Project-Based Technology: Instructional Strategy for Developing Technological Literacy

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We live in a society that increasingly depends upon technology. Citizens who understand and are comfortable with the concepts and workings of modern technology are better able to participate fully in society and in the global marketplace (ITEA, 2003a). It is in the interest of science education to help students develop a greater understanding and appreciation for technology and engineering (Bybee, 2000). For these reasons a growing number of voices are calling for the mandatory study of technology by school-aged children worldwide. Technological literacy is the ability to use, manage, assess, and understand technology. It involves the application of knowledge and abilities to real-world situations (ITEA, 2003a). The Israeli national curriculum for junior high school includes a subject called "Science and Technology." One major learning goal, as determined by the Ministry of Education, is developing technological literacy. In order to prepare pre-service teachers to teach this subject in junior high school a mandatory methods course has been developed by the Department of Education in Technology and Science at the Technion, Israel Institute of Technology. The course is based on the national curriculum of science and technology in junior high school. One objective of the course is to prepare future teachers to design and manage learning environments that promote technological literacy.

Professional Development Standards for Technology Teachers

Professional development standards for staff, teachers, and educators are common. Some examples include those from the Center for Science, Mathematics, and Engineering Education (1996); National Staff Development Council (2001); Maryland Department of Education (2006); New Jersey Department of Education (2006); and Blasie & Palladino, 2005. ITEA (2003b) has developed professional standards for use in ensuring the effective and continuous in-service and pre-service education of teachers.

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Standards are written statements about what is valued that can be used for making a judgment of quality. The professional development standards for technology teachers are based on standards of technological literacy (ITEA, 2003c). *Guidelines* are specific requirements or enablers that identify what needs to be done in order to meet a standard.

The course described in this paper – Methods for Teaching Science and Technology in Junior high School – has been designed to meet the standards following the guidelines. In order to prepare students in the course to design and manage a Project-Based Technology (PBT) learning environment, the instructors set the following main learning objective: upon completion of the course, the students should be able to apply design considerations and processes to real projects. This paper presents implementation issues and processes that pre-service teachers encountered in a PBT environment and the extent to which they applied design considerations to real projects.

Project-based Learning (PBL)

To develop a broader view of technology and understand how it is both like and unlike science, students should become familiar with the nature of engineering and design (AAAS, 1989). Project-Based Learning was found to be a learning environment that may promote technological literacy (Frank, 2002). According to 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, & Steinberg, 1997; Laws, Sokoloff, & Thornton, 1999). Bonwell and Eison (1991) summarize 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. Because design does not happen by happenstance, 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 develop long-term learning skills. In some studies, a positive correlation was found between self-esteem 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 a study reported by Shepherd (1998), it was found that grades for the Critical Thinking Test (a 32-item, 40-minute test that measures skills in clarifying, analyzing, evaluating and extending arguments) received by students who were taught 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 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, & Smith (1998) found that, across the board, cooperation improved learning outcomes relative to individual work. This included academic achievement, quality of interpersonal interactions, self-esteem, perceptions of greater social support, and harmony among students. *Teamwork* is a central characteristic of PBL. In most cases group decisions, expressing the various perspectives of the team members are better than individual decisions (Parker, 1990). The students in the course presented by Verner and Hershko (2003) also went through all the 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. In another study, students learning in a PBL environment showed significantly higher achievement than students who had been taught using traditional teaching strategies (Sabag, 2002).

Project-based Science (PBS) and Project-based Technology (PBT)

Based on the PBL principles, Krajcik, Czerniak, & Berger (1999) suggested the Project-Based Science (PBS) approach for team projects in science education. The authors suggested the following benefits for the students: first, learners develop deep, integrated understanding of content and process; second, this approach promotes responsibility and independent learning; third, this approach actively engages students in various types of tasks, thereby meeting the learning needs of many different students; and fourth, students learn to work together to solve problems. Collaboration involves sharing ideas to find solutions to problems. In order to succeed in the real world, students need to know how to work with people from different backgrounds. PBS offers multiple ways for students to participate and demonstrate their knowledge consistent with their varied learning styles. PBS promotes the development of inquiry skills, problem solving skills, and information skills. Students may acquire lab experience and gain a higher level of cognitive skills (such as asking questions) and affective outcomes (such as curiosity and skepticism).

Based on the PBS approach presented by Krajcik et al. (1999) and the systems' life cycle model (Sage, 1995), we suggest a Project-Based Technology (PBT) model for designing a learning environment that will help promote technological literacy (see Figure 1).

The PBS approach engages learners in exploring important and meaningful questions through a process of investigation and collaboration. Students ask questions, make predictions, design investigations, collect and analyze data, use technology, create products, and share ideas. According to the PBT approach, students are required to design a technological product/system based on scientific, technological, social, and environmental principles. To emphasize technological and not merely scientific literacy, a unique quality of PBT is that the starting point is that of the actual technological requirements and needs

PROJECT-BASED LEARNING

PROJECT-BASED TECHNOLOGY

Design

- **Identifying needs**
- **Determining system requirements (what would be required of the system)**
- **Collecting and analyzing data: conducting a feasibility study**
- **Examining alternative solutions and choosing optimal solution**
- **Designing the system**
- **Producing and testing a prototype/physical model**
- **Presenting outcomes**

Small team collaboration

Literature review

Continued assessment

PROJECT-BASED SCIENCE

Inquiry

- **Research question**
- **Formulating scientific prediction**
- **Designing and conducting investigation**
- **Gathering and analyzing information and data**
- **Making interpretations and identifying alternative explanations**
- **Drawing conclusions**
- **Reporting finding**

Figure 1. Project-based technology versus project-based science.

rather than a research question as in PBS. The students first identify the needs, define the system's mission and goals, and analyze the requirements. They then investigate alternatives for implementation, collect and analyze data through a process of investigation and collaboration, and conduct a trade study, after which they design the system, using a top-down approach (Frank, 2005: pp. 27-28).

The final outcomes of the project are group and individual written reports, a portfolio, a multimedia presentation in the classroom presented to the course colleagues and staff, and a physical artifact, which can assist a secondary school teacher in demonstrating a scientific and/or technological principle underlying the system.

Following are examples of students' projects: a car driven by solar energy, a water desalination system, a remote cardiologic testing system, an automated watering system, a hot air balloon system, and an automated purification system for aquarium water.

Our goals in designing a PBT learning environment were to expose the students to the synthesis processes (not just the analysis processes), and to familiarize them with technological design procedures and some engineering principles. We wanted the students to learn to apply an important technological principle - how to arrive at an *optimal* design. Our intention was to familiarize them with feedback loops, the need to make trade-offs, and the need to consider constraints while designing a product.

In PBS (Krajcik et al., 1999) as well as in PBT learning environments, learners develop deep, integrated understanding of content and processes. They learn to work together to solve problems. These approaches promote responsibility and independent learning and actively engage students in various types of tasks, thereby meeting the diverse learning needs of many different students. Students build their own knowledge by active learning and interacting with the environment as suggested by the constructivist approach, working independently or collaborating in teams, and creating a real product. Since students deal with relevant issues, their motivation increases. Students' awareness of scientific, technological, social, and environmental aspects increases and academic achievement may be improved.

The role of the teacher in both approaches differs from the traditional role. The teacher is no longer merely a provider of facts but rather a resource provider, learning environment shaper, and a tutor (Buck, 1999). The teacher may also find the work more interesting and motivating since teaching will vary every year. The teacher continually receives new ideas, thus becoming a lifelong learner.

Objectives

The objectives of the study were to: (1) investigate which implementation issues and processes pre-service teachers encounter in a PBT environment whose design is based on the guidelines and professional development standards for technology teachers, (2) learn about the students' ideas (cognitive aspects), emotions (affective aspects), difficulties, and behavior (behavioral aspects) while learning in a PBT learning environment, and (3) identify the benefits and challenges, from the perspective of the students, of the PBT learning environment.

Method

The study was based on a combination of qualitative and quantitative data analyses. Qualitative tools for collecting data included "the participant as observer," observations in the classroom, and semi-structured interviews with students. The trustworthiness of the qualitative findings was achieved by recording the interviews, cross-referencing sources, and triangulation. The latter involved omitting all findings not found in at least three interviews or at least three different data collection techniques from among observations, interviews, open questions, and students' final reports. The findings were presented to the subjects in order to assess the extent of their agreement with the interpretations (respondent validity). The data analysis strategy used was content analysis. To assure reliability, data were collected at different times and stages during the course.

The tools for collecting quantitative data were a questionnaire and analyses of students' final reports and products. The questionnaire was comprised of three parts – demographic information, closed questions, and open questions. The scale of the closed part ranged from 1 (strongly disagree) to 5 (strongly agree). To assure the questionnaire's content validity, each item was based on literature review, study objectives, and broad agreement between the three course instructors.

From the demographic part of the questionnaire, the authors learned that the course participants (i.e., the subjects of this study) were pre-service teachers studying towards a teaching certificate in the Department of Education in Science and Technology, parallel to their studies towards a B.Sc. degree in one of the faculties of Sciences or Engineering. The study was conducted in three consequent courses, fourteen weeks each. Overall 92 students, 51 females and 41 males, participated in the study. The average age of the subjects was 24 years and nine months. Every weekly class included a one-hour lecture, two hours of microteaching, and three hours dedicated to the team project.

As mentioned above, the PBT approach was the main teaching method applied in the courses. In addition, three more teaching methods were implemented: introductory lectures, textbook evaluation (using rubrics), and micro teaching. The course assessment was based on the formative assessment of students' performance in microteaching, active learning in the National Museum of Science and Technology, group assignments, and interdisciplinary team projects based on the PBT approach. The project grade was 55% of the final course grade. 10% (out of 55%) was for the physical model, 5% for a Power Point presentation, 10% for meetings with the course staff, 20% for a group report, and 10% for a personal reflection report. Several rubrics were developed for assessing the above assignments: an analytical rubric for assessing the group report and holistic rubrics (Birenbaum, 1997; CPS, 2000) for assessing the personal report, the Power Point presentation, the physical model, and the documentation of the meetings. Using the rubrics enabled both instructors and students to monitor progress and help guide them throughout the project.

An interdisciplinary team, two lecturers and one teaching assistant, carried out the course teaching as well as the research. One lecturer is an expert in technology teaching and the second is an expert in biology teaching. The teaching assistant has a M.Sc. degree in chemistry/biology teaching.

Major Findings and Discussion

This section describes how the course was designed to apply five out of seven of ITEA's professional development standards by implementing some of the guidelines. The sixth and seventh standards deal mainly with in-service teachers and were not included.

Standard PD-1: *Professional development will provide teachers with knowledge, abilities, and understanding consistent with Standards for Technological Literacy: Content for the Study of Technology (STL).*
Guideline A: *Prepare teachers to understand the nature of technology*

To expose the students to the nature of technology and to teaching methods suitable for revealing the nature of technology, the course included lectures dealing with the nature of technology, discussions, and analysis of students' work. For example, in one lecture, a comparison between science and technology was discussed (see Table 1).

As mentioned earlier, the main learning objective was the following: Upon completion of the course, students should be able to apply design considerations and processes to actual projects. After analyzing the students' final reports, it was found that 67% of the students took trade-offs and optimum considerations into account, 89% presented more than one alternative to resolve design issues and had chosen the optimal solution based on comprehensive and reliable data, and 85% began the design process with top level considerations and only afterwards went over the details. In addition, after analyzing the answers to the questionnaire, it was found that students became aware that engineering design operates within constraints (67%) and that in engineering there is always more than one possible solution (89%). The students became familiar with the nature of engineering and design, with 56% indicating that learning by PBT helped them to better understand that technology draws on science and contributes to

Table 1
Comparison between Science and Technology

Dimension	Science	Technology
Analysis and Synthesis	Analysis – to explore, analyze and explain natural phenomena	Synthesis – to design, create, and build new products; to assemble parts into a system
Abstract and Concrete	Theory and theoretical aspects	Theoretical and applied aspects
Inquiry and Design	Inquiry	Design
Idealization and Optimization	Perfection	Optimum
Variables and Constraints	Variables	Constraints
First phase	Inquiry question	Need of definition and requirements analysis
Driving force	Curiosity	Human need
Precision and tolerance	Accuracy	Tolerance, trade-off
Hypotheses and alternatives	Hypotheses	Alternatives

it. In fact, 61% indicated that PBT helped them understand that science and technology are strongly connected and that engineers should use their knowledge of science and technology to solve practical problems. In addition, nearly all experienced the importance of the cooperation between the team members, with 89% indicating that it is important for them to know what other team members do, how they progress, what difficulties they face, and what their contributions to the project are.

Guideline B: *Recognize the relationship between technology and society*

The students understood that, in addition to the scientific-engineering aspects, one must also consider the social-environmental aspect. For example, here are quotes from three interviews with students, all related to social-environment aspects:

> After extensive reviewing of dozens of Internet sites, we put a lot of effort into sorting out the data and selecting the sites that deal with scientific, technological, and social aspects related to a car that operates by means of solar energy.
>
> While building an artifact for demonstrating the pulse in the human body we decided it was very important to investigate the issue of physical fitness and its significance for keeping the heart healthy.
>
> We had to explain the chromatography method. We decided to refer also to the issues of pollution and purification of the drinking water and to explore the methods used by some countries to reduce water pollution.

Guideline D: *Prepare teachers to develop abilities for a technological world*

According to many authors, there are eight levels of ability for technological problem solving (for instance, see Mioduser 1998): (1) the knowledgeable consumer (knows what and how to check prior to purchasing), (2) the knowledgeable user (is able to operate technological systems and products by using manuals), (3) the problem solver (is able to resolve simple malfunctions and failures at home), (4) one who uses technology in order to pursue a hobby (builds, assembles and repairs technological systems and products), (5) the vocational education graduate, (6) the artisan-technician-practical engineer, (7) the engineer and (8) the scientist-engineer.

This eight-level model was introduced to the students. Since the course described in this paper was designed for junior high school pre-service teachers, the emphasis was on the first level – *the knowledgeable consumer*. The main issues discussed with the students were how to choose between commodities and products based on the Life Cycle Cost model, maintenance and operation considerations, user friendliness, environmental considerations, etc. The students were required to apply these principles to their project.

Standard PD-2: *Professional development will provide teachers with educational perspectives on students as learners of technology*

Guideline B: *Prepare teachers to provide cognitive, psychomotor, and affective learning opportunities*

Analyzing the raw data collected in the study revealed that the PBT learning environment may serve to enhance the students' self esteem. For example, one of the students attests to the following:

> At first I had many apprehensions, but the more we progressed in our work and were able to successfully accomplish more and more tasks, the more my self

> confidence increased and the more I began to believe in our ability to complete the project and meet all the course requirements.

Whereas another student stated the following about a team-mate:

> In the beginning, M. was the weakest link in the team. We demanded that she be a more active participant and the more progress we made, the more active and creative she became. Suddenly, she started to raise many new ideas … her self-esteem increased …

Researchers of the PBL method relate to the issue of self-esteem in an indirect manner. In some studies, a positive correlation was found between self-esteem and receiving positive assessment (Battle, 1991). Therefore, it is likely that in the PBT environment, which is based on formative assessment and continuous support such as the case here, an increase in certain students' self-esteem would be found.

Guideline C: *Prepare teachers to assist students in becoming effective learners*

Active learning is a principal characteristic of the PBT environment that is based on the constructivist approach to teaching. In the course presented here, students were, in fact, required to construct their knowledge by means of active experience and learning in the form of trial and error. Krajcik et al. (1999) suggested the following benefits of this approach for the students. Firstly, learners develop a deep, integrated understanding of content and process. Secondly, students learn to work together to solve problems. Collaboration involves sharing ideas to find answers to questions. In order to succeed in the real world, students need to know how to work with people from different backgrounds. Thirdly, this approach promotes responsibility and independent learning. One student articulated it very eloquently:

> While deliberating on a certain issue and searching for information sources related to this issue, I was able to come to a conclusion of my own. It was a great experience, and I am sure that I will never forget this material.

Another student emphasized the intensive activity of searching and categorizing relevant interdisciplinary information:

> After extensive reviewing of dozens of Internet sites, we put a lot of effort into categorizing the data and selecting the sites that deal with scientific, technological and social aspects related to a car that operates by means of solar energy.

Standard PD-3: *Professional development will prepare teachers to design and evaluate technology curricula and programs.*

Guideline A: *Prepare teachers to design and evaluate curricula and programs that enable all students to attain technological literacy*

One of the main assignments in the course was to evaluate the national curriculum of science and technology in junior high school. They were required to assess, according to given criteria, the learning goals, teaching strategies and methods, assessment and evaluation approaches, learning environments design and the learning materials.

The students were requested to discuss the advantages and challenges of the PBT approach in their reports based on what they had experienced in their project work. By analyzing the answers to the questionnaire, it was found that 85% of the students indicated that they would attempt to integrate this approach in their teaching and think that the process they experienced will help them design and manage PBT learning environments in the future.

Guideline B: *Design and evaluate curricula and programs across disciplines*

The national curriculum of science and technology in junior high school is characterized as an interdisciplinary subject. The learning and teaching is based on the Science/Technology/Society approach. It integrates aspects of science (biology, chemistry, physics and earth science), technology, and society.

While working on the projects, students noted that they acquired interdisciplinary knowledge. For example, one student related to the need to gain knowledge from various disciplines:

> We were required to cope with issues from various disciplines – Biology, Chemistry, and Technology. Each of us studies a specific subject and the need to perform a joint project forced us to study subjects from other disciplines. I understood that using this method helps the student acquire knowledge from other domains.

Other students indicated teamwork as a means of acquiring interdisciplinary knowledge:

> Each of us contributed his share. We were exposed to various work methods of our own … we were exposed to a variety of ideas … we learned from one another … I learned from my colleagues' unique subjects.

Or:

> There existed among us team members a readiness to share information and ideas … each team member came from a different field, and through our mutual work, a variety of ideas and scientific aspects were raised … I majored in chemistry, whereas the other members of the team majored in agricultural and civil engineering…. I helped them understand concepts in chemistry, which were totally new to them.

The students' perception of the interdisciplinary knowledge acquisition as an advantage of PBT was also manifested in their answers to the questionnaire. Based on their experience in the course, 95% of the students maintained that PBT allowed them to acquire knowledge and enhance their understanding in interdisciplinary subjects. Indeed, according to Krajcik et al. (1999), students in

PBS are engaged in active learning and gain interdisciplinary knowledge while working in a real-world context.

Standard PD-4: *Professional development will prepare teachers to use instructional strategies that enhance technology teaching, student learning and student assessment*

Guideline C: *Prepare teachers to utilize student assessment*

The formative assessment strategy that were applied in the course served, among other things, as a means of locating students' difficulties and choice of intervention in regard to assisting the students who face difficulties. The feedback we provided related mainly to the quality of the work and included advice suggesting what the students could do to improve their work (Black & William, 1998). Each group met with one of the course teachers for a formal meeting once every three weeks.

The students reported on what they had done since the previous meeting. Students' hardships were discussed, as well as coping methods for dealing with these hardships. The focus was on assessment for learning – assessment whose purpose is to enable students, through effective feedback, to fully understand their own learning processes and the goals they are trying to accomplish (Elwood & Klenowski, 2002). The interaction between the teacher and the team also included feedback and assessment regarding the degree of progress made. Each team kept the reports and the summary of the meetings with the teachers in a group portfolio.

By analyzing the students' final reports, it was found that the majority of the students maintained that continuous assessment throughout the course advanced the learning process in general. The students indicated six reasons: it helped them to understand the course goals and requirements (89%), it assisted them in evaluating the degree of progress (86%), it helped them cope with difficulties and locate the specific points that required correction or improvement (84%), it emphasized the need to examine additional aspects related to the project (82%), it assisted them in coping with conflicts among team members (77%), and it allowed the course teachers to identify the students who were experiencing difficulties (75%).

Standard PD-5: *Professional development will prepare teachers to design and manage learning environments that promote technological literacy*

Guideline B: *Prepare teachers to design and manage learning environments that encourage, motivate, and support student learning of technology*

In answering the questionnaire, 85% of the students agreed that working in a PBT environment raised their learning motivation and responsibility. 90% of the students agreed "to a large/very large extent" that PBT allowed them to be engaged in everyday relevant issues. These findings are also substantiated in the literature.

Reviewing the literature reveals that many researchers believe that in PBL the student's responsibility for learning is higher compared with traditional learning methods and that under certain conditions, the students' motivation for learning is increased (Buck, 1999). Green (1998) noted that learning by means of a project is likely to increase motivation and provide students with a sense of satisfaction. Students know that they are full partners in this learning environment and share the responsibility for the learning process.

Guideline D: *Prepare teachers to design and manage learning environments that reinforce student learning*

One advantage identified by a large number of students, is that in the PBT approach, the responsibility for the learning lies with the student. 90% of the students agreed 'to a large/very large extent' with this item in the questionnaire. This finding is also substantiated by some students' responses in the interviews. For example, one of the students mentioned social pressure within the team as a factor that stimulated her to strive harder:

> During the course of the teamwork, I realized the magnitude of my responsibility. I undertook a task and my teammates expected me to perform it to the best of my ability. I realized that I could not let them down. If I "screwed up," the quality of the teamwork could be adversely affected and we would all lose.

Another student expressed a similar idea, only in slightly different words, while mentioning the relevance as a learning motivation rising factor:

> Regarding the work allocation among us, I was in charge of a certain issue. I promptly understood that I had to master that issue so that I could later teach it to the other members of the team. The subject I had to learn was selected by me because I was interested in it. It was something I had encountered in a different course. It was really "fun" to dwell on it.

There were students who felt that participation in and responsibility for the learning processes was greater in the PBT environment than in a traditional course:

> In this course, we were the focus…it all depended on us… Whoever really wanted to learn made the effort and those who didn't could be passive members of the team…
>
> There were no tests… grades were given according to the effort we invested, the quality of production and presentation to our colleagues…What you give is what you get…

Conclusion

The course described in this paper – Methods for Teaching Science and Technology in Junior high School – was designed to meet the professional development standards through the guidelines offered by the ITEA. While working on their projects, the students experienced the advantages and challenges of the PBT approach. The advantages and challenges are detailed herein. Most students indicated that they would attempt to integrate this approach in their teaching and think that the process they experienced will help them in the future to design and manage PBT learning environments. It was found that in the course of their active experiencing, the students acquired interdisciplinary scientific/engineering knowledge and pedagogical knowledge, and also familiarized themselves with the design process.

While working on the projects, the students were exposed to the nature of technology and to teaching methods suitable for revealing the nature of technology. The students learned how to take trade-offs and optimum considerations into account, present more than one alternative to resolve design issues, and begin the design process with top-level considerations. It was found that students became aware that engineering design operates within constraints and that, when it comes to engineering, there is always more than one possible solution. They became familiar with the nature of engineering and design and experienced the importance of cooperation among team members. The students also understood that, in addition to the scientific/engineering aspects, one must also consider the social-environmental aspects.

Applying the PBT approach and the professional development standards and guidelines may promote technological literacy and serve as a means for preparing future teachers to design and manage learning environments for developing technological literacy. The findings and implementation tips presented in this paper may serve as a basis for a follow-up empirical/quantitative study based on a random sample and inferential data analysis.

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