

# Assessment of an International Freshmen Research and Design Experience: A Triangulation Study\*

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*As part of a university-wide initiative to help students develop a greater awareness of international issues and compete in a global market, our College of Engineering piloted a bi-national program for freshmen engineering students. To evaluate course effectiveness and assess student learning for the University of Washington students we implemented a comprehensive plan utilizing triangulation through multiple methods. Our assessment results indicate course goals were met: freshmen were able to participate and learn from authentic international research and design projects. By adopting a triangulation approach we were able to cross-validate results and develop an enhanced course and more streamlined assessment instruments.*

## INTRODUCTION

INTEGRATING DESIGN experiences into engineering education is at the center of current efforts to transform the undergraduate engineering experience [1–5]. This trend has expanded the *scope* of design education from capstone to freshmen year experiences [6], and the *range* of design activities from individual and linear approaches to team-based and systems-oriented approaches to solving design problems [7]. Similarly, concerns about how we prepare our students to interact in a global society has encouraged engineering educators to embed design experiences in a global context of real-world issues. These trends have helped encourage an emphasis on promoting research experiences or project-based learning as a standard for undergraduate engineering education [4, 5].

In engineering education, project-based learning has been adopted at both programmatic [8] and course levels [9]. Adopting such an approach provides opportunities for students to increase their exposure to engineering processes and concepts, link professional practice skills such as communication and teamwork to engineering course work, develop a broader understanding of the context of engineering problems and solutions, and participate actively in an engineering community [5]. Many of these goals characterize learning objectives stated in current accreditation policies for engineering programs [10].

As part of a university-wide initiative to promote undergraduate research and to help students develop a greater awareness of international

issues and compete in a global marketplace, our College of Engineering piloted a bi-national and bi-institutional course for freshmen engineering students [11]. This course was designed collaboratively by Professor Gretchen Kalonji, of the University of Washington in Seattle, and Professor Tetsuo Shoji, of Tohoku University in Sendai, Japan. The project linked freshmen design courses at the two universities in an international project-based approach. Bi-national teams of students and faculty engaged in authentic research and design projects in the research labs of participating faculty.

To evaluate the effectiveness of the teaching methods and course content for the University of Washington course, we implemented a comprehensive and rigorous evaluation plan that utilized triangulation of data through multiple methods [12]. As a mode of inquiry, triangulation creates opportunities to compare complementary and contrasting data from different vantage points. Such a process reduces uncertainty in interpretations and establishes contextual validity [13, 14].

For this evaluation plan ethnographic observations, a content analysis of student work, surveys, concept maps, and interviews were utilized to:

- assess the impact of the course on changes in students' learning;
- evaluate the match between learning objectives and the educational benefits for students, and
- pilot a range of assessment instruments and methods to identify 'best practices' for assessing student learning for future course offerings.

In this paper we provide a description of the course and our evaluation plan, present a summary of our results, and illustrate the benefits of adopting a multiple methods assessment approach.

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## AN INTERNATIONAL RESEARCH AND DESIGN COURSE FOR FRESHMEN

Students enrolled in freshmen design courses at their respective universities. At Tohoku University (TU), students enrolled in an existing freshmen design course, Sozokogaku: Creativity Engineering. The Sozokogaku course is part of an education reform and restructuring effort in which the Japanese Ministry of Education criticized the educational system as discouraging students' creativity, limiting individual potential, and lowering the level of scholarship [15, 16]. The main objective of Sozokogaku is to encourage students to take initiative and be motivated to study and perform research independently. The course is structured to provide students with an early exposure to design and research environments, foster creativity, and apprentice students within a Tohoku research laboratory group, a Kenkyushitsu. The Kenkyushitsu serves as both a research and educational space in which faculty and graduate students mentor undergraduate students both academically and socially [16].

At the University of Washington (UW), students enrolled in a modified section of an existing introductory freshmen design course, ENGR 100: International Freshmen Interest Group (Tohoku pilot). Freshmen Interest Groups are mechanisms for encouraging entering freshmen to enroll as cohorts in a specific series of courses. For this cohort, students also enrolled in a Mathematics course of their choice, a second term chemistry course (Chemistry 142), and a seminar

on Japanese culture, technology and society (General Studies 197). The goals of the UW Tohoku pilot were to impart engineering skills and knowledge associated with research and collaboration at an early point in the curriculum, provide an opportunity for students to envision their place in the profession, and promote the importance of teamwork and communication.

Course activities were structured to provide an authentic exposure to team-based research and design projects, a high level of peer and faculty interaction, an awareness of international issues and professional practices, and access to multiple telecommunications formats for their international collaborations. Given this implementation strategy, the learning objectives for the UW Tohoku pilot were to promote student learning in the following areas:

- broad engineering knowledge and skills (e.g., communication, teamwork, problem solving);
- scientific and engineering knowledge related to their individual projects;
- an ability to work in international engineering teams;
- an understanding of global and societal issues.

The course also included affective learning objectives such as increased self-confidence in students' abilities to contribute to science and technology and increased motivation to pursue engineering.

Twenty-five freshmen enrolled in the UW Tohoku pilot. Students met three times a week for two hours, and the course was organized into

Table 1. Description of research and collaboration goals

Project	Research Goals	Collaboration Goals
<i>Fiber Optics</i>	Create a procedure for drawing a polymer fiber for use in the design of a solar powered optical laser for a satellite communication system.	Share knowledge comparing manufacturing and material properties of polymer (UW*) and glass (TU) fibers.
<i>Fuel Cell</i>	Characterize a next generation of materials for solid oxide ceramic fuel cells that operate at lower temperatures.	Determine optimum processing techniques in terms of maximizing mechanical (UW) and electrical (TU) properties.
<i>K-San</i>	Study of crystalline defects at the atomic level utilizing a molecular dynamics simulation program (K-San)	Conduct simulations to 1) test hypotheses regarding relationship between heat capacity and number and distribution of vacancies and 2) investigate mechanisms of grain boundary motion (UW and TU).
<i>MEMS</i>	Design, manufacture, test and calibrate a working MEMS microvalve that would be leak proof and quickly expand in response to a variety of flow conditions.	Design a polymer (UW) and piezoelectric (TU) microvalve, and exchange information to find opportunities to combine designs.
<i>Polymerase Chain Reaction</i>	Improve efficiency of PCR processes in order to make it faster and more accurate.	Share and compare PCR results to determine optimal concentration and thermocycling temperature.
<i>Piezoelectric</i>	Demonstrate possible applications for a ferroelectric-based piezoelectric material.	Build a knowledge base on the use of novel materials in the design of sol-gel (UW) and ceramic based (TU) piezoelectric devices.
<i>Shape Memory Alloy</i>	Design and build a working model of an inter-tubular device for correcting abnormalities in arterial flow utilizing shape memory alloy actuators.	Each team pursued their own design utilizing different kinds of actuators.
<i>Wind power generator</i>	Design, build and evaluate an airfoil blade that maximizes power extraction from an air stream.	Each team pursued independent projects.

\*UW = University of Washington; TU = Tohoku University

classroom and laboratory components. In the classroom, students reported on their project progress, received course assignments, and discussed career and educational opportunities associated with the different engineering fields. The classes were held in the Integrated Learning Factory (ILF), an area designed specifically for students to engage in collaborative design projects. The classes lasted approximately 45 minutes. The remainder of the course time was utilized for conducting research in individual research laboratories.

As seen in Table 1, research projects ranged in complexity, novelty, context, and goals. Project goals included studying a process or technique, characterizing or finding an application for a novel material, researching a scientific principle, and improving on an existing design. Similarly, the goals of the international collaboration included sharing and exchanging information, building and synthesizing a knowledge base, decomposing a larger project into more manageable sub-projects, and in some situations pursuing independent projects.

Each research project team had contributors from the University of Washington and Tohoku University. Teams consisted of a faculty member from each institution, a senior peer or graduate assistant from each institution, and up to four students from each institution. Various electronic media were utilized to promote the exchange of information and ideas between the two institutions. Examples include electronic mail, bulletin boards on the course web site, video conferencing, videotapes of student presentations, and facsimiles. A communication technology specialist was provided to aid in the use of the various technologies and created a course website where students could post and receive information [11].

## THE EVALUATION PLAN

This section includes a description of our evaluation strategy, the specific assessment methodologies and instruments chosen, and how the data were collected and analyzed. A more complete description is provided in references [12, 17]. As stated earlier, our primary evaluation goals were to provide insight into the educational benefits of the course for the UW students and to inform decisions regarding the improvement of curricula, instructional practices, and assessment instruments.

To meet these goals we adopted a multiple methods assessment approach. We had four justifications for this decision. First, there was no single existing instrument that would be valid, appropriate, or relevant for this particular learning experience. We did adopt items from existing instruments that have established utility and credibility for assessing specific aspects of this learning experience (e.g. teamwork, attitudes

about engineering) [18–19]. Second, we wanted to take the opportunity to develop a comprehensive and robust picture of student learning so we could contribute to the development of new educational experiences or policies related to freshmen research experiences. Third, we wanted to be responsive to the exploratory nature of some of our evaluation questions. And fourth, we wanted to pilot a range of instruments so that we could identify the most effective means for assessing student learning.

The selection of individual assessment methods was based on comparing advantages and disadvantages regarding the kind of information the method provided, ease in facilitating cross-validation with other methods, and our level of experience with that particular method [12]. Our selections integrated both quantitative and qualitative methods and included: closed-ended surveys, open-ended surveys, a concept map task, observations and interviews with students and faculty in design teams, a content analysis of course work, and a statistical analysis of archival data. Each of these methods is described in Table 2 in terms of:

- the purpose of the instrument (e.g. the outcomes measured);
- the format of the instrument and how data was analyzed;
- how instruments were administered;
- the number of participants.

As part of our evaluation we followed the guidelines of our human subjects application process for obtaining informed and voluntary consent.

As seen in Table 2, the closed-ended surveys were used to analyze changes in students' self-confidence in specific engineering skills and abilities, such as problem solving, teamwork, and communication. Responses from the open-ended surveys were used to analyze changes in students' conceptions of four key issues: engineering, design, teamwork, and the kinds of knowledge necessary for solving complex engineering problems. The concept maps also provided insight into students' understanding of engineering, yet from a perspective of the skills and knowledge needed for engineering practice.

Data from the observations and interviews were instrumental in describing team roles and structures, and articulating attributes of successful international collaborations and research projects that promoted the course learning objectives. A content analysis of course work was utilized to analyze students' knowledge of specific subject matter, their project plans and accomplishments, and their contributions to engineering and science, as well as what students learned about their international collaborations. Finally, archival data was utilized to determine differences in student backgrounds that may limit the utility of the evaluation results.

Table 2. Summary of assessment methods used in our evaluation

Method	Purpose	Format of Instrument	Data Analysis	Collection	Participants
Closed-Ended Surveys	Document changes in students' (1) perceptions of their knowledge and skills and (2) self-confidence and motivation to pursue engineering.	(1) 20 items corresponded to ABET EC 2000 criteria (e.g., teamwork, communication, global/societal issues); 20 items corresponded to an understanding and application of design knowledge (e.g., planning, problem scoping) operationalized based on references [20, 21]. Items on 5 pt. scale. (2) 4 items corresponded to motivation and self-confidence in pursuing engineering. Items on 4 pt. scale.	Both (1) and (2) analyzed in terms of: paired t-test across surveys ( $\alpha = 95\%$ ), and frequency distributions across surveys (decrease, no change, and increase in self-confidence).	Pre and post-test surveys.	(1) 25 paired sets (2) 20 of 25 paired sets
Open-Ended Surveys	Document (1) changes in students' understanding of engineering, design, and teamwork concepts, as well as reasons for enrolling and (2) students' evaluation of the course.	(1) Open-ended questions such as "What kinds of information would you need to solve an engineering problem?" and "What does teamwork mean to you?" (2) Open-ended questions such as "What do you think you learned in this course?" and "Has this course met your expectations—please explain?"	(1) Coded for patterns and themes and compared quantitatively across surveys; analyzed for differences in sophistication and organization. (2) Analyzed for patterns and themes associated with course learning objectives.	(1) Pre and post-test survey. (2) New questions in post-test survey.	(1) and (2): 19 of 25 paired sets
Concept Maps	Describe students' conceptions of engineering and engineering practice.	Students were asked to generate a list of ideas they associated with the anchor "engineering" (also known as a <i>word association</i> [22]). Students later used list to create a map illustrating how ideas related [22].	Analyzed for: (a) number of concepts in list and map, (b) number of concepts in map related to 6 self-coded ABET EC 2000 categories, (c) organization, (d) complexity of links, and (e) sophistication.	Administered as a learning activity mid-quarter.	16 of 25 completed maps
Observations	(1) Understand the ways students learn and communicate in a group and in an international setting and (2) describe characteristics of the research experiences.	To limit the size of the ethnographic study only 2 teams were selected (K-San and Fuel Cell). Data included: classroom and laboratory observations, forwarded email transactions among team members, informal interviews, and exit interviews.	Notes compiled into a document [17]. Emergent themes identified and probed for qualifying evidence such as: (a) how students worked as a group, (b) students' conceptions of engineering, and (c) the nature of their international interactions.	Throughout the experience.	2 teams: 7 students, 2 faculty, 1 graduate asst., and 2 senior peers
Interviews	Explore and/or confirm issues identified in the observational study. Both (1) students and (2) faculty were interviewed.	(1) Example questions: what did the team accomplish, how did they work as a group, how has the experience affected their understanding of engineering, and what was the nature of their international communications. (2) Example questions: how did they become involved, how was their project created or transformed, their opinions regarding the feasibility and utility of the course, and what problems they encountered.	Responses compiled into a document and organized in terms of the interview questions [17]. Emergent themes identified and probed for qualifying evidence.	During the first and last weeks (follow-up interviews 2 quarters later).	(1) 25 students (11 follow-up) (2) 10 faculty, 2 graduate assistants, 8 sr. peers (4 follow-up)
Course Work	Describe (1) information regarding the nature of the individual projects and (2) student learning related to the individual projects.	Students were required to prepare 3 documents: a plan identifying their preliminary goals, an interim report describing their current progress, and a final report.	A content analysis of: (a) project goals, plans, accomplishments, and collaboration activities, (b) students' descriptions of the project content, and (c) students' statements of what they learned.	Reports due every 3 weeks.	All reports for 8 teams
Archival Data	(1) Compare students in sample to population and (2) monitor retention.	(1) UW academic index for the UW Tohoku pilot and students in the traditional freshmen course for Fall 1999. (2) Continuation with project monitored through Spring.	(1) Chi-squared analysis with a critical value of $p < .001$ . (2) The number of students who continued.	First week, and monitored thru '99-'00.	All 25 students

### Triangulating data across assessment methods

We developed an articulation matrix to identify how data from each assessment method was utilized to respond to our evaluation questions (see Table 3). As stated earlier, the goals of our evaluation were to assess the effectiveness of the teaching methods and course content in terms of the impact of the course on student learning and motivation to pursue engineering, and the match between course learning objectives and student learning outcomes.

The map in Table 3 identifies these evaluation goals, the educational objectives of the Tohoku pilot for the UW students, and whether or not an assessment method provided any data relevant to the evaluation dimension.

The results from each method were summarized as separate reports and organized according to the evaluation issues identified in Table 3. Compiling and synthesizing results across the different assessment methods for each evaluation question generated the final evaluation report [17]. The general approach to the triangulation process was to utilize the closed-ended surveys, the content analysis of the reports, and the observations to identify areas of learning or dimensions of the learning experience. The open-ended surveys, the concept maps, and the interviews were used to compare and contrast trends or provide richer detail. In addition, circumstances in which a method provided the most effective insight into the course were pursued in order to inform the revision of assessment instruments. A summary of cross-validated results and some illustrative examples of the triangulation process are provided in the following section.

## RESULTS

Overall, the course was a great success. The students accomplished a considerable amount in their research projects. Students engaged in meaningful roles and authentically participated in their

projects. More specifically, students generated their own roles, plans, and processes for meeting their goals, and took ownership of their projects. Many of the student teams became members of their research and laboratory communities, and three of the eight teams have decided to prepare research publications to disseminate their results. In addition, the students completed significant engineering and scientific work. Students in two projects were able to develop new applications for novel materials or refine existing applications, and students in three projects generated new information about processing techniques for novel materials. One team generated and tested hypotheses about a theoretical phenomenon and compared their results with a recent theoretical study. And one team designed and built a prototype that is currently being used as an instructional device at a local community college. Also, five of the eight projects were presented at the UW Undergraduate Research Symposium in May 2000, a forum in which approximately 85% of the undergraduate researchers were at a junior or senior level.

The above depicts an example of what we learned from our overall evaluation [17]. Given the comprehensiveness of the evaluation, there are clearly many detailed results we could report. In this paper, we concentrate on:

- the impact of the course on student learning along six dimensions;
- the impact of the course on student motivation to pursue engineering;
- how the course met student expectations.

These results are presented in a synthesized format and examples of triangulating across multiple methods are provided.

### Impact on student learning

Findings summarizing the impact of the course on student learning are presented in Table 4. The

Table 3. Articulation of assessment methods across evaluation questions

Dimensions	Closed-ended Survey	Open-ended Survey	Concept Map	Observe & Interview	Course Grades	Archival Data
<i>Evaluation Goals:</i>						
Impact of course on learning and motivation to pursue engineering	×	×	×	×	×	×
Comparison of learning objectives to learning outcomes	×	×	×	×	×	×
<i>Learning Objectives:</i>						
Design	×	×	×	×	×	
Apply math, science and engineering knowledge to solve problems	×	×	×		×	
Conduct experiments and analyze data	×			×	×	
Function in team	×	×	×	×	×	
Communicate effectively	×		×	×	×	
Understand engineering as a field and as a career	×	×	×	×	×	
Understand global and society issues	×	×	×	×	×	
<i>Other Objectives:</i>						
Motivation to pursue engineering career	×	×		×		
Motivation to pursue international or research opportunities		×		×	×	
Attitudes about their ability to be creators and contributors to engineering knowledge		×		×	×	
Retention in engineering	×	×		×	×	×

Table 4. Impact on student learning along six dimensions

1) *Design*

Students engaged in a variety of design activities, regardless of whether or not they were in a project that was technically 'design'. Students developed a broader and more sophisticated understanding of design:

- Students identified 74% more design concepts on their post-test survey (e.g., decompose a problem, iterate, find viable solutions)
- Students were twice as likely to describe design as a process made up of specific activities to address a particular need in the post-test survey

Students developed design skills:

- Statistically significant increases in students' self-assessment of their ability to: identify the problem need, define problem requirements, identify feasible solutions, evaluate solutions, and recognize when changes to an original understanding of a problem need to be made

Some skills that may be representative of design activity increased but were not statistically significant (e.g., generating ideas, selecting a model to analyze a solution, building a solution, suggesting solution refinements, planning design activities, and documenting a design process)

2) *Problem Solving*

Students engaged in a variety of problem-solving activities (e.g., utilized experimental techniques and equipment, performed comparative analyses of data, fabricated or processed samples and prototypes).

Students perceived increases in their ability to utilize computational tools and techniques, and utilize information resources to gather information, but these were not significant.

Students developed problem-solving skills:

- Statistically significant increases in students' self-assessment of their ability to: recognize limitations and know when to seek additional information and evaluate the quality of information sources
- Students developed a broader understanding of what kinds of information may be necessary for solving engineering problems (a 36% increase from the pre-test survey)

3) *Teamwork*

Team roles were observed to be a function of the leadership structure, the team environment, and the flexibility of the project. Teams that were more collegial and had a shared leadership structure were more likely to continue with their projects as a team. Students' understanding of teamwork became broader and more sophisticated:

- Students identified 70% more teamwork concepts on their post-test survey (most of these related to a better understanding of themselves and their teammates, as well as the kinds of team roles and responsibilities)
- As a group, students were twice as likely in the post-test survey to describe the purpose of teamwork as working towards a mutual goal

Students commented that their team experience increased their motivation to pursue engineering.

Students developed teamwork skills:

- Statistically significant increases in students' self-assessment of their ability to: describe the components of an effective team meeting, identify the characteristics of effective communication, understand team roles and responsibilities, and modify own style to accommodate others

4) *Communication*

Students were engaged in a variety of communication formats throughout the course (e.g., written, oral, communication technology).

Overall, students developed more effective communication skills:

- 5 of the 8 bi-national teams presented their results at the UW Undergraduate Research Symposium
- Statistically significant increases in students' self-assessment of their ability to: produce written documents, produce professional presentations, and document their project activities
- 67% of the students responded that making effective presentations was one of the most important things they learned

5) *Engineering Knowledge and Understanding*

Students developed a broader, more sophisticated, and more cohesive understanding of engineering:

- By the end of the course, 70% of the students developed an understanding of engineering that was more cohesive and succinct
- Students identified 61% more engineering concepts on their post-test survey

Self-generated themes in students' concept maps suggest a broad understanding of engineering issues and knowledge (e.g., activities related to engineering problem solving, teamwork, the context or purpose of engineering, attitudes and knowledge engineers need, engineering fields)

Students also learned specific engineering knowledge related to their projects:

- Students from 6 of the 8 projects were able to describe the underlying principles related to a process, material, or phenomenon, as well as identify and explain relationships across key variables studied

6) *Understanding of Engineering in a Global and Societal Context*

Students had little opportunity based on their actual project experience to develop an understanding of global and societal issues.

- Only a few of the teams were able to maintain an effective international collaboration/communication

Given this situation, most students still developed a better understanding of the impact of engineering solutions in a global society:

- The number of students who included impact issues in their post-test survey responses increased by 80%—of these 56% provided a more insightful and sophisticated understanding of the impact of engineering solutions in a global/societal context
- Post-survey responses migrated from describing technical concerns to issues concerning the context of engineering problems and solutions
- Significant increases in self-assessed ability to recognize successful global engineering solutions and identify key issues related to global and societal contexts

details of the full evaluation report are available in a technical report [17]. Table 4 represents a comprehensive listing of each of the findings that emerged from our analysis and is organized according to the following learning objectives:

- design skills;
- problem solving skills;
- teamwork skills;
- communication skills;
- understanding of engineering and subject matter knowledge;
- understanding of global and societal issues.

Each of these findings is substantiated by triangulation across the data collected. Also, in a separate analysis we have determined that while the students in the Tohoku pilot may be perceived as special—they were not atypical freshmen engineering students. No significant differences were found between UW students in the Tohoku pilot and those enrolled concurrently in the three traditional freshmen ENGR 100 sections [21].

Measures for comparison included: combined academic index for their admissions profiles (e.g. combination of SAT scores); high school GPA; high school math and science levels; likelihood of declaring engineering as a major. There were also no significant differences across groups in terms of the representation of women and under-represented minorities.

#### *Complementary findings across methods:*

##### *Teamwork*

One of our hypotheses was that students would acquire valuable teamwork skills and knowledge as a result of their experience in the course. For this analysis closed-ended survey responses were used to identify significant changes in learning outcomes, open-ended survey responses and concept maps were used to analyze students' understanding of teamwork, and a content analysis of project reports was used to identify the number and kinds of team activities in which students engaged. Synthesizing across findings supports a hypothesis that students' understanding of teamwork and their ability to function in a team improved considerably and illustrates the variety of students' teamwork experiences.

Students' understanding of teamwork became broader and more sophisticated. By the end of the course, students were able to articulate a broader and more sophisticated understanding of what it means to function in a team. As an example, the number of teamwork concepts for the question 'what is teamwork?' increased by 70% on the post-test survey. New concepts on the post-test survey were more sophisticated and examples included: understanding your own abilities and communication patterns, working across different communication styles, sharing data, and perceiving project accountability as a group rather than at an individual level. Similarly, the number of

concepts on the post-test survey describing the kinds of team roles and responsibilities increased by 75% and included such concepts as sharing data and ideas, having an open mind, adjusting or being sensitive to individual differences, compromise, and knowing your strengths and weaknesses and how to make them work for the group. Overall, by the end of the course students were more likely to describe teamwork in terms of better understanding themselves and their teammates.

The number of concepts on the survey related to the purpose or value of teamwork increased by 80%, and the number of students who described these concepts doubled on the post-test survey. New concepts included working together to solve a problem, sharing and combining ideas, and working towards a common goal. Finally, when asked how the experience changed their understanding of teamwork, many students provided a list of 'lessons learned'. These include: being sensitive to the needs of their teammates and adjusting their own style; 'you really do get more work done as a team'; the nature of team responsibilities should be responsive to the kind of project; a shared leadership structure is more appropriate for a dynamic research or design project; and negative individual and group issues can be overcome. Some students commented that the experience increased their enthusiasm and confidence about future team experiences.

Students developed teamwork skills. In general, students' self-confidence in their teamwork skills increased, and many of these were significant gains. In specific, students' self-confidence in their ability to describe the components of an effective team meeting ( $p < 0.001$ ) and identify the characteristics of effective communication ( $p = 0.04$ ) significantly increased. Students' self-confidence in their ability to understand team roles and responsibilities also significantly increased ( $p = 0.02$ ), as well as their ability to modify their own style to accommodate others ( $p = 0.01$ ). Students who had successful international communications or who successfully resolved negative team dynamics issues were among those who perceived that their ability increased by two or more ranks on the Likert scale. Also, students' self-confidence in their ability to provide feedback to their team members increased, but this was not significant. Students in teams that had a more collegial environment were among those who perceived that this ability increased by more than one rank on the scale.

Two kinds of team environments were observed. Students had different opportunities to learn about teamwork because they experienced different types of teams. Some project teams displayed a collegial environment, while the others displayed a managerial environment. A collegial environment occurred most often in situations in which leadership was shared. In the collegial environments team members were more likely to interact bidirectionally or dialogically as peers, and this

includes peers who had more authority or expertise (e.g. faculty and graduate students). Tasks were often assigned from a systems perspective in which the division of labor was shared among team members. As a result, team members were more likely to be accountable to each other and the project, and the team environment promoted more social learning. In contrast, a managerial environment occurred most often in situations in which there was a dominant leader. In the managerial environments, team members were more likely to interact uni-directionally or authoritatively. Tasks were often assigned from a merit or ability perspective, and team members were more likely to be held accountable to the leader than the project.

Teams that were more collegial and had a shared leadership structure were more likely to continue with their projects as a team. Some students explained that part of their decision to continue with their projects was a desire to retain their team membership. In the follow-up interviews, students from two teams expressed a belief that part of the strength of their group was that they shared the leadership, and that they worked complementary to each other. Teams that were more managerial and had a dominant leader were less likely to continue with their projects *as a team*, and more likely to continue *as individuals*. In addition, one team was observed to evolve towards a more collegial structure. In their final report this group described how they revised their division of labor from a more managerial to a more collegial format in order to better meet their project goals.

*Complementary findings across methods: impact on student motivation to pursue engineering*

A second hypothesis was that students' motivation to pursue engineering would increase as a result of their experiences in the course. To analyze the impact of this experience on students' motivation, the pre- and post-test closed-ended survey responses were used to analyze changes in student affective outcomes, the open-ended survey responses were used to describe students' motivation to pursue engineering, the interviews were used to provide insight into significant differences, and retention in the projects was monitored to explore which projects and teams were most likely to continue after the course concluded.

Overall, our findings suggest that the course reaffirmed students' motivation and increased students' self-confidence that engineering was the right choice for them. The responses from the open-ended survey suggest that the course either reaffirmed or confirmed an already existing interest in engineering: 60% of the students responded that the experience increased their motivation to pursue engineering. Reasons provided included: helped them better understand engineering, increased their confidence that engineering is the right choice; reinforced or confirmed an existing interest and motivation; and generated enthusiasm about future engineering course work and projects.

A review of responses on the post survey to the question 'What did you learn in this class?' suggests that students were more informed about what engineers do, the kinds of knowledge engineers need, and the necessary general engineering skills. As some of the students suggest—a better understanding of engineering would enable students to make better decisions about their interest and confidence in pursuing engineering.

Students remained with their projects after the course had concluded: 6 of the 8 projects continued after Fall quarter. Members from 7 of the 8 projects enrolled in independent study credits in Winter and Spring quarter. Three projects continued on as a team, individual members from three projects continued on with some aspect of their original project, and one individual from a project that did not continue joined an existing team. By the end of Spring quarter, students from all of the continued projects were considered members of their individual research and laboratory communities. In their final reports, students identified a variety of reasons for continuing on with their projects. These include refining their design, pursuing a new direction related to their project, and continuing on with their original activities. And most teams could identify revisions they would like to address about their design or about the techniques they utilized.

*Complementary findings across methods: how the course met student expectations*

To analyze how the experience met students' expectations, the open-ended survey responses and the interviews were used to analyze students' reasons for enrolling, and the closed-ended survey responses were analyzed in terms of how students' expectations compared to students' evaluations of the course. A synthesis across findings suggests that students were able to accomplish most of their individual learning goals. In addition, the students provided considerable insight into why some learning goals were not achieved.

For most of the students the course met their expectations, and they were able to accomplish their individual learning goals. Overall, 80% of the students responded that the course either often (60%) or always (20%) met their expectations, and 20% of the students responded that the course met their expectations at least a few times. In general, students responded positively to an educational environment that promoted project-based learning in the context of real research projects. 53.5% of the students responded that the best part of the course was related to attributes of their projects and team experiences. These include: an interesting or creative project, the diversity and novelty of the projects, the practical and hands-on experience, setting and attaining their own goals, working closely with faculty and being a member of a highly motivated team, and meeting their peers.

Students identified three reasons for enrolling in



the course: to learn about engineering, to be able to answer their own questions about pursuing engineering, and to learn about another culture or work with the students from Tohoku. When asked at the end of the course what they thought they learned, students identified the following: how to create more effective presentations and reports (67%), specific engineering knowledge related to their projects (52%), an understanding of what engineers do and how (47.6%), and better teamwork skills (33%). Also, in the pre-test survey responses statements about learning about engineering were simple and direct (e.g. 'learn engineering skills'); on the post survey, responses were broader and more descriptive. For example, students were able to describe what engineers do, what they need to know, what kinds of problems they work on, and what the different departments do. Because students were able to articulate a broad and sophisticated understanding of engineering, this suggests that students would be more able to determine if engineering is the right choice for them. By the end of the course 76% of the students ranked their self-confidence that engineering is the 'right choice for them' as 'highly confident', as compared to 33% on the pre survey.

However, some learning goals were not met. 57% of the students responded that the course did not meet their expectations in some way. When asked to explain, 43% of the students identified the poor communication and collaboration with Japan. At least one student from each project responded that their communication and collaboration with Japan did not meet their expectations, and one student responded that the failed collaboration was the worse part of the course. Reasons provided focus on the misalignment of project goals, activities, and schedules. Outcomes such as learning about another culture or what it means to collaborate across cultures and societies were generally not present in students' comments about what they think they learned. Only those students from the one project that had prolonged technical interactions with their Tohoku teammates responded that they learned about what is involved in collaborating across cultural and language barriers. For most students, the level of communication was infrequent, and was most likely to involve social rather than technical communications. This suggests that students had little opportunity to develop a better international working ability.

Also, students described their classroom and laboratory activities as belonging to separate and distinct worlds. Students engaged in different kinds of activities in the two learning spaces, and perceived different kinds of learning roles. In the interviews, students described their laboratory activities as more representative of 'real-world engineering'. In their labs, students were actively engaged and were more likely to perceive their role as contributors of knowledge. In the classroom, students were passive and were more likely to

perceive their role as recipients of knowledge. Students often did not engage in classroom discussions even though the instructors encouraged questions and discussions. This suggests that the structure of the learning spaces (e.g. classroom and laboratory) may have promoted different learning. As an example, many teams had free access to their labs, interacted frequently with their research colleagues, and some teams used the lab space for working on their projects as well as engaging in activities unrelated to their project (e.g. work on homework, interact socially with peers). In other words, for some students the lab space was a research space, an educational space, and a social space. This multiplicity is one of the characteristics of the Kenkysushitsu's at Tohoku University.

Students perceived the classroom activities and the collaboration goals as external to their project goals. In the interviews, the students described the classroom as external to their activities—as an extra activity that was unrelated (an 'add-on') to what they were doing that took them away from their project time. Similarly, whereas students' laboratory work was organized around research goals and accomplishments, their classroom work was organized around traditional engineering classroom activities such as clock hours and grading policies. Many students were frustrated about the amount of classroom time required. In the interviews some students explained that some course lectures were unnecessary or unrelated to their projects. For example, students commented that the 'working-in-groups' lecture was unnecessary since many had been working in groups since grade school. This is also supported in the pre-survey: 50% of the students ranked their level of experience with working in teams on the highest scale ('a great deal'). One interpretation is that issues discussed in the lecture were too rudimentary, or students weren't engaged or interested in the topic. In summary, these findings suggest that the course organization needs to be better integrated across the educational spaces.

#### *Conflicting findings across methods: information gathering*

Our hypothesis concerning students' information gathering skills provides an instance where we encountered conflicting findings across assessment methods. Given the structure of the course, we hypothesized that students' information gathering skills would improve as a result of their experiences in the course. Information gathering is considered to be an important aspect of design activity and has been associated with greater engineering experience and design success [25, 26]. For this analysis, pre and post-test closed-ended survey responses were used to identify significant changes in the learning outcomes, open-ended survey responses and concept maps were used to analyze students' understanding of design and engineering, and a content analysis of team reports

was used to identify the number and kinds of design activities in which students engaged.

As a preface, students developed a broader and more sophisticated understanding of design. As a group, students identified 74% more design concepts on their post-test survey. Similarly, students were more likely to express significant gains in their self-assessed design abilities related to identifying and stating the problem needs ( $p=0.0075$ ) and defining problem requirements ( $p=0.007$ ). Also, students' self-confidence in their ability to identify evaluation criteria increased significantly ( $p=0.004$ ). Many of the projects were open-ended and this required students to identify their own goals and criteria for success, rather than follow a predetermined plan. When asked to identify 'What kinds of information would you gather to solve an engineering problem?' and 'What kinds of issues and concerns would you consider when solving an engineering problem?' students were more likely to emphasize issues related to reviewing the history of the problem on the post-test than on the pre-test survey. Understanding the history of a problem is an important information gathering activity associated with being able to recognize and state the problem needs and the requirements.

As a group, students developed a broader and more sophisticated understanding of the kinds of information needed to solve engineering problems. Many students sought information beyond the scope of traditional resources (e.g. libraries and databases) and sought outside resources such as vendors and customers to better understand their project. When asked to identify the 'kinds of information needed to solve an engineering problem', responses on the post-survey spanned a range of issues that was 36% larger than on the pre-test survey. New concepts included safety, user needs, legal issues, and issues related to the context of the engineering problem in a global society. In addition, the number of students that included impact issues on their post-test survey responses increased by 80%. Also, students were more likely to organize issues into categories such as information about problem requirements, technical knowledge, finances, scheduling, project history, and impact.

Students' self-confidence in their information gathering skills increased, however many of these increases were not statistically significant. In specific, students' self-confidence in their ability to recognize their own limitations and seek additional information ( $p=0.03$ ) and in their ability to evaluate the quality of information resources ( $p<0.001$ ) significantly increased. These findings compare well with the level of information-seeking activities students performed and the breadth of students' understanding of the kinds of information necessary for solving engineering problems. However, students' self-confidence in their ability to identify and utilize information did not noticeably increase. For this particular design skill, the

results from the open- and closed-ended responses were not complementary. These conflicting findings suggest that students developed a more sophisticated understanding of what kinds of information are important for solving engineering problems, yet their perceptions of their information gathering skills or abilities across some measures did not significantly increase. One explanation is that the open-ended questions asked students to describe their understanding of *what kinds* of information are necessary to solve the problem, whereas the closed-ended question asked students to rate their ability to identify information sources. Given that most students did not identify information gathering behaviors or skills in their open-ended responses (e.g. where to find information, how to use information resources) this interpretation may have some validity. This would suggest that students might need additional instruction in information gathering skills. An alternate interpretation is that these particular survey items were not well designed. The mean values for students' abilities to utilize information resources prior to their enrollment ranged from 3.7 to 3.8, which compares to a rank of 'very good'. This suggests that students already had a high level of self-confidence in some of their information-gathering behaviors, and that the survey question was not sensitive enough to capture differences.

## DISCUSSION

Overall, the evaluation illustrated that the course achieved many of the stated learning objectives. Students learned both broad and specific engineering and problem solving skills, as well as teamwork and communication skills. Students also developed a broader and more sophisticated understanding of engineering, design, research, and teamwork issues. Also, students developed a broader and more conceptual understanding of the context of engineering solutions in a global society, and were able to articulate issues related to the impact of engineering solutions. Finally, the experience either confirmed or reaffirmed students' confidence that engineering is the right choice for them. From the perspective of students' abilities to take on complex research projects, our findings suggest that students were able to: 1) solve complex research and design problems, 2) engage in meaningful roles as colleagues within a research community, 3) take ownership of their projects, and 4) contribute to engineering knowledge and practice.

These results illustrate the first benefit of adopting a multiple assessment methods approach—the results make for a compelling story of student learning. In most situations, data across the assessment methods was complementary and provided a more comprehensive picture of student learning outcomes. And the triangulation process allowed

for themes to emerge naturally from individual methods and for us to identify issues that may not have been readily accessible.

Situations in which findings conflicted were most often due to differences across the projects and poorly designed or missing questions on the surveys. Changes to the pre- and post-test surveys that were incorporated into the Fall 2000 Tohoku course include:

- deleting questions that were not likely to be representative across projects;
- adding questions that require students to describe attributes of effective international communications and collaborations;
- modifications to questions that were poorly worded or not sensitive enough to capture differences in learning (e.g. information-gathering abilities).

Our multiple methods assessment approach also helped us to identify significant challenges associated with such a course. In our course, students divided learning time between the classroom and laboratory, worked on different projects, and collaborated with international partners. Each of these dimensions presented particular challenges that need to be better addressed in future course offerings.

To summarize:

- *Segregation of classroom and laboratory spaces.* Future offerings will need to find ways to integrate and connect the laboratory and classroom activities in more meaningful ways. Some ideas include using the classroom time to facilitate reflective discussions about learning objectives and issues related to the individual research projects, promoting team activities across the educational spaces, finding better ways to integrate grading policies across both spaces, and requiring different kinds of presentation formats

that promote student discussions about their research.

- *Variation among projects.* We observed that there were substantial differences in student learning and attitudes across the individual projects: not all projects had equal success in promoting the course learning objectives. As a result, we developed a framework for characterizing the projects in terms of the kinds of educational environment they provided [23, 24]. We have used this framework as an evaluation tool and as a guide in the development and improvement of freshmen research and design projects. A summary of project characteristics found to have a positive effect on student learning is provided in Table 5.
- *Supporting international collaboration.* Several teams experienced difficulties integrating the international collaboration component within their individual research projects. Although some of the problems can be traced to structural and language difficulties, one of the most salient issues was that many of the collaboration plans were not integral to the success of the project. These difficulties and contributing factors are described in detail in the complete evaluation report [17]. Based on our analysis, we have identified several factors we believe are important for effective international collaboration in this type of class structure. These are summarized in Table 5.

## CONCLUSIONS

In conclusion, our multiple methods evaluation approach was very informative and resulted in practical recommendations for improvement. By triangulating across methods we were able to cross-validate results and instruments, determine if learning objectives were met, and identify course successes and weaknesses. In many situations we

Table 5. Project collaboration Characteristics that may Influence Success

Project Characteristics that Influence Success	Collaboration Characteristics that Influence Success
<ul style="list-style-type: none"> <li>• Instructors' belief in student capabilities</li> <li>• An unconstrained project</li> <li>• A project that was authentic to the discipline</li> <li>• A project that included both 'analysis' and 'application' phases</li> <li>• A collegial team environment that supported a shared leadership team structure</li> <li>• A hands-on start-up task to familiarize students with the research area</li> <li>• An adequate resource network</li> <li>• A mature project that was well organized and administered.</li> </ul> <p><i>Characteristics that were most likely to have a negative effect on student learning outcomes were essentially the opposite of those identified above.</i></p>	<ul style="list-style-type: none"> <li>• Infrastructure that provides access to multiple forums for communicating</li> <li>• An ability to share the same method, equipment or materials without a large start-up cost</li> <li>• Accountability for promoting successful communication and collaboration</li> <li>• Support for working through language barriers</li> <li>• Structured communications (e.g., designated communication leaders, preparing and distributing an agenda)</li> <li>• Negotiation of the structure and goals of the collaboration effort</li> <li>• Building rapport and trust within the team (e.g., face-to-face video exchanges)</li> <li>• Providing opportunities for teams to reflect on issues generated during communications</li> <li>• Mediating major decisions outside of a public forum</li> </ul>

were able to provide evidence of learning that may not be easily accessible. Although this approach requires extensive buy-in and resources, the results can be more readily applied to the improvement of future course offerings in terms of characterizing measures of student learning related to course objectives and developing more streamlined assessment instruments that have been tested for validity, credibility, and utility.

Our evaluation results were utilized to characterize successful projects and collaborations and modify assessment instruments, as well as inform the selection of a more streamlined evaluation plan. These, in turn, were used in the Fall 2000 offering of the course and in the development of a

three-year international research initiative between the University of Washington and Sichuan University in China.

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