A Systems Approach for Developing Technological Literacy

Moti Frank

In order to examine the implications of applying a teaching strategy that integrates a systems approach and project-based learning (PBL), it was implemented in two courses. The objective of the first course was to train pre-service teachers to teach the subject of "science and technology for all." The second course was an introductory freshman course in the Faculty of Mechanical Engineering. This paper describes a qualitative study that followed the progress of the two classes. The students in the courses were the participants in the study.

In order to prepare pre-service teachers to teach the subject of "Science and Technology to All" (mandatory subject in all of Israel's junior high schools), a mandatory methods course has been developed in the Department of Education in Technology and Science at the Technion – Israel Institute of Technology: "Methods for Teaching Science and Technology for All". The course participants were pre-service teachers who were studying toward a teaching certificate in the Department of Education in Science and Technology parallel to their studies for a B.Sc. degree in one of the Technion's science Faculties. Most students in this course lack basic knowledge in engineering and technology. The course lasts fourteen weeks (one semester). Every once-weekly class meeting includes a one-hour lecture, two hours of microteaching, and three hours in a lab (team project). The challenge for the course instructors was two-fold. First, students had to be given content knowledge. That is, they had to be taught technological subjects as they appeared in the national curriculum of the junior high school science and technology course. Second, students needed to acquire pedagogical content knowledge so that they could teach the subject content in the future.

The idea underlying the second course was to achieve certain objectives through experiential learning. These were to provide students with a clear overview of the different fields in mechanical engineering; to introduce them to the essence of engineering work and the processes of design and development of new technological products; to raise their awareness of the importance and necessity of analysis for finding optimal solutions for engineering problems, and

---

Moti Frank (frankm@tx.technion.ac.il) is Senior Lecturer in the Department of Education in Technology and Science, Technion – Israel Institute of Technology, Haifa, and in the Department of Technology Management, Holon Academic Institute of Technology, Holon, Israel.

to acquaint freshmen with the Faculty of Mechanical Engineering and familiarize them with the different aspects of mechanical engineering expertise (Elata & Garaway, 2002).

In both courses it was obvious from the start that the objectives could not be met in a 14-week semester if they were taught in the traditional way. Therefore, it was decided to try to implement a systems approach in a project-based learning environment (PBL). The concept of teaching/learning via a project is not new. The innovation here is the integration of PBL and the systems approach, and the implementation of this combination in courses that up until today had been taught in traditional ways. This was an attempt to exploit this integrated approach to teach technology through a top-down process, without explaining the details to students lacking a technological background. This paper presents what was learned during implementation of this approach in these two courses, as well as thoughts on future implications.

The Systems Approach in Technology Education

The traditional approach in engineering or technology teaching is bottom-up, i.e. from component to system. For example, the order of the courses in a typical communications engineering program is: mathematics (calculus, etc.), science (physics, etc.), electricity basics, components, linear circuits, modules, basics of transmission and receiving, subsystems, and communications systems. In most traditional curricula, both in high school and undergraduate programs, the stage of dealing with a complete system is sometimes not fully addressed by the curriculum.

The larger, more complex, more dynamic and more interdisciplinary the specifications for a technological systems get, the harder it is for a lone engineer, as skilled as he or she may be, to design a complete system. Given this, students and their teachers, who are not required to be proficient in engineering, but who should be technologically literate, should not be expected to know so much as trained engineers as they go about manipulating entire technological systems.

Based on the systems thinking approach, what follows is a proposal for a way to teach technology and instill technological literacy without first teaching the details (for instance, electricity basics and linear circuits for electronics, or calculus and dynamics basics for mechanical engineering).

The central idea in this premise is that complete systems can be handled, conceptually and functionally, without needing to know their details. According to this approach, when trying to develop technological literacy in students who are not required to be proficient in engineering, the favored teaching strategy is top-down. In other words, the focus must be on the characteristics and functionality of whole systems and the interdependences of the subsystems.

The Main Benefits of the Project-Based Learning Approach

In PBL, learning comes through a process in the framework of which students, working in teams, build a product. The product may be something tangible (such as a model/prototype, a system or a robot), a computerized product (such as software, a presentation, or a multimedia product), or a written product (such as a report, an evaluation summary or a summary of experimental findings). The product must answer a question, solve a problem, and meet requirements or needs set by the course instructor or identified by students. In the courses described herein, students were assigned to build a tangible product. Some examples include a car driven by solar energy, a remote cardiologic testing system, an automated watering system, a hot air balloon system, an automated purification system for aquarium water, a bridge of straws, and a tea cart.

According to Krajcik, Czerniak and Berger (1999), and Buck (1999), students in PBL are engaged in active learning and gain multidisciplinary knowledge while working in a real-world context. The importance of student engagement is widely accepted and numerous researchers have provided considerable evidence to support the effectiveness of student engagement on a broad range of learning outcomes (Prince, 2004; Hake, 1998; Redish, Saul, and Steinberg, 1997; Laws, Sokoloff, & Thornton, 1999). Bonwell and Eison (1991) summarized the literature on active learning and concluded that it leads to better student attitudes and improvements in students' thinking and writing. According to Hill and Smith (1998), the project-based courses in technology education use design processes. Since design does not happen by default, a design process must become part of the course curriculum and students must be guided through the process.

Green (1998) noted that project learning increases motivation to study and helps students to develop long-term learning skills. Students know that they are full partners in this learning environment and share the responsibility for the learning process. Green also stated that this approach helps to develop a long-term learning ability. Krajcik et al. (1999) suggested the following three benefits for the student: first, learners develop deep, integrated understanding of content and process; second, this approach promotes responsibility and independent learning; and third, this approach actively engages students in various types of tasks, thereby meeting the learning needs of many different students (see also Hill & Smith, 1998). Krajcik et al. (1999) indicated that PBL offers multiple ways for students to participate and demonstrate their knowledge that can be matched to the various learning styles of students. In some studies, a positive correlation was found between self-esteem and success and receiving a positive assessment (Battle, 1991). Hill and Smith (1998) also found that the PBL environment in their courses increased students' self-confidence, motivation to learn, creative abilities, and self-esteem.

In research described by Shepherd (1998), it was found that grades for the Critical Thinking Test received by students who had learned in a PBL environment were significantly higher than those of students in a comparative group, who had studied in the traditional fashion. The PBL students also demonstrated greater self-confidence and an improved learning ability. Norman and Schmidt (2000) pointed out that having students work in small teams has a positive effect on academic achievement. In a review of 90 years of research, Johnson, Johnson, and Smith (1998) found that, across the board, cooperation improved learning outcomes relative to individual work, including academic achievement, quality of interpersonal interactions, self-esteem, perceptions of greater social support, harmony among students. Team work is a central characteristic of PBL. In most cases, group decisions, expressing the various perspectives of a team's members, are better than individual decisions (Parker, 1990). One benefit of PBL is that students learn to work together to solve problems. Collaboration involves sharing ideas to find resolutions to questions. In order to succeed in the real world, students need to know how to work with people from different backgrounds (Krajcik, Czerniak & Berger, 1999).

The Principal Challenges in PBL

The following elaborates the challenges facing instructors wishing to integrate PBL into their teaching. First, team work requires interpersonal skills such as communication skills, negotiation skills, and an ability to cope with conflicts (Hertz-Lazarowitz, 1990). The second challenge relates to the large amount of time that the teacher invests to implement PBL. Another challenge is the need to cope with new course content in a learning environment that is neither structured nor organized in advance. Thus we see that teaching by means of PBL presents several challenges. These include students' lack of experience in this new approach and their preference for a traditionally-structured approach; their preference for a learning environment that requires less effort on their part; and problems arising from time pressures. Students struggling with ambiguity, complexity, and unpredictability are liable to become frustrated in an environment of uncertainty, where they have no notion of how to begin or in which manner to proceed. The PBL method is rather time-consuming and requires the teacher to invest a lot of effort over an extended period of time. Class management, in which the students have the freedom to talk together, is often more difficult. Teachers regularly feel a need to direct lessons to ensure that students get the "right" information. Teachers frequently give students too much independence without structuring the situation, or providing feedback (Krajcik et al. 1999, pp. 322-328; Buck Institute of Education, 1999, Potential Problems section).

Method

In the two courses included in this study, students were required to design and build a physical model of a technological product/artifact/system based on scientific, technological, social and environmental principles. To emphasize technological and not merely scientific literacy, the unique feature of the projects was their starting point—technological requirements and needs rather than a research question as in project-based science. Students first defined what would be required of the system. They investigated alternatives for implementation, collected and analyzed data through a process of investigation and collaboration, and then conducted a trade-off study. Having done all this they designed the system, using a top-down approach.

The teaching staff of both courses directed students to choose subjects for their projects such that their process of working would serve the courses' objectives. The emphasis was on developing technological literacy in accordance with the course goals. During the courses, students' progress was continually observed and supervised by the teaching staff. Periodically students were required to submit a report about implementation versus design and a plan for further work and/or technical reports. At the end of the project students had to present their work to the teaching staff and their classmates, as well as submit summary group and individual reports.

The objective of the study that followed the progress of the two classes was to identify the benefits and challenges, from the perspective of the students, of the teaching strategy based on a combination of PBL and a systems approach for instilling technological/engineering literacy. There were 107 students who participated in the two courses: 62 students in the first course (given twice to two different groups) and 45 in the second course. The qualitative paradigm was found to be suitable for this study mainly because the study focused on processes as well as final outcomes, and on personal aspects such as students' thoughts, feeling, actions, and difficulties (Guba & Lincoln, 1985).

The study was carried out in three stages. In the first stage the researcher spent many hours in the role of "the-observer-as-participant" (Adler & Adler, 1994), conducting on-site observations at the classrooms. The second stage involved semi-structured interviews with eight teams of students, with three students in each team. The third stage consisted of a survey based on an open-ended questionnaire and on analyzing students' reports and products. The number of interviews and observations was not decided in advance. The criterion for stopping data collection was saturation; that is, additional interviews presented no significant new findings. The study structure was developed during the process of data collection, without prior assumptions. A spiral layout was employed—one that begins with an unknown, collects some data, updates and corrects, and so on (Spradley, 1980). The strategies adopted to increase the trustworthiness of the study were those suggested by Guba and Lincoln (1985). The data analysis strategy used was "content analysis": it defines the analysis units and establishes the *categories*, that is, the outstanding repeated elements, for analyzing the raw data.

Major Findings and Discussion

Analysis of the raw data collected from observations, interviews, questionnaires, and student reports and products revealed several frequently repeated items, which defined the categories as mentioned above. These items were classified into two meta-categories—benefits and challenges. Overall, fifteen benefits and three challenges were identified. They are presented in Table 1.

Table 1
The fifteen benefits and three challenges identified in the study

Meta-categories	No.	Categories
Benefits	1	Acquiring Multidisciplinary Knowledge
	2	Learning in Active Learning Environment
	3	Learning Through Meaningful and Authentic Learning
	4	Developing Information Literacy Skills
	5	Focusing on Synthesis Processes
	6	Experiencing Design Process
	7-8	Exploring the Top-Down Approach and Developing Capacity for Systems Thinking
	9	Executing Cost/Benefit Analysis
	10	Learning Project Management Methods
	11-13	Increasing Motivation, and Developing Independent Learning and Learning Skills
	14	Improving Academic Achievements
	15	Experiencing Team Work (Collaborative Learning)
Challenges	1	Facing Conflicts While Working in Teams
	2	Investing More Time and Effort
	3	Learning in an Unstructured Learning Environment

Note: Please see in the Method section the strategies adopted to increase the trustworthiness of the findings. Triangulation was employed, i.e., categories not found in at least three interviews or in three observations were omitted.

The benefits from the perspective of students that may be derived by using a teaching strategy that integrates PBL and a systems approach will be presented below.

Acquiring Multidisciplinary Knowledge

Many students noted that in the course of the project they acquired multidisciplinary knowledge, which they believe is one of PBL's advantages. Other students marked the interaction between the team members as a means of acquiring multidisciplinary knowledge. Yet other students emphasized the importance of working as part of a team as a way of coping with a wide variety of issues and a large amount of information.

The students' perception of the multidisciplinary knowledge acquisition as an advantage of PBL was also manifested in their answers to the questionnaire. Based on their experience in the course, 95% of the students in the first course maintained that PBL allowed them to acquire knowledge and enhance their understanding of multidisciplinary subjects.

Indeed, according to Krajcik et al. (1999) and Buck (1999), students in PBL are engaged in active learning and gain multidisciplinary knowledge while working in a real-world context. In PBL environment the teaching/learning process can be directed for the acquisition of multidisciplinary knowledge by students. This finding is not surprising since the subjects of the projects were chosen such that, in order to carry them out successfully, students required knowledge of different disciplines.

The need to have multidisciplinary knowledge is becoming evident in every facet of life. For instance, in research done in industry (Frank, 2002), it was found that electrical/electronics engineers, who as undergraduates had taken courses in the area of electricity and electronics engineering, needed in their professional jobs additional information from areas such as software engineering, mechanical engineering, industrial engineering and management, quality assurance and sometimes aeronautical engineering as well. Multidisciplinary knowledge is a must today in research, development, teaching, industry, administration, and other areas as well. Over the past few years there has been a rise in the number of multidisciplinary study programs being offered by academia.

Learning in Active Learning Environment

Another advantage identified by the students in a PBL environment is that learning is active and experiential. While collaborating on projects, they acquired knowledge through active and interactive learning. Other students emphasized the intensive activity of searching and sorting through relevant interdisciplinary information. Indeed, about 80% of the students in the first course strongly agreed that learning in a PBL environment is active and experiential learning—as opposed to other lecture-based courses where they have a passive role only.

These findings are also substantiated by the literature. The importance of student engagement is widely accepted and numerous researchers have provided considerable evidence to support the effectiveness of student engagement on a broad range of learning outcomes (Prince, 2004; Hake, 1998; Redish et al., 1997; Laws et al., 1999). Bonwell and Eison (1991) summarized the literature on active learning and concluded that it leads to better student attitudes and improvements in students' thinking and writing.

Many elements of active learning are derived from the constructivist teaching approach. Constructivism is a theory concerning learning and knowledge that suggests that humans are active learners who construct their knowledge based on experience and on their efforts to give meaning to that experience (Glasersfeld, 1995). In the courses presented here, students were required to construct their knowledge by means of active experience and learning by trial and error.

Learning Through Meaningful and Authentic Learning

The teaching staff in both courses directed students to deal with real-life areas and situations in the framework of their projects. When students are involved in realistic and relevant topics, the chances are greater that their learning will be meaningful. Meaningful learning occurs when the student sees the teaching material as related to his or her objective (Rogers, 1969). Since students deal with relevant issues, their motivation is increased (Green, 1998).

Some students mentioned the relevance as a learning-motivation enhancing factor. And indeed, in answering the questionnaire, about 85% of the students in the first course agreed that working in a PBL environment strengthened their learning motivation and sense of responsibility. About 90% of the students agreed "to a large/very large extent" that PBL allowed them to be engaged in everyday relevant issues.

Developing Information Literacy Skills

From an analysis of the raw data collected during observations, it became clear that students were required to develop different skills. These ranged from inquiry and problem solving skills, to ones for handling information (locating, evaluating, analyzing, presenting, sorting, using, organizing, processing, finding, retrieving, identifying, and integrating information), through thinking skills (such as creating thinking), and various laboratory skills (such as building models/prototypes, measuring, and troubleshooting).

Focusing on Synthesis Processes

Traditional teaching methods stress the importance of analysis processes. According to Bloom's taxonomy, analysis is the disassembly of a unit of content into its component elements while retaining the components' interconnections. The purpose of analysis is to arrive at an understanding of the content components. Similarly, system analysis is the disassembly of the system into its components with the purpose of analyzing its operation. Some researchers assert that analysis is a way to acquire knowledge and understanding.

In contrast to this, in a PBL environment, students experience synthesis processes. Synthesis is the combination, arrangement, organization, and assembly of elements and parts with the purpose of creating a system that did not previously exist. Synthesis is the connection of components or sub-systems into a whole system. In a PBL environment students choose appropriate elements from different sources and join them together in order to create the final product required by the project.

Experiencing Design Process

The findings also distinctly showed that the students had been exposed to engineering design procedures, and to the basic principle of systems engineering, in which an engineering/technological project begins with a requirements analysis. Under the guidance of the teaching staff, students in both courses performed the following stages in executing their projects: needs identification, requirements analysis, a trade-off study based on collection and analysis of data, defining alternate solutions and presenting with each one the benefits, disadvantages, costs, resource requirements and estimated time schedule, selection of the optimal alternate solution, pre-design, detailed design, model or prototype building, and evaluation of the model/prototype.

Indeed, according to Hill and Smith (1998), the project-based courses in technology education use design processes. Because design does not happen by default, a design process must become part of the course curriculum and students must be guided through the process.

The students in the course presented by Verner and Hershko (2003) also went through all stages of interdisciplinary design. In order to execute their projects, the students went through six design stages: project idea, specification, concept design, detail design and creation, operation and tuning, and evaluation.

Exploring the Top-Down Approach and Developing Capacity for Systems Thinking

In the course of completing their projects students were required to simultaneously use top-down and bottom-up approaches. The design was executed according to the former—defining the systems requirement, doing the pre-design and moving to detailed design. The production, integration, and tests were conducted according to the latter approach—joining several components, assembly testing, adding components, re-testing the new assembly, and so forth until assembly and testing of the entire product.

As they were executing the project, students had to "see" the whole (the final product) and understand the interrelationships and interdependencies among the components of the product that they were attempting to design and build. This galvanized students into improving their systems thinking abilities. By observing the students activities while working on the projects it was clear that most of the students tried to begin by clarifying the "big picture" and consider the widest aspects of the system and the environment in which it should perform.

The ability to see the big picture is an important aspect of engineering, as has been shown in previous studies. For example, many interviewees in a study by Frank & Waks (2001) defined engineering systems thinking as the understanding of the whole system. A problem may not be optimally solved just by breaking it down into elements and finding a separate solution for each of those elements. One must be able to see the whole picture while considering particular solutions for different functions that compose the system (Senge, Kleiner, Roberts, Ross, and Smith, 1994; Senge 1994; O'Connor & McDermott, 1997; Kim, 1995; Waring, 1996). An engineer with a capacity for systems thinking is therefore an engineer who understands the whole—the entire system and the whole picture. He or she understands the whole system beyond its single components (part, box, card, element) and understands how the single component functions as part of the entire system or assembly. An engineer with a capacity for systems thinking also understands how sub-systems integrate into a whole single system, which should fulfill predetermined requirements and specifications.

From the students' answers, it seems that the awareness of the notion of a "big picture," even though this big picture may not be clearly seen, is of great importance in itself. For an experienced engineer, seeing the big picture means a concrete vision of the system in a large perspective. However, for inexperienced students, the realization that there is a big picture is an important first step.

Executing Cost/Benefit Analysis

Execution of the project exposed students to cost/benefit analysis considerations and to the need for trade-offs due to various constraints. Students learned through their experiences that they should not always opt for the solution with the best performance, but that rather they should seek the one that provides the optimal solution—and that these are not always the same.

In practice, the students conducted an intuitive trade-off study. There are multiple techniques for performing trade-off studies. Our students intuitively used the decision tree approach, i.e., they prepared a list of viable alternative solutions, a list of selection criteria (performance, weight, cost, etc.), a metric for each of the selection criteria, and assigned weighting values to each of the selection criteria.

Learning Project Management Methods

During the two courses, the instructors introduced topics from the area of project management such as project integration management, project scope management, project time management, project cost management, project risk management, and knowledge management (Laufer & Hoffman, 2000; PMBOK, 2000). Students in both courses were required to work according to these principles.

Increasing Motivation, and Developing Independent Learning and Learning Skills

There were students who felt that participation in and responsibility for the learning processes was greater in the PBL environment than in a traditional course. Many claimed that in PBL the responsibility for the learning devolves on the student. Other students mentioned the social pressure within the team as a factor that stimulated them to strive harder.

PBL essentially allows the student to adjust the rate and the level of learning according to his/her abilities. During observations, it was noted that in one of the courses the class was largely heterogeneous. In an interview, the teaching assistant affirmed that the rates of progress of the different teams obliged him to adjust the level of instruction accordingly. As the course proceeded and he adjusted the instruction and assignments for each team, he felt that those who had initially been weaker had improved greatly during the course, achieving impressive results. According to the follow-up of the different teams, the discrepancies between them decreased as the course drew to its close.

Many of the students also felt that this type of course increased their motivation to learn. They felt themselves called upon to exert themselves more in the right direction, and to persist. It is evident that students felt that the course developed their engineering thinking and their intuition, increased their motivation to study, permitted a rate and level of progress according to the needs of each team, and made the students feel that they were responsible for the learning process.

These findings are also substantiated in the literature. Green (1998), for instance, noted that project learning increases motivation to study and helps students to develop long-term learning skills. Students know that they are full partners in this learning environment, and share the responsibility for the learning process. Green also stated that this approach helps to develop a long-term learning ability. Krajcik et al. (1999) suggested the following three benefits for the student: first, learners develop deep, integrated understanding of content and process; second, this approach promotes responsibility and independent learning; and third, this approach actively engages students in various types of tasks, thereby meeting the learning needs of many different students.

Hill and Smith (1998) also found that the PBL environment in their courses increased students' self-confidence, motivation to learn, creative abilities, and self-esteem. It would certainly seem advisable for teachers of other school subjects to examine the benefits of moving from teacher-centered to student-centered courses and applying this model in their courses.

Improving Academic Achievement

What have researchers discovered about the usefulness of the PBL approach? In research described by Shepherd (1998), it was found that scores for the Critical Thinking Test received by students who had learned in a PBL environment were significantly higher than those of students in a comparative group who had studied in the traditional fashion. The PBL students also demonstrated greater self-confidence and an improved learning ability. In another study, students learning in a PBL environment showed significantly higher achievements than students who had been taught using traditional teaching strategies (Sabag, 2002).

Norman and Schmidt (2000) pointed out that having students work in small teams has a positive effect on academic achievement. In a review of 90 years of research, Johnson et al. (1998) found that, across the board, cooperation improved learning outcomes relative to individual work (academic achievement, quality of interpersonal interactions, self-esteem, perceptions of greater social support, harmony among students). Springer, Stanne, and Donovan (1999) found similar results looking at 37 studies of students in science, mathematics, engineering, and technology. In the courses described here, the students worked in small teams. The assessment in both courses was not based on exams, but building on the above-mentioned findings, it can be assumed that the learning was more effective than if a traditional lecture-based method would have been used.

Interestingly, Rosenfeld and Rosenfeld (1999) found that students with low academic records who studied in the conventional framework did better in courses based on PBL, whereas those with higher grades in regular studies achieved less when PBL methods were applied (or abandoned the project completely). Based on their findings, the researchers suggested that styles of teaching and learning environments should be adapted to the student's learning mode. Low academic grades do not necessarily demonstrate a lack of ability, but rather hint at the unsuitability of the pedagogic system. They recommended that students be exposed to PBL in order to give those who may be failing a chance of doing better, and to encourage those with high academic achievements in subjects taught traditionally to develop additional expertise.

Experiencing Team Work (Collaborative Learning)

In a PBL environment, students experience working as part of a team. The importance of this kind of experience, as part of their preparation for work life in the modern business world, is obvious. PBL provides a natural environment in which to promote effective team work and interpersonal skills. For engineering faculty, the need to develop these skills in students is reflected by the ABET engineering criteria. Employers frequently identify team skills as a critical gap in the preparation of engineering students (Prince, 2004).

Team work is a central characteristic of PBL. In most cases group decisions, expressing the various perspectives of a team's members are better than individual decisions (Parker, 1990). One benefit of PBL is that students learn to work together to solve problems. Collaboration involves sharing ideas to find resolutions to questions. In order to succeed in the real world, students need to know how to work with people from different backgrounds (Krajcik, Czerniak & Berger, 1999).

Team work is not a natural process arising from a meeting of a group of people. Rather, it is an *initiated* process that requires organizational activities and specific procedures over a period of time. The term "organizational activities" relates to such matters as distributing the agenda in advance, writing up protocols of meetings, defining the preparations needed, characterizing the ways of distributing the reports, nominating a leader, and determining the structure of the meetings such as reviewing the status of previous decisions, presenting a new subject, holding discussions, summing-up, and making decisions. "Specific procedures" are ones such as how decisions are made (vote, consensus, by the chairman, etc.), and how to cope with conflicts.

It is thus evident that in order to achieve effective learning in a team, the students must be trained in team work. A random collection of students does not necessarily make for an effective team (see also Hill & Smith, 1998). From the evidence that we collected, it is apparent that in the courses described here the students were not given any introduction to team work, and this impacted on the effectiveness of some of the teams.

For PBL to be an effective learning environment, students must be trained to work in teams, both before and during the project. This prepares them for coping with conflicts among team members, for making group decisions, for meting out tasks, and for the necessary organizational preparations. Thus, faculty should be trained in group mentoring. A trained instructor would better build the working teams and lead them to produce effective and synergic work.

Conflicts Students Faced While Working in Teams

The following elaborates the challenges facing instructors wishing to integrate PBL into their teaching. First, team work requires interpersonal skills such as communication skills, negotiation skills, and an ability to cope with conflicts (Hertz-Lazarowitz, 1990). From analysis of the students' personal reports, we learned that some of them were indeed exposed to situations of conflicts during the team work. Hopefully, experiencing conflict situations during their work with the team and working through them prepared the students to better coach their future pupils for working in a team.

Investing More Time and Effort Learning in an Unstructured Learning Environment

The second challenge, as identified by the students, relates to the large amount of time that the teacher invests to implement PBL. Another challenge faced by the students is the need to cope with new course content in a learning environment that is neither structured nor organized in advance.

Thus we see that teaching by means of PBL presents several challenges. These include: students' lack of experience in this new approach and their preference for a traditionally-structured approach; their preference for a learning environment that requires less effort on their part; and problems arising from time pressures. Students struggling with ambiguity, complexity, and unpredictability are liable to become frustrated in an environment of uncertainty, where they have no notion of how to begin or in which manner to proceed.

Conclusion

Analyzing the findings of this study leads to the conclusion that a teaching strategy that integrates a systems approach and PBL comprises a valuable tool for developing preliminary technological literacy among students who lack a technology/engineering background. In the context of this study the term "developing technological literacy" refers to the following dimensions: acquiring technological multidisciplinary knowledge, experiencing synthesis and engineering design processes, becoming familiar with the engineering top-down approach, performing cost/benefit analyses, and becoming familiar with the concept of engineering systems thinking, with some principles of project management.

From the students' point of view, this teaching strategy offers some valuable pedagogical benefits. The learning is active. Students deal with real-world authentic tasks and are likely to develop information literacy and independent learning skills. Their motivation is also liable to increase. They are exposed to and experience team work, and finally, their academic achievements are likely to be better than in traditional learning environments.

Nonetheless, this teaching strategy also addresses a few inherent challenges. First, team work requires interpersonal skills such as communication skills, negotiation skills, and an ability to cope with conflicts. From an analysis of the students' personal reports, it was clear that some students were indeed exposed to situations of conflicts during the team work. To mitigate this challenge, instructors should consider preparing their students for team work by having them participate in a pre-course workshop led by a team work expert. Second, this approach is rather time consuming and requires teachers and students to invest a lot of effort over an extended period of time. Practice may lead instructors to better manage courses based on this approach. Third, students in academic courses often lack experience in this approach and many prefer one that is traditionally-structured. Students struggling with ambiguity, complexity, and unpredictability are liable to become frustrated in an environment of uncertainty, where they have no notion of how to begin or in what manner to proceed. Class management, in which the students have the freedom to talk together, is often more difficult. Teachers frequently give students too much independence without structuring the situation, or providing feedback. To mitigate this challenge, instructors should consider integrating two approaches – the more structured teaching methods (lectures, discussions, presentations) and the method proposed in this paper (integrating systems approach and project-based learning). Usually, novice teachers lack the training necessary to teach PBL effectively mainly because they have not been trained in this area. Integrating PBL in teaching requires training the teaching staff both in the content knowledge as well as the pedagogical knowledge. Centers for staff development in some universities and colleges offer PBL workshops. Novice instructors are encouraged to attend a PBL workshop prior to the first time they implement this method.

This manuscript presented the findings of a qualitative study. Based on the results presented, a follow-up study that includes quantitative measurements is being designed. For example, a test for assessing the capacity for systems thinking is currently being developed. If such a tool existed, the effect of the teaching strategy presented here on the capacity for systems thinking of students could have been quantitatively measured.

References

Adler, P. A. & Adler, P. (1994). Observational Techniques. In: Denzin & Lincoln (eds.). *Handbook of Qualitative Research.* Thousand Oaks, CA: Sage.

Bonwell, C.C., & Eison, J.A. (1991). *Active learning: Creating excitement in the classroom.* (ASHEERIC Higher Education Report No. 1). Washington, DC: George Washington University.

BUCK Institute for Education (1999). *PBL overview.* Retrieved October 10, 2005 from http://www.bie.org/pbl

Denzin, N. K. & Lincoln, Y. S. (1994). *Handbook of Qualitative Research*. Thousand Oaks, CA: Sage.

Elata, D., & Garaway, I. (2002). A creative introduction to mechanical engineering. *International Journal of Engineering Education, 18*(5), 566-575.

Frank, M. (2002). Characteristics of engineering systems thinking – A 3-D approach for curriculum content. *IEEE Transaction on Systems, Man, and Cybernetics, 32*(3), Part C, 203-214.

Frank, M. & Waks, S. (2001). Engineering systems thinking: A multifunctional definition. *Systemic Practice and Action Research, 14*(3), 361-379.

Glasersfeld, E.V. (1995). A constructivist approach to teaching. In P. Leslie, & J. Gale (Eds.), *Constructivism in Education*. Hillsdale, New Jersey: Lawrence Erlbaum Association.

Green, A. M. (1998). *Project-Based-Learning: Moving students toward meaningful learning.* (ERIC No. ED 422 466).

Guba, E. G. & Lincoln, Y. S. (1985). *Naturalistic Inquiry.* Beverly Hills CA: Sage.

Hake, R., (1998). Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-65.

Hertz-Lazarowitz, R. (1990). An integrative model of the classroom: The enhancement of cooperation in learning. *Paper presented at the Annual Meeting of the American Educational Research Association.* Boston, MA, April 17-20.

Hill, A. M., & Hopkins, D. (1999) University/school collaboration in teacher education. In M. Lang, J. Olson, H. Hansen, & W. Bunde (Eds.), *Changing Schools/Changing Practices: Perspectives on Educational Reform and Teacher Professionalism.* Louvain, France: Garant, 171-182.

Hill, A. M., & Smith, H. A. (1998). Practices meets theory in technological education: A case of authentic learning in the high school setting. *Journal of Technology Education, 9* (2), 29-41.

Jewell, L. N., & Reitz, H. J. (1984). *Group effectiveness in organization.* New York: Warner Books.

Johnson, D,. Johnson, R., & Smith, K. (1998). Cooperative learning returns to college: What evidence is there that it works? *Change, 30*(4), 26-35.

Kim D.H. (1995). *Systems thinking tools*. Cambridge: Pegasus.

Krajcik, J., Czerniak, C., & Berger, C. (1999) *Teaching science: A project-based approach.* New York: McGraw-Hill College.

Larson, E.C., & La Fasto, F. (1981). *Team work.* New York: Mcgraw-Hill.

Laufer A., & Hoffman E. (2000). *Project management*. New York: Wiley.

Laws, P., Sokoloff, D., & Thornton, R. (1999). Promoting active learning using the results of physics education research. *UniServe Science News, 13.*

Norman, G., & Schmidt, H. (2000). Effectiveness of problem-based learning curricula: Theory, practice and paper darts. *Medical Education, 34,* 721-728.

O'Connor J. & McDermott, I. (1997). *The art of systems thinking*, San Francisco: Thorsons.

Parker, M.G. (1990). *Team players and team work.* New York: Prentice-Hall.

PMBOK (2000). *A guide to the project management body of knowledge*. Retrieved October 11, 2005 from http//:www.pmi.org.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231.
Redish, E., Saul, J., & Steinberg, R. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics, 65*(1), 45-46.
Rogers, C.R. (1969). *Freedom to learn.* New York: Charles E. Merrill Publishing.
Rosenfeld, M. & Rosenfeld, S. (1999). Understanding the surprise in PBL: An exploration into the learning styles of teachers and their students. Paper presented at the *8th Conference of EARLI - European Association for Research in Learning and Instruction.* Goteburg, Sweden: EARLI.
Sabag, N. (2002). Characteristics of projects-based learning in electronics. Unpublished Ph.D. thesis, Department of Education in Technology and Science, Technion - Israel Institute of Technology (in Hebrew, abstract in English), Haifa, Israel.
Senge, P.M. (1994). *The fifth discipline: The art and practice of the learning organization*. New York: Doubleday.
Senge, P. M., Kleiner, A., Roberts, C., Ross, R. and Smith, B. (1994). *The fifth discipline fieldbook*. New York: Doubleday.
Shepherd, H. G. (1998). The probe method: A project-based learning model's effect on critical thinking skills. *Dissertation Abstracts International, Section A, 59* (3A), 779-780.
Springer, L., Stanne, M., & Donovan, S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research, 69*(1), 21-52.
Verner, I., & Hershko, E. (2003).School graduation project in robot design: A case study of team learning experiences and outcomes. *Journal of Technology Education, 14* (2), 40-55.
Waring A. (1996). *Practical systems thinking*, Boston: Thomson Business Press.
Weber, R.C. (1982). The group: A cycle from birth to death. In *Reading Book for Human Relations Training.* Alexandria, VA: NTL Institute for Applied Behavioral Science.