Chapter 15
A Solar Car-Based Learning Community

15.1 Introduction

Most of the ideas in this chapter are originally from Thacher and Compeau (1999). That material is copyrighted by Roskilde University Press and is used with permission. I gratefully acknowledge the contributions of Dr. Larry Compeau, my collaborator for several years, and co-advisor of Clarkson University's Solar Car Team.

Chapter 1 asserted that acquiring the art of solving ill-posed problems should be the primary objective of education. This chapter explores four questions raised by that assertion. What should be the means for acquiring the problem-solving art? What knowledge and skills facilitate problem solving? What should be the general structure of a curriculum designed to teach ill-posed problem solving? Into what form might an institution evolve when it centers itself on teaching problem solving?

15.2 Acquiring the Art

The PBLC The ill-posed problem-solving art includes the art of collaboration. Hence, it must be learned in a collaborative setting. Formal collaborative associations, teams, are not necessarily the easiest or most efficient means of solving a problem. But ill-posed problems are often complex enough so that collaboration is the only practical alternative. On the other hand, the concept of a lone creator generating a solution in isolation is probably a myth. Collaboration, that is, idea exchange and complementary work, even if carried on only through the technical literature and between persons unknown to each other and separated by space or time, is part of the solution of every ill-posed problem.

A team of students and mentors working on a project constitutes a project-based learning community (PBLC). PBLCs have the defining characteristics given below.

1. Collaboration must not be artificial, but driven by the demands of the problem to be solved. A PBLC should therefore be centered on a project that is multidisciplinary, thus requiring collaboration between students and faculty from different

E. F. Thacher, *A Solar Car Primer,* DOI 10.1007/978-3-319-17494-5_15

academic departments. It should be functionally demanding so that all of the students are challenged in their complementary work.

2. A PBLC is not necessarily destroyed and created as semesters come and go. Its schedule is shaped by the requirements of its project, and not by the regular academic year schedule.
3. Students of all grade levels, freshman through graduate, may participate.
4. The project goal, not grades, provides the motivation.
5. The project forces engineering and business cooperation with industry and other professionals outside of the school.
6. Students in the PBLC have real responsibility and authority, and the possibility of success or the risk of failure that accompanies them.
7. Learning takes place primarily through mentored experience. The mentoring may come from faculty, from other professionals on- or off-campus, and from students in the PBLC.

Solar car-based PBLCs have all of the preceding characteristics. They operate continually. Developing and racing a solar car includes *many* technical and business issues, as the reader has seen. Beyond this, the relatively small amount of energy available drives the PBLC to seek the lowest weight, most efficient racing system. However, the possibility of failure, the safety requirements, the concurrent demands of the academic schedule, and the need to sell the project in order to acquire resources, provide constraints. These conflicts force trade-offs and tend to balance the project on the sharp edge of reality. Students must mature and grasp the requirements of professional work.

Motivation The characteristics of a PBLC motivate students to accomplish tasks that would be impossible in ordinary courses. This motivational engine is the PBLC's principal advantage. It unlocks the door to professional-level experience. This high-level experience, properly mentored, can produce graduates who are actual entry-level professionals, that is, junior engineers, not proto engineers.

Knowledge originally comes from the need to solve problems: it is created out of necessity or curiosity. After the problems are solved, the knowledge of them is written in books for students to study. In a PBLC, the need for solutions is reunited with learning and, therefore, tends to motivate study.

Integration Large multidisciplinary projects, such as a solar car, force students to apply integrated knowledge. For example, the design and manufacture of a solar cell array on a car is a balance of electrical, mechanical, and aerodynamic requirements. Students are often required to learn beyond their specialty. An engineering major may have to work with marketing majors to develop and present proposals to prospective sponsors, or to speak about the project to the local Rotary Club. Also, skills and knowledge already acquired, but untapped by conventional courses, are often utilized. The SCP makes use of machining and welding expertise, and radio communications experience. This characteristic gives students avenues for making contributions which are valued, even if not academic.

Business A PBLC is essentially a small business, embedded in an academic institution. It is product driven. The profit it returns to its members is experience, which cannot be conventionally measured. Its costs are direct, and financing them is part of the experience the PBLC supplies. The monetary benefits to the school are indirect, but real.

A PBLC may require office space, computers, service vehicles, manufacturing facilities, extensive travel, and insurance. If it is properly operated, a PBLC will continually seek to improve its plant and equipment to provide an ever-higher level of experience. There is no apparent reason why a PBLC should not rise to operate at the highest professional level, with state-of-the-art equipment. The institution must provide a supporting framework in the form of administration and design space, manufacturing facilities, schedule and organizational innovation, and flexibility. When a particular community's members realize that the potential of their PBLC is really in their hands, this will further fuel the motivational engine. So, most of the cost of its operation and growth should be born by the PBLC itself.

Mentoring The relationship between students and faculty in a PBLC tends toward that between senior and junior colleagues. This has proven much more fruitful than the somewhat adversarial relationship characteristic of conventional courses.

If asked to define teaching, many would consider it to be imparting knowledge. Further, they might describe it as taking place in a classroom and from a specially-trained teacher. However, following the definition of "education" adopted herein, teaching may be pragmatically defined as any activity that facilitates the acquisition of the art of the application of knowledge by the students in the PBLC. A mentor's intent must be to create an environment in which such activities may go on.

Mentors must be willing, and able, to relinquish some real authority to the students—and sometimes to allow them to fail, or nearly fail—while still maintaining overall control so that one can maintain safety, solvency, legality, and continue to progress. This is difficult and requires seasoning. It requires irregular working hours because to keep fully informed and to gain the trust of the students one must, to a certain extent, be present when they are working.

Faculty are used to being consulted and to pontificate. But to be an effective mentor, one must know when and how to speak, and when to keep silent. This is not always easily learned. One must always keep in mind that discovery is the best method of learning; what a student discovers is her own and has a vivid relevance. A remark by motion picture producer-director Steven Spielberg succinctly defines the art of mentoring (Corliss and Ressner 1997): "The delicate balance of mentoring someone is not creating them in your own image, but giving them the opportunity to create themselves."

Although one may have a Ph.D., one may still not be well trained in all areas of a large, multidisciplinary project. One must be willing to endure the loss of student-perceived omniscience to show them how research proceeds from the known into the unknown. Not every student is mature enough to retain her respect for the mentor when the perception of omniscience is lost. Respect must sometimes be built, or rebuilt, on shared accomplishment, rather than credentials.

Portfolio A portfolio provides a way of recording and giving structure to the experiential learning of the PBLC. It can help to create a symbiosis between the PBLC and the laboratories and classroom courses that relate to it, provide the basis for the mentoring staff to certify the experience credits of the students, establish cross-training requirements between the disciplines of a PBLC's project, and provide the requirements for training peculiar to the PBLC, such as solar race-team training. Portfolio also provides a place to record special qualifications and reward excellent work, say by inserting letters of commendation.

An element of the symbiosis, mentioned above, is to have portions of the portfolio incorporated as assignments in relevant courses and laboratories. Selling this idea to the relevant departments is a job for the mentoring staff.

The Solar Car Project (SCP) portfolio might have three elements: satisfactory written answers to a set of questions, passing oral examinations on the solar car's systems, and satisfactory performance of a set of operations. These three elements would be divided into basic and specialized levels of knowledge. Each student in the PBLC would complete both the basic portion of the portfolio and the specialization section appropriate to her position in the team. She could also be allowed to complete as many other specialization sections according to her ability.

The questions, oral examinations, and operational qualification requirements might be focused on topics or areas such as vehicle dynamics, body system, suspension and steering, wheels and brakes, power system, instrumentation, energy-management system, race operations, marketing and public relations, and project administration. A few sample questions, oral examinations, and operational qualifications follow. These are intended to suggest the level and scope of the material that should be considered.

15.2.1 Vehicle Dynamics

Basic Explain the origin and characteristics of each force acting on a solar car in the cruise condition, and how these forces are influenced by the characteristics and speed of the car.

Mechanical Specialist Using a mathematical model, predict the energy required by a solar car to traverse mixed (hilly and flat) terrain at different average speeds.

15.2.2 Power System

Basic How do solar cells convert solar energy into electric energy?

Electrical Specialist Design, construct, and test a small solar cell array to supply a direct current (DC) load. Compare its actual and predicted performance. Explain any differences.

15.2.3 Marketing and Public Relations

Basic Write an essay describing an event that required you to speak to the public about the SCP.

Business Specialist Develop and deliver a presentation to solicit a corporate partnership. Include visual, audio, and scripted elements. Present in a convincing and professional manner.

15.2.4 Project Administration

Basic Construct an organization chart of the SCP. Fill in the names, telephone numbers, and e-mail addresses of each manager and mentor. Show your position on the chart.

Mechanical or Electrical Specialist Participate in the development of a plan, a set of milestones, and a budget for the design, construction, and test of your portion of the car.

15.2.5 Examinations

Oral Each oral exam would be conducted at the car and consist of both theoretical and operational questions. The questions would be keyed to the section of the portfolio the student desired to complete. For example, a basic question from the wheels and brakes area would be to explain how the brakes work while pointing to and naming each component. The examiner (a qualified SCP member) would be free to take the examinee as far as she could go in the subject area.

Skill The operational skills demonstration would also be keyed to a subject area. For example, as part of the power system basic subject area, the student could be asked to demonstrate how to set up the solar array for charging (other team members would of course be needed here). Or, the student could be asked to show how to turn on and shut off the car, operating each switch in its proper sequence. Students specializing as race-team drivers would demonstrate race-qualification maneuvers, highway operation (highway convoy procedures, passing), urban operation, blowout procedure, and minimum energy operation.

15.3 Attainments that Promote Problem Solving

Listed below are the knowledge, characteristics, and skills that graduates should have in order to effectively participate in the solution of ill-posed problems.[1] Comments are included that support or amplify each item, especially as it relates to experiential learning in mentored learning communities.

1. Competence in employing the "design process."

The term "design process" refers to the process used to work through the solution of an ill-posed problem. This is the heart of problem-solving art. The parts of this process were illustrated by the house-building example in Chap. 1. The process cannot be effectively taught academically, that is, in the abstract. A student may study a book about design, receive an "A" on a test covering the book, but be unable to solve an actual ill-posed problem. The process must be taught by an experienced mentor.

The design process should be the unifying theme in education because it is the process used by all the persons who solve ill-posed problems, and because real problems are ill-posed. Then what would differentiate one student's educational path from the other would be the kind of problem being solved, its context, or the form the solution must take. An author produces a book; an engineer produces a machine; an artist produces a quilt.

If this unifying theme were woven through all education, it would revolutionize its results: Students would become creatively mature much earlier, and in larger numbers, because they would understand and utilize the design process routinely. Such is not the case now, of course; there is no such unifying theme. In grade school and high school, students take an eclectic set of courses in separate subject areas. In college, students enter "disciplines." These disciplines, such as mechanical engineering, are rubrics for sets of related specialty areas in which the faculty are studying, such as heat transfer or chemistry. But even though the specialty areas are related, there is generally no unifying theme.

Furthermore, well-posed problems, like the distance–time example described in Chap. 1, are pervasive in our technical-education system. Students are quite accustomed to, and expect, them. Thus, when students are given an ill-posed problem to solve for the first time, the problem's lack of definition is disconcerting. What should be done first? Where are the formulas? What specific result is required? What information should be used? It is as if an implied contract between the students and the educational process had been violated. Their task had always been: To study analytical techniques and facts, do well-posed homework problems, and then take well-posed tests. This was the definition of "learning," to them and to their teachers.

This culture must be changed to one that embodies Whitehead's idea. Examples from the other creative arts[2] confront engineering educators. A composer does not

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[1] Based partly on a list in Redish (1988).

[2] Yes, engineering is *quintessentially* a creative art. Can anyone who has seen a well-executed solar car doubt this? Before you is a concrete expression of an ideal: transportation with minimum

simply study music theory, he composes. Painters and sculptors do not just study abstract techniques, they create objects of art. Who would think of awarding a music degree to a trumpet player who had neither performed a solo nor played in a band? In other professions, a heavy emphasis is placed on professional-level experience under tutelage.

2. An integrated understanding of mathematics, science and the engineering sciences, and applied disciplines built upon them.

"Integrated" means that the student should grasp the connections between these subjects, not just view them as disconnected specialties. A very effective way of forcing the integration of knowledge is to give students multidisciplinary problems to solve; the knowledge is integrated in its application, which is the natural state of things.

3. A strongly-developed physical intuition and an ability to apply a variety of insights to evaluate the plausibility of a proposed solution.

The design process is a decision-making process, whatever the problem to which it is applied. The basis of a decision can often be physical intuition, which brings insight. This is more effective than constructing an elaborated computer model for certain decisions, particularly in early phases of the design process when alternative concepts are being generated and selected. Competency in the application of intuition and insight is developed over time by mentored experience.

4. Competence in transforming a physical system into a mathematical model and in extracting meaning from that model by numeric or analytic solutions, approximation, or estimation.

Model-making is an important design-process tool. Students often can be quite expert at getting answers when the model has been constructed. Teachers tell them "Given that…" and "Assume that…" but this does not exercise them in the most important skills: To make the model and to understand the limits of the model and the errors it introduces. When students are given a physical object to model they are often quite reluctant to make modeling assumptions.

Partly because of this reluctance, there is a tendency to jump directly to sophisticated computer packages, and then to accept their results uncritically. Skepticism should be taught; naiveté in the design process leads to errors. Make a simple model first and find out which football field, or which part of the field, the solution is in, and to provide a check on the sophisticated model. Also, in the design process, time–money is often important. If a decision can be made with a calculation on the back of an envelope, it should be that The philosophy of modeling should be taught.

Confidence and skill in modeling comes with modeling experience, especially experience in which the predictions of the model can be compared to the actions of the object modeled. Mentored project experience creates many opportunities to teach and to learn modeling skills and philosophy.

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waste. Thus it's beauty derives from the intelligence it expresses and because it is a realization of how our hearts know things should be, but are not.

5. Clear communication in written, oral, or graphical form.

Communication on a project team requires effort; it is not the casual conversation on familiar subjects or the quick exchange of greetings to which people are accustomed. It means discussing design choices, writing technical specifications, reporting calculations, keeping clear and complete records, and finally making drawings of the design that contain the information necessary to build it. This kind of communication was illustrated in the house-building example of Chap. 1.

This more intense, detailed, and focused communication is often difficult for students to achieve at first. It needs to be taught and practiced. Mentored experience, again, is requisite.

6. Competence in collaboration with professionals of differing backgrounds.

This characteristic cannot really be separated from characteristic 5, communication: The essence of collaboration is communication. However, there are other issues bearing on collaboration, or teamwork, that arise when training students to work in teams.

Students are not accustomed to working in teams. They have different academic schedules and thus different overall objectives and priorities, are accustomed to working at their own pace, and have widely varying levels of knowledge and maturity. Consequently, the work load is often nonuniformly distributed over the team, consistent attendance at meetings is difficult to achieve, and assignments made by the team to its members are often not completed when required.

Overcoming these obstacles and learning teamwork is a maturing process requiring time and consistent mentoring. The time required to thoroughly learn these skills is probably much longer than one semester. Joining a learning community as a first-year student would provide four years to learn the skills.

7. An understanding of the effects of a proposed action on the social, economic, man-made, and natural environments.

The interactions of the device being designed with the social, economic, man-made, and natural environments enters forcefully and specifically into the design process. It is these interactions that shape the design. As Chap. 8 illustrates, the entrance begins with the design specification where weight, cost, appearance, and other characteristics that constrain the design are listed. The limits of these are quantified, otherwise there is no ruler against which the design can be measured. The quantification is developed by benchmarking against other products, market studies, researching environmental regulations, experimental results, etc.

More generally, it is important for professionals not to be simply producers of technology for sale. The work they do affects, in some way, the life on this planet. So they must be aware of the social, economic, and environmental context of their work also from a philosophical perspective. Life is an ill-posed problem; humanity is the ultimate design team. What are the guides we have to solve this problem?

8. Knowledge of the range and history of ideas.

An engineer, or other professional, should know what ideas have been proposed and explored in both the narrow "literature search" sense and also in the broad cross-disciplinary and historical senses. What is the history of the effects of the genre of the technology that engages him? What is its relation to other areas of thought? It seems almost dangerous for an individual's intellect to be only narrowly informed. Would such an individual be too easily manipulated to be trusted with higher responsibilities?

9. Ethical professional behavior.

Struggling to solve a real complex problem in close collaboration with others of differing views tends to remove any abstract, academic sense about ethics. It replaces this sense with direct experience of their relevance to the problem at hand. There is an ethics of collaboration. It is difficult to collaborate with someone, one does not trust.

Ethical issues play an important role, sometimes in the design process, and frequently in engineering practice, as the Challenger disaster and other cases show. Profitability can be a false guide in the engineering business, but it is not easy to recognize when this is so. Experience in actual work, but with mentors present to point out ethical issues when they arise, strengthens the student's ability to navigate ethically in professional life.

10. A philosophy of continuous intellectual growth.

New ideas are constantly being uncovered. Some computer equipment retailers say that about every two months much of what they have for sale becomes obsolete. Global competition forces companies to be flexible. Consequently, they look for employees who are flexible, and can move from project-to-project with a minimum of retraining. The employee must adopt a policy of continuous learning to avoid obsolescence.

Ideally, experience in a PBLC forces students to recognize that they are responsible for their own learning; that in professional life it will not be prepackaged and handed to them. A properly-selected, posed, and mentored problem should force the members of the PBLC to study beyond their current academic training. However, not all students are mature enough to appreciate the opportunity to acquire this element of professionalism. Weaning these individuals from their dependency is one of the important activities of the mentor.

Beyond this, intellectual growth is necessary to life, to a sense of progress and unfoldment. In the long run, perhaps this is its strongest justification.

15.4 Curriculum Structure

PBLC Core Learning ill-posed problem solving is the primary goal of a curriculum, the project work (the application of knowledge to ill-posed problems) in the curriculum, rather than the accumulation of knowledge, becomes the most important part. It becomes the trunk of the tree, instead of just one of the branches because that is where the “art of the utilization of knowledge” is acquired. This experience would be provided by the integration of a set of PBLCs into the curriculum. The combination of the PBLCs, which emphasize mentored, but professional-level, design process experience, and the traditional courses, which emphasize knowledge, will the meet the educational objective. Both components would be present and support each other as an integrated system. Learning the art of the application of knowledge cannot be separated from learning the knowledge. The roots, branches, and trunk of the tree are one; they are related symbiotically.

Organization No organizational feature or rule should compromise the defining features of the PBLCs. Such compromise will limit or destroy the motivational engine. This engine is indispensable.

A line and task organization is required. The task groups are the PBLCs; the line organizations are the regular academic departments and schools. Each PBLC would be continuously supported by several academic departments, depending on the technical, social, and economic demands of the project. The support would have two levels: “embedded” and “ancillary.” Embedded support from a department means the department would supply a teacher to the PBLC, academic support to its portfolio, and a basic level of financial support. Ancillary support means the department would only give academic support to the PBLC’s portfolio. For example, the SCP would be embedded in the (local equivalents of the) Mechanical Engineering, Electrical Engineering, and Marketing departments. The Physics, Mathematics, Civil Engineering and Chemical Engineering departments would furnish ancillary support.

“Academic support” means that the essays and projects in the PBLC’s portfolio would be integrated into the courses taught by the department in some combination of the following points: by direct assignment; by instruction in the subject areas supporting the portfolio; by consulting with individual students.

Each PBLC would have its own budget. Each school would support the PBLCs via the embedded departments’ budgets. This would be a floor, seed money, and not intended to meet the entire expense of the PBLC; the PBLC must make industrial, and other outside contacts and raise support.

Let us call the PBLCs, the departments supporting them, and the facilities assigned to them the Experiential Learning Project (ELP). Some representative body, a Deans’ Council perhaps, should have general oversight of the ELP and help to guide its growth. The objective would be to promote the evolution of the ELP into a “super-learning community,” explained below. The presence of all the Deans would be necessary because of the integrated nature of the ELP.

Staff The staff of a PBLC should include faculty mentors from the embedded departments. It may also include advisors from other organizational units from inside, or from outside, the school. The more genuine connections the PBLC makes to the expertise present in the University and external communities, the more effective it will be in accomplishing its objective

The PBLC faculty mentors, with the student managers, set up the portfolio requirements for the PBLC, specific to the PBLC but based on the general rules herein, set standards and certify their attainment, insure safety, the proper management of funds, and establish a framework so that the product of the PBLC is properly designed, manufactured, marketed, and operated.

Mentors would be assigned to the project by their departments as part of the teachers' regular course load, and not a voluntary add-on. By agreement between the embedded departments, one teacher would be designated as in charge of the PBLC. When the schedule of a PBLC requires summer work, faculty would be compensated for summer time spent on the project.

A successful PBLC requires continuity of faculty presence and effort. Therefore, faculty assignments should last at least for two periods over which a PBLC goes through a characteristic cycle, such as the 2-year race cycle of the SCP. Departments would be required to insure that replacement faculty are trained, and not just simply rotated in with no preparation. If the success of the ELP depends upon the continued presence and energy of particular persons, the ELP will eventually fail. A goal of the Deans' Council should be to continually broaden the faculty base of ELP. Mentor training and rotation will help to do this.

Registration and Credit Students of any grade level could register for the PBLC as a course. Ideally, each PBLC should constitute a single course, not segmented by grade level. These might be called "Multi-disciplinary Project" courses, or MP courses. The enrollment should be limited to keep the PBLC to a practical size. Students not registered may earn credits if they execute independent study topics based on their PBLC work while volunteering, or use part of their PBLC work for a conventional, department-centered, or design course (PBLCs will exist side-by-side with conventional design courses at first). Graduate projects can sometimes be based on PBLC work.

15.5 Evolution of the School

Industrial and governmental "in kind" donations include, in effect, training for the learning community members. For example, Clarkson University's SCP members obtained a donation of wind-tunnel time at the Advanced Aerodynamic Laboratory in Ottawa and tested a quarter-scale model of their car there (Chap. 12). The wind tunnel engineers trained the team members. Team members have also helped high school students with solar car projects and made presentations at high schools and grade schools on the SCP. Building up such outside contacts and alliances incorporates them into the school. The "campus" becomes enlarged and decentralized. The school plus the outside organizations becomes a *super-learning community* linked by project-team visits and modern communications: electronic mail and perhaps video conferencing and groupware.

At the core of the super-learning community, would be the project teams both continuing and noncontinuing. The continuing PBLCs would be engineering competition teams or teams doing nationally-recognized work, such as designing and flying space shuttle payloads. Projects of this magnitude tend to attract sponsor support and are multifaceted enough to keep many students involved. So the actual number of continuing, core projects, would not be large. There would be a mechanism for establishing new projects, which projects would not necessarily be continuing.

Each evolutionary step should be managed such that the ELP always builds on the foundation of ideas that work, and that preserve the amazing driving engine of the PBLC: The thirst of the students for real experience. The evolution will probably never quite reach an end; the school must always be considering the next step of improvement of community building.

The connections made between academic departments by the necessity to support multidisciplinary projects at levels commensurating with national competitions will tend to unify the campus around this curriculum. The boundaries between departments will fade as the campus reorganizes to support multidisciplinary projects, rather than disciplines.

At first, this evolution may be most developed among the professional schools of Engineering and Business.

15.6 Educational Outcome

Business and engineering undergraduates would leave the school as junior professionals with a certain level of knowledge certified by course grades and a certain level of project experience certified by an approved PBLC portfolio.

As the super-learning community develops, the boundary between the world of its industrial and governmental members and the world of the school will blur. Companies will find the school's graduates require far less in-house training before becoming contributing professionals. Graduates will find the transition from mentored experience at the school to professional experience in industry to be an extension or continuation, rather than a discontinuous jump.

Note that the benefit of the ELP is not primarily the raising of grades, although that it will probably take place because of the motivation for study supplied by the PBLC. The primary benefit will be to supply an element that may be mostly missing in the school's curriculum: training and experience in the solution of multidisciplinary, ill-posed problems at a professional, or near-professional level.

References

Corliss, R., & Ressner, J. (1997). Peter Pan grows up. *Time*, May 19, 1997, p. 75.

Redish, E. F. (1988). From here to the future: The impact of the computer on college physics teaching. *Academic Computing,* 18.

Thacher, E. F., & Compeau, L. D. (1999). *Project-based learning communities at Clarkson University, in project studies—a late modern university reform?* (pp. 194–207). Denmark: Roskilde University Press.