future development (system knowledge). Another concerns which values and

norms can be used to form goals of the problem-solving process (target knowledge). A third relates to how a problematic situation can be transformed and improved (transformation knowledge). Transdisciplinarity requires adequate addressing of the complexity of problems and the diversity of perceptions of them, that abstract and case-specific knowledge are linked, and that practices promote the common good.

Transdisciplinarity arises when participating experts interact in an open discussion and dialogue, giving equal weight to each perspective and relating them to each other. This is difficult because of the overwhelming amount of information involved, and because of incommensurability of specialized languages in each field of expertise. To excel under these conditions, researchers need not only in-depth knowledge and know-how of the disciplines involved, but skills in moderation, mediation, association and transfer.

The research presented here as a case study represents one example of the necessary collaboration between social scientists and engineers, a collaboration illustrating the value of transdisciplinarity in technological futures. A critical defining characteristic of transdisciplinary research is the inclusion of stakeholders in defining research objectives and strategies in order to better incorporate the diffusion of learning produced by the research. Collaboration between stakeholders – social scientists and engineers in our case – is essential, not merely at an academic or disciplinary collaboration level, but through active collaboration with people affected by the research and community-based stakeholders. In such a way, transdisciplinary collaboration becomes uniquely capable of engaging with different ways of knowing the world, generating new knowledge, and helping stakeholders understand and incorporate the results or lessons learned by the research.

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