COLLABORATIVE LEARNING AND CYBER-COOPERATION

In Multidisciplinary Projects

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The National University of Singapore (NUS) and the Eindhoven University of Technology (TU/e) recently formed a strategic alliance with the aim of offering joint PhD programs. Existing scientific contacts between both universities and the preparation of this strategic alliance initiated the additional concept of joint collaborative learning among several interested departments at both universities.

The Department of Chemical and Environmental Engineering (ChEE) at NUS consists of more than forty faculty members and a thousand-plus student body. The undergraduate programs train over six hundred students who go on to foster the growth of chemical and environmental engineering in Southeast Asia. The quality of teaching in the ChEE department has been greatly enhanced by its in-depth and integrated research, which requires multidisciplinary expertise and can be generally categorized into the areas of chemical engineering fundamentals, environmental science and technology, materials and devices, and process and systems engineering.

TU/e is one of fourteen Dutch universities dedicated to educating over five thousand students in technical scientific education and research. It comprises eight faculties offering twelve full engineering degree programs (for the Dutch "ir" title). The five-year degree programs lead to an academic title equivalent to a Master of Science degree in engineering. In addition, TU/e offers a 3-year BSc and a 4-year PhD program.

Research teams at both TU/e and NUS carried out certain tasks to meet the objectives given by a company, Global Cooling, under comparable, yet different, settings. The TU/e team designed a photovoltaic refrigerator with a Stirling cooler, while the NUS team incorporated a direct-current compressor with an identical refrigerator. The project was partially sponsored by Global Cooling, with additional support supplied by the multidisciplinary project (MDP) program at TU/e and the Undergraduate Research Opportunity Program (UROP) at NUS. The company participated by supplying the Stirling cooler and feedback on the design. Various overseas communication methods were established to facilitate communication and to ensure that the parameters and experiments were conducted under comparable conditions.

UROP PROGRAM AT NUS

The Undergraduate Research Opportunities Program (UROP) initiated by the faculty at NUS is a special program that helps undergraduate students strengthen their research experience and their life-long learning ability. The program encourages research that involves cross-departmental participation, allowing undergraduate students to enhance and apply their knowledge of the latest technology. Due to the significance of the program, the National Science and Technology Board in Singapore elevated it to the national level by holding an annual UROP congress where the participating students could present their research findings and receive commendable recognition.

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The students participating in the UROP projects were required to start their research during their second- or third-year of study to ensure its completion. A minimum of 65 hours over two consecutive semesters was scheduled to complete a satisfactory project. Each student had to submit a 4-page paper for final assessment, and a pass-or-fail grade was awarded. It should be noted that additional requirements for the project were given due to the special nature of its international connection with the MDP program at TU/e. Specification of the requirements and assessment are discussed in detail below.

The working team at NUS comprised eight undergraduate students who were in their second year of study. Supervision was provided mainly by two full-time academic staff members in the ChEE department, while other engineering departments (such as the mechanical engineering and electrical/computer engineering departments) were occasionally consulted for relevant technical questions.

MDP PROGRAM AT TU/E

The inter-departmental Centre for Sustainable Technology at TU/e played a key role during the 1990s in initiating multidisciplinary project work as an optional activity for students of different departments to work together on a subject related to sustainability. Participating departments include chemical engineering and chemistry (400 MSc students), mechanical engineering (700 MSc students), and applied physics (100 MSc students). Multidisciplinary projects are now a compulsory part of the curriculum for most TU/e departments.

In the departments of chemical engineering/chemistry and applied physics, the MDP program is placed in the fourth year of study, at the beginning of Master-degree work, so the students will have sufficient background to apply their knowledge and integrate different expertise from other students. On the other hand, other departments at TU/e, such as mechanical engineering, place MDP projects during the third year of the curriculum in order to conclude the phase of fulfilling the Bachelor degree. As a result, the various research teams of MDP programs often consist of students with different backgrounds in educational experience (different years) and scientific/engineering training (different departments).

An MDP group at TU/e usually consists of 5 to 7 students, preferably with different backgrounds. A 6-credit unit is awarded, requiring approximately 240 working hours to complete the project within a single trimester (10-12 weeks). The students usually work on the design of a prototype based on literature study. For the current project, the team at TU/e consisted of six undergraduate students from three different departments (chemical engineering/chemistry, mechanical engineering, and applied physics), some of whom had previous experience in collaborative project work. In addition to the supervision facilitated by two full-time faculty members, the students were encouraged to search for additional expertise, both inside and outside the university.

EDUCATIONAL GOALS

The proposed international Multidisciplinary Project (MDP) was a design-oriented collaboration with a specific economic and societal context. The operating procedures in the project were conducted in parallel by two research teams at NUS and TU/e. The educational goals to be achieved included

- *Working on projects*
- *Dealing with practical problems*
- *Applying already-acquired integrated (technical) knowledge*
- *Localizing and acquiring new knowledge and information*
- *Working on a team with students from different backgrounds*
- *Developing and applying communicative skills, presentation skills, and discussion techniques*

The purpose of an MDP is to involve undergraduate students in ongoing collaborative design work. MDP should benefit students by

- *Enhancing their knowledge of the newest technology*
- *Providing an opportunity to acquire skills for the intellectual process of inquiry*
- *Encouraging students, faculty members, and client companies to interact and form closer ties*
- *Rewarding students with certificates of participation for successful completion of an MDP project*
- *Exchanging information and ideas with a parallel group abroad*

In addition, to focus on the goal of group dynamics, a number of team-building sessions were held to address some of the aspects that play an important role within a group, such as decision making, leadership, communication, conflict handling, group-style inventory, and pilot peer-review.

The NUS group found that the project involved acquisition of new knowledge because the group members were only equipped with two years of undergraduate education and were still under basic training in chemical engineering. Hence, the group spent a substantial amount of time on self-study to familiarize themselves with the project-related subjects.

THE INTERDISCIPLINARY STRUCTURE

The students operated as two teams of engineers from the virtual company MDP International (the virtual contractor) within a (virtual) budget agreed to by Global Cooling. Estimation of various costs was included as part of the project. Students participating in the program were from the Department of Chemical and Environmental Engineering at NUS, and the Departments of Chemical Engineering and Chemistry, Applied Physics, and Mechanical Engineering at TU/e.

Global Cooling and MDP International agreed on a contract and the groups were responsible for documenting and periodically reporting on the virtual cost. Global Cooling supplied the Stirling cooler and knowledge, while the team at TU/e purchased the refrigerators and (initially) the solar panels for both parties, to ensure that the parameters and experiments were conducted under comparable conditions. On the other hand, the National Undergraduate Research Opportunity Program and the Centre for Advanced Chemical Engineering at NUS jointly supported the NUS group by offering the necessary facilities and funding for the purchase of a DC compressor, along with the construction materials and required accessories.

OBJECTIVE OF THE JOINT PROJECT

The objective of the project was to design a photovoltaic refrigerator. The World Bank estimates that in today's world, about two billion people have no access to modern energy services. They live, for the most part, in developing countries in parts of Africa, Asia, and Latin America. For their energy supply, they are dependent on often-scarce biomass sources such as wood and dried dung. Photovoltaic (PV) energy technologies now make it possible to offer sustainable modern energy services to those who live relatively far from a central electric grid.[1,2] In most countries, there are three major areas in which PV will be preferably applied: lighting, communication, and cooking and cooling. This project focused on building a solar-powered cooling system.

The objective of the project was to design and manufacture two PV refrigerator prototypes to function as efficiently as possible, using either the Stirling cooler or the DC compressor. A test protocol had to be created that would enable comparison of the results for the two systems (PV-refrigerator connected to PV-panels). Finally, a testing report comparing both systems had to be presented. Efficiency was considered in terms of the conversion of sunlight energy to maintain the cooling chamber at desired temperatures. The teams used identical refrigerators and solar panels as their base material.

The requirements regarding the functioning of the refrigerator were

- *At environmental temperatures between 32 °C and 43 °C, the inner temperature of the cabinet should remain between 0 °C and 8 °C*
- *With respect to cooling rate, a minimum of 2 liters of water should be cooled down to 5 °C within 24 hours*
- *The system was limited to using a thermal storage buffer (such as water), while the use of a chemical battery was not allowed*
- *Without sunlight, the thermal storage should be able to maintain the refrigerator at temperatures between 0 °C and 8 °C for at least 24 hours*

The refrigerator using the Stirling cooler was required to meet two additional conditions of

- *It should have a thermal siphon at the cold and the hot end of the system*
- *It should preferably have a maximum temperature difference over the heat exchanger of 5 °C per side*

The variable factors in this project were the selection of the cooling system and the interaction between the cooling system and the solar panel. The NUS team used a DC compressor as a cooling engine, while the TU/e team used a Stirling cooler. Initially, both groups focused on the theoretical research of the subject matter and individual components. Next, some experiments were conducted to assess individual components regarding the working properties, which included

- *Heat leakage in the Samsung refrigerator*
- *Variation of the output voltage of the solar panels with the intensity of light*
- *COP and capacities of the DC compressor at various conditions*

Apart from the actual design, attention was also given to areas such as safety, environmental concerns, and marketability. One of the major problems in producing equipment for markets in developing countries is the initially limited volumes to be marketed. The chances of a PV refrigerator being produced in substantial numbers would significantly depend on the richer parts of the world also presenting a market for such a device. One of the niches for this device could be the outdoor (sporting and camping) market.

An appreciable amount of attention was directed toward the question of sustainability. The subject of the MDP shows close relevance with the use of sustainable technology, and therefore sustainable technology had to be a key feature of the research question. That is, in addition to the technical aspects of the subject, students had to research environmental and social aspects of the subject and had to consider sustainability aspects. In this way, students were required to integrate their specific technical skill with knowledge of sustainability in their design and final report.

The students on both teams had assistance from technicians in building the prototype, to ensure sufficient progress. The main areas in which assistance was required were the construction of the buffer container and the disassembly of the original refrigerator.

A market analysis was conducted simultaneously with the construction of the photovoltaic refrigerators. Factors that were considered included pricing the photovoltaic refrigerators so that it would be attractive to targeted customers, namely the medical sectors in developing countries or sport and camping companies in developed countries. Other aspects included in this economic analysis were production volume, shipping, and assembly.

TIME TABLE

Schedules of the academic year at TU/e and NUS vary greatly (trimester vs. semester), a severe drawback when scheduling such inter-university projects. The initial schedule was planned through a consensus between the staff members from both universities, with preliminary input from students being solicited. During the first videoconference, the schedule was modified subsequent to a discussion between two student teams. To achieve comparable progress for evaluation, a 17-week timetable was eventually compiled (from September 2000 to June 2001) that accomodated the holidays and examination periods at the respective universities. Based on the expected 240 hours per student at TU/e, this corresponded to roughly 14 hours per week.

PHASING OF THE PROJECT

The various phases of the project spanned 17 weeks and included the components of research, coupling, testing, marketing, and ending the project. It should be noted that some of the phases had to be done simultaneously to achieve proper progress. The following paragraphs contain more details about the activities planned for the various phases of the project.

1st Phase (week 1 through week 4) • This phase, which took about one-quarter of the total project time, was divided into two parts: orientation and purchase. Orientation was focused on gathering and processing information on the various elements of the photovoltaic refrigerator. The aim was to gain as much insight as possible regarding its operation and the efficiencies of the individual elements, which were an important consideration in the calculation of the required power of the solar panels.

A lot of self-reading and sales research was carried out in parallel to find a suitable DC compressor (the Stirling cooler was provided by Global Cooling). During this phase, a project plan was devised that required deliverable goals and realistic planning in detail. A financial budget that met the target range of the project served to conclude the first phase. The budget proposed by both teams actually showed virtual expenses. The "virtual" budget consisted of four primary costs: wages, equipment and material, working facilities, and stationery costs. The total virtual budget was around US $14,000. In contrast, the real project budget, excluding the cost for wages and working facilities, came to about US $2,500. The overall expenditures were about 92% of the proposed project budget (NUS team), which is a valuable outcome for executing the project.

2nd Phase (week 5 through week 8) • During the second phase, which spanned the same length of time as the first phase, students started their research relevant to the project. Attention was paid primarily to the design of couplings between the various elements. Couplings between the refrigerator and the DC compressor or Stirling cooler, between the solar panels and the refrigerator, and between the buffer and the refrigerator were investigated. The theoretical design was accomplished in the last two weeks of this phase, while the prototype design was consolidated in the 6th week. At the end of the second phase, students had to produce an interim report with details about the relevant choices and assumptions that they had made, along with a report of their progress and possible adjustments for the remaining project. In addition, students had to present their up-to-date results.

3rd Phase (week 9 through week 17) • The third phase comprised the major milestones of the project over 9 weeks (half of the project time). During this phase, development of a test protocol was initiated. Both student teams used the initial period of this phase to clarify and streamline the measurement standards and criteria for reasonable comparisons between the prototypes. The first round of testing was carried out during weeks 13 and 14, and both teams conducted a second round of testing as well as some extra tests (which differed for each team) during the 15th week. In preparing the final report, each of the team members worked on a different chapter, with the results being compiled by a team editor. At the end of the third phase, students were expected to finalize their project and submit the final report. A final presentation during a videoconference concluded this MDP project.

GRADING

Table 1 shows the assessment scale of the various grading criteria of the project. The grading criteria included (with corresponding weighing factor in parentheses) the final report (3), the final presentation (2), the project plan (2), in-between oral and written presentations (2), and group participation (1). The (sub) grades are on a 1-to-10 scale, rounded off to multiples of 0.5. Evaluation of teamwork effectiveness assessed delegation among group members and organization of the research work. The MDP students also had to give a formal interim presentation on their preliminary results to their respective project tutors at TU/e and NUS. They were asked to focus on the project progress as compared to the original project plan. In addition to the interim and final report, feedback from the client, Global Cooling, also played an important role in evaluating the final deliverables of the individual groups.

TABLE 1
Grading Approach

Assessment	*Scale*	*Supervisor of EUT OR NUS*	*Global Cooling*
Effectiveness of Team Work	1	•	
Project Plan	2	•	•
Interim Report	1	•	•
Interim Presentation	1	•	
Final Report	3	•	•
Final Presentation	2	•	
Total	*10*		

A pilot peer review that included individual and mutual assessment was part of the MDP educational goal at TU/e. It was first exercised on a trial basis halfway through the project. Students were asked to evaluate each other on two aspects: 1) specific (positive) ways a member contributed to teamwork and 2) additional improvement the student should strive for. In addition to discussion, the students compiled a brief confidential report for the supervising staff. This peer review was also exercised at the end of the project to evaluate the progress of individual students in light of the previous suggestions from team members.

A final report (in electronic format) to the client and the tutors at both TU/e and NUS had to be submitted for grading a week before the final videoconference. A final evaluation was then completed by the client and staff members toward the end of the final videoconference. Within one week after grading, students were expected to submit a corrected report that addressed the remarks provided by the staff members at the respective universities and Global Cooling, so that the printed edition could be processed in time.

ROLES OF CLIENT/COACH/ORGANIZER

There are a number of roles played by different people during the project. One role is the "contractor"—the person who has a research question and who is highly interested in the project's outcome. This person is often an expert on the subject. The contractor can co-decide on the quality of the project plan and on the quality of the interim and final reports and presentations.

Another role is the "coach," who follows the progress and process of the project and is the person to whom students can turn with daily questions. He/she can also act (if necessary) as an intermediary between the group and the people from the "outside world." As a coach, this person can stimulate and motivate the group and guide and promote their progress.

A third role is the "organizer." This person works mainly in the background, making sure that facilities such as special training, overall finance, and a place to work, are available.

Interaction between the three participants above and the students was made possible via regular e-mails and ICQ sessions. In addition, there were four videoconferences held during the program that facilitated idea exchange via direct "face-to-face" discussion. The MDP students were also required to give a formal interim presentation on their preliminary results to their respective project tutors at both universities. They were asked to focus on the project progress rather than the original project plan.

The feedback and comments from the client (Global Cooling) were considerations in grading the interim report, the presentation, and the final report. The MDP students used multimedia facilities to record the relevant project materials in electronic form (*e.g.*, CD-ROMS). These materials were mailed or e-mailed to the respective client, coaches, organizers, and partner-group members for their comments. The feedback was subsequently incorporated into the latter part of the MDP project work and report.

COMMUNICATION FORMATS

Since the groups came from different cultures, mutual understanding between them was very important for stimulating constructive working dynamics and for enhancing comparable interpretation of the project. The leaders of both projects communicated at least once a week to monitor the groups' progress and to ensure achievement of the short-term goals. In addition, frequent communication between the several subgroups at both universities took place via e-mail and ICQ sessions (real-time "chat" communication over the internet). Four videoconferences were scheduled to obtain mutual understanding and to enhance cohesive execution of the research project. Furthermore, there was communication between the academic staff members at both universities to resolve questions that arose and on administrative matters such as scheduling and the agenda of the videoconference.

Meeting minutes included actions taken, results obtained, and decisions made and were mailed to the other teams and coaches in order to achieve the desired synchronization. Each TU/e student had a notebook computer, and the group as a whole had its own MDP room with network connections. In addition, they had a group e-mail account and a separate website for communication purposes. Additionally, the students frequently used ICQ accounts for exchanging ideas and making decisions with the counter group abroad. The MDP groups at TU/e had a weekly meeting in which the academic staff members were present.

The NUS group members were given laboratory space in the engineering workshop that was equipped with networked personal computers and the necessary facilities for regular meetings. Individual group members took turns organizing the meetings to discuss the project's progress.

EXPERIMENTAL RESULTS

Individual prototypes built with a Stirling cooler and a DC compressor were accomplished at the end of the project. Both teams performed comprehensive and identical tests, comparing the efficiency of the systems. Daylight cycles were characterized and calibrated in both countries to ensure that the testing environments were comparable. Due to different voltage requirements by the Stirling cooler and the DC compressor, the exact daylight cycle and various parameters of the DC compressor, such as suction pressure, input voltage, and current, were investigated before the final tests. Initial experiments were conducted with varying buffer amounts and container types to obtain an estimate of the heat leakage rate from the refrigerator.

Water was chosen as the buffer material, due mainly to its availability and well-known properties. Using energy conservation laws, an estimate of the buffer amount was obtained after considering the heat transfer (enhanced by fins) between the buffer surroundings inside the refrigerator and the buffer itself. Due to the different power-supply levels, designing the buffer container and the fins was different for both groups. While certain additional adjustments were made by both teams before the final performance tests of the refrigerators coupled with solar energy, a mutually agreed test protocol was established to assess the efficiency of the individual designs.

To examine the efficiency of the refrigerators, three major stages were evaluated as a function of time needed: the start-up stage, the temperature-maintenance stage, and the cool-down stage. The test results successfully met the requirements posed by Global Cooling. Table 2 shows one of the tests for both refrigerators. In general, the Stirling-cooler system showed a higher efficiency and demonstrated more steady temperature profiles, shorter start-up time, and longer "keep-cool" time. In contrast, the DC-compressor system gave faster cool-down, with favorable temperature profiles.

TABLE 2
Test Results of Refrigerator Performance
(Courtesy contribution by both MDP groups)

	Stirling Cooler	*DC Compressor*
Start-up Time (hrs)	152	177
Cool-down Time (hrs)	12	5.8
Keep-cool Time (hrs)	47	31.6
Start-up COP (-)	1.32	0.97
Cool-down COP (-)	0.88	0.56
Heat Leak (W)	16.6	11.8

EVALUATION

Part of the project evaluation was devoted to illustrating how the project objectives were achieved.

Team Work • Overall, the multidisciplinary project exposed students to a research project in a practical way. Although the initial period of team formation was fraught with difficulties in work allocation and coordination, the members learned to work with one another and coordinate advanced planning, establishing infrastructure, decision making, critical thinking, self-evaluation, corresponding improvement, dealing with conflicts, and overcoming differences.

Applying Technical Knowledge • The various tasks enabled students to apply learned knowledge and to acquire new knowledge. For example, foundation training may suffice to test the solar panels, but in-depth studies were required to resolve more complex problems such as the proposed power conditioning unit. Students also found that theories given in class don't always agree with real life, so they developed creative approaches and independent thinking to properly interpret data for situations beyond their academic expertise.

Resolving Practical Problems • Students experienced several practical problems, such as how to best design the buffer container for the refrigerator powered by a compressor. Such first-hand experience in problem solving is not offered by current academic courses.

Developing and Applying Communication Skills • The students learned to refine their communication skills to efficiently pin-point useful resources, clearly convey problems, and effectively communicate with others. The videoconferencing presentations reinforced students' technical communication skills, and they found it a challenging way to interact with overseas counterparts.

CONCLUSIONS

This project contained the uniqueness of multidisciplinary, international, and industrial collaboration. Students were particularly challenged to apply fundamental knowledge, use their creativity, and interpret results. Furthermore, they experienced the importance of communication skills and learned the importance of a constructive attitude.

Coordination of such a project is complicated and requires a lot of effort. It provides, however, a unique learning opportunity in working with peers, with different knowledge backgrounds and different cultural backgrounds.

The impact of different backgrounds was underestimated. It was late in the project that these differences were identified, because they resulted in misunderstandings. Solving these misunderstandings by intensive communication brought both groups much closer and greatly improved cooperation.

The importance of video conferencing for decision making was overestimated, whereas the usefulness of chat sessions was underestimated. Chatting was preferred by the students in spite of local time differences. Direct communication proved essential for mutual understanding and agreement on important points.

Different academic calendars at the two universities made it difficult to plan the project, but spreading it over the entire academic year proved essential because of its practical and experimental aspects (*i.e.,* material delivery times, construction of and debugging the prototype, testing experiments).

The students were enthusiastic about the multicultural communication aspect and the opportunity for experimental design and consequently spent 70% more time on the project than originally intended.

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