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Projects in Technology Education and Fostering Learning: The Potential and Its Realization

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Abstract The current study aimed at examining the efficacy of technological projects as learning tools by exploring the following questions: the extent to which projects in technology develop students as independent learners; the types of knowledge the students deal with in working on their projects; the role of problem-solving in technological projects; and how projects integrate into traditional schooling. The subjects were 53 high school (12th grade) students who prepared graduating projects in technology under the supervision of nine teachers. Data were collected by observing the students in the laboratory, administrating two questionnaires to both the students and the teachers, and analyzing 25 portfolios prepared by the students of their projects. The findings indicate that projects in technology provide a good opportunity to engage students in challenging tasks that enhance their learning skills. To maximize this potential, it is necessary to employ the project method from the early stages of learning technology. It is especially important that teachers having a strong engineering orientation also acquire pedagogical knowledge on issues such as fostering independent learning, creativity, peer learning and reflective practice in the technological classroom.

Keywords Project-based learning · Technology · Learning skills · Problem-solving

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Introduction

There is widespread agreement that a major goal of science and technology education is to foster students' general learning competencies such as independent learning, problem-solving, and teamwork (American Association for the Advancement of Science (AAAS) 1993; National Research Council (NRC) 1996; International Technology Education Association (ITEA) 2000). To accomplish this end, schools must shift from the traditional methods of delivering content by teachers to more constructivist-oriented instruction. Project-based learning is considered by many as a good platform for promoting meaningful learning and fostering higher-order cognitive skills (Blumenfeld et al. 1991; Marx et al. 1997; Barak 2002; Barlex 1994). Projects, according to Thomas (2000), are complex tasks based on challenging questions or problems that involve students in design, problem-solving, decision-making or investigative activities; they give students the opportunity to work relatively autonomously over extended periods of time, and they culminate in realistic products or presentations. Employing the project method in schools, however, is not an easy task for several reasons (Marx et al. 1997): projects often take longer than anticipated; it is hard to let students to work on their own, on the one hand, while maintaining control of the class, on the other; and there is the question of how to integrate the project method into a system that is based generally on formal evaluation and exams. How is it that, despite these difficulties, the project method has become a central ingredient in technology education in Israeli high schools, particularly in fields like electronics, electricity and mechatronics (Barak 2002, 2004; Verner and Hershko 2003; Mioduser and Betzer 2008)? The origins of engaging students in extensive advanced technological projects in high school go back to the 1970s and 1980s, when many of the technology teachers came from the advanced industry and brought into school the sprit of innovation and creativity characterizing Israeli industry in fields like computers, electronics and mechanical engineering. However, in a reform that took place in the curriculum in the early 1990s, the preparation of a graduating project was eliminated from the required curriculum, which was shifted to place more emphasis on performing standardized 'scientific-style' laboratory experiments. For example, the students 'investigated' the properties of a specific transistor or operational amplifier circuit and described its properties in a table and a graph showing the relation of the output current to the input voltage. Although this hands-on learning method is much easier for the students and the teachers compared to projects, many teachers saw this change in curriculum as one of the reasons for the decline in students' interest in electronics studies and the decrease in the number of high-achieving students who chose to major in electronics during the 1990s. Towards the end of this decade, a growing number of teachers, with the support of Ministry of Education supervisors, gradually reintroduced the preparation of final projects by the students as a partial substitute for conventional pencil-and-paper matriculation exams. The number of students preparing final projects in electronics grew nationwide from only 25 students in 1999 to 90 students in 2000, 200 students in 2001, 400 students in 2002, 700 students in 2003, up to 1,500 students in 2007. Today, over 50% of 12th grade electronics majors prepare a graduating project in electronics or other technological fields as part of the formal matriculation exam. This phenomenon prevailed despite the fact that the schools have recently had to face increasing pressure to cut learning hours, reduce expenses, and emphasize teaching of the compulsory curriculum, such as mathematics and languages, over elective subjects, such as electronics or robotics. Moreover, it is important to mention that projects in technology differ from projects in science in that technological projects require the student to construct a working artifact, for example, a system for temperature control or a small robot. This demands not only that the school have well-equipped laboratories and purchase expendable components for the projects, but also that the students and the teachers invest considerable effort in the projects, often beyond regular school hours. Apparently, the fact that the teachers continue using the project method in technology studies, in spite of the above-mentioned difficulties, indicates that project work is not a temporary trend and the teachers are acknowledging the educational advantages of the project method over conventional instruction. However, after almost a decade in which the preparation of a graduating project has become a central ingredient in technology studies in many of our high schools, we felt that there is room for examining the efficacy of projects as learning tools, as well as students' and teachers' views on project work, by following the work of students in four high schools on their final projects, as reported in the rest of the paper.

Literature Review

Technological Projects and Promoting Meaningful Learning

The educational literature points to a range of learning environment characteristics that promote meaningful learning and foster the development of higher-order intellectual skills. Among these parameters are (Barak 2004; Brandt 1998; Bransford et al. 1999; Schraw et al. 2006):

- Linking what is learnt at school to issues that are personally meaningful for the student;
- Engaging the students in challenging tasks;
- Adopting the curriculum to students' prior knowledge and cognitive development level;
- Giving the students freedom to learn in their own way and have control of and responsibility for their learning;
- Encouraging social interaction and peer assistance in the class; and
- Providing the students with helpful feedback and furthering reflection and meta-cognition in the class.

Rooted in the constructivist view of learning, project-based learning appears to be one of the best tools education has for establishing a rich learning environment, as described above. De Vries, in his 2005 book entitled *The Philosophy of Technology for Non-Philosophers*, describes technology as "the human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, various kinds of natural (material, energy) and cultural (money, social relationships, etc.) resources." This definition highlights that technology education could serve as a natural framework for utilizing the project method for several reasons: First, because technology addresses human needs and desires; second, because technological studies closely involve students in problem-solving and decision-making processes; third, because projects in technology often conclude with constructing a "working solution" to a problem, for example, an artifact or control system, which is personally meaningful to each student and could be shared with others and reflected upon. These aspects, which are very important to project-based learning (Thomas 2000; Harel and Papert 1991; Kafai and Resnick 1996), are less significant in fields such as science or mathematics in which students frequently accomplish their project by suggesting conceptual analysis or theoretical answer to a question.

Types of Knowledge Addressed in Technological Projects

In the epistemological literature, it is common to distinguish between several types of knowledge (Hiebert 1987; McCormick 1997, 2004):

- *Declarative (descriptive) knowledge*—propositional knowledge, knowledge about how things are, also known as 'knowing that.' In mathematics, for example, it is knowing that $2 + 2 = 4$; in science, it is knowing that water boils at 100°C.
- *Procedural knowledge*—knowledge about how to handle a specific task, how to perform it; it often consists of formal language, symbolic representations, rules, algorithms, procedures, techniques and methods. For example, procedural knowledge in mathematics is how to calculate $2 + 2$ or similar exercises; in electronics, it is how to design an electronic circuit or write a computer program.
- *Conceptual knowledge*—knowledge about the interrelationships among basic elements within a larger structure, or, as McCormick (1997) put it, "understanding the relationships among items of knowledge." In mathematics, for example, conceptual knowledge has to do with understanding how concepts like 'number' or 'function' appear in different mathematical contexts; in science and technology, conceptual knowledge aims at understanding how concepts such as energy, system or feedback apply across biological, mechanical and electrical systems.

It is useful to mention some aspects of knowledge unique to technology, beyond the definitions presented above. McCormick suggested the term 'qualitative knowledge,' which refers to an individual's ability to evaluate a specific phenomenon in a system without relying too heavily on mathematical-physical equations (procedural knowledge). For example, a student can understand how a gearbox affects the speed and force (torque) of a robotic car without learning the formal theory in mechanics. De Vries (2005) highlights additional kinds of technological knowledge. First, there are several types of knowledge about technological processes or systems that cannot be expressed properly in propositions. For example, a carpenter, a mechanic or a chef often 'know' or 'feel' how to do things but are unable to explain exactly what they are doing. Second, engineers and architects often use sketches and drawings to express knowledge that cannot be expressed entirely in a verbal fashion. Third, technologists frequently rely on the knowledge of norms. For example, people and designers living in different countries may regard the same artifact or solution to a problem as being 'eligible' or 'ineligible' depending on local norms, cultures or customs.

This concise discussion of types of knowledge in general, and technological knowledge in particular, is significant to the current study since educators expect that students will acquire higher level knowledge in school, beyond declarative or procedural knowledge. Do projects in technology contribute to achieving this end? We will return to this point when describing the findings of this study.

Problem-Solving in Technology

Although the development of student competencies relating to problem-solving and creativity is a central aim of education in general, and project-based leaning in particular, these terms are rather vague and there is no consensus as to their exact meaning. The term "problem" expresses a state of difficulty, situation, condition or issue that needs to be resolved, or a question to be solved. Problem-solving can be, for instance, seeking solutions to an individual's needs and desires, inventing new artifacts, improving technological systems, or troubleshooting. The literature on engineering and technology education often presents a general problem-solving model that consists of the following stages (in diverse variations): identifying a human need or problem to be resolved; carrying out an investigation; setting demands or specifications for the desired solution; suggesting a number of solutions and selecting the optimal one; implementing; evaluation; improving. However, this model, which originates from the general problem-solving model suggested by Dewey in 1910, has been subject to considerable criticism (McCormick 2004; Williams 2000) since describing problem-solving as a linear or sequential process reflects only little the ways expert problem solvers work. Wankat and Oreovicz (1993), who broadly discuss the issue of problem-solving in their book on teaching engineering, contend that experts have thousands of "chunks" of specialized knowledge and patterns stored in their brains in a readily accessible fashion, and they use many techniques and heuristic strategies to re-describe or re-define a problem and solve it (Barak 2007).

To what extent is the notion of problem-solving significant to project work in schools? To examine this point in the current study, we used the Problem-Solving Taxonomy (PST) suggested by Plants et al. (1980) specifically for the context of engineering education (Waks and Barak 1988; Waks and Sabag 2004; Wankat and Oreovicz 1993; Yokomoto 2001). This taxonomy classifies problems according to the following five levels: (1) Routines—execution of a procedure; (2) Diagnosis—selection of the correct procedure or procedures; (3) Strategy—selecting among applicable routines; (4) Interpretation—modeling real-world situations for problem-solving and interpretation of the results; and (5) Generation—invention/creation of new routines. In the Findings section, we show how the students and teachers evaluated their projects according to this taxonomy.

Research Questions

Since technological projects play an important role in technological studies in high schools, we examined their efficacy as learning tools by exploring the following questions among a group of electronic students in four high schools in Israel:

1. The extent to which projects in technology develop students as independent learners.
2. The types of knowledge the students deal with in working on their projects.
3. The role of problem-solving in technological projects.
4. How projects integrate into traditional schooling.

Method

Participants

The subjects in the current study were 53 students (12th grade, aged 17–18) who studied electronics in four high schools under the supervision of nine teachers. All of the students were considered high-achievers in their schools and took the most advance course in electronics; many also took advanced mathematics or physics courses. The study encompassed all students majoring in electronics in each school rather than focusing on a selected group.

Setting

The students learned subjects such as electricity and magnetism, analog electronics, digital electronics, and computing for about 10 h a week during grades 10, 11 and 12. All of the schools have fairly well-equipped electronics labs, including updated instrumentation, such as power supplies, signal generators, oscilloscopes, kits for constructing and testing electronic circuits, and computers. Commonly, the schools have a wide selection of professional software tools for the simulation of electronic systems, and the electronics students have almost unlimited access to computers connected to the Internet. The students work on their projects during their final year in high school. They have to prepare a portfolio of their project and attend a final oral examination in school, in which they demonstrate their working system and explain how it works. One example of a student's project in the current study was a 'light organ'—an electronic device that automatically converts a rhythmic music signal into multicolored light effects, as is often seen in discotheques and dance parties. A second example was a small robot that identifies barriers using an infrared beam. A further example was a system for controlling a traffic light system via the Internet.

The Teachers

All of the nine teachers participating in the current study had a background in electronics engineering; five had a university degree in Electronics Engineering and four had a Practical Engineer diploma from a technological college; six had prior electronics engineering working experience in industry.

Data Collection and Analysis

The research study was performed throughout one school year (September–June) during which the students worked on their graduation projects in technology. One of the researchers, the co-author of this paper, visited the schools during regular school hours and met with the students and the teachers in each school at least twice—at the beginning, and towards the end of the project work. Data were collected using qualitative and quantitative tools, as detailed below:

1. Observing the students working in the lab and talking with them freely; examining their drawings, electronic circuits and computer programs.
2. Interviewing all of the students in each school in the first round, and half of the students in the second round in groups; during these 60-min interviews, the interviewees were asked questions such as: how were they progressing in their projects, what difficulties did they encounter, who was helping them, and what they thought about preparing a project or learning electronics in general.
3. Interviewing the teachers about questions such as: what are the objective of integrating the project method into the school, what are the impacts on the students, and what did they feel their role was in the process.
4. Collecting copies of 25 (out of 29) portfolios prepared by the students of their projects toward the end of the school year and analyzing their contents.
5. Administrating two questionnaires to the students and the teachers: one about the participant's outlook about the project work in electronics, and the other relating specifically to the issue of problem-solving in the projects. More details on these questionnaires are provided in the Findings section.

In our opinion, the fact that the research took place during the regular school day and not as part of introducing a new curriculum or preparing students for a technological contest, was advantageous because it increased the likelihood that the findings are authentic and reflected the reality of teaching technology and applying the project method in Israeli high schools.

Findings

This chapter is divided into six sections, each of which relates to a different aspect of students' and teachers' practices and perceptions related to the project work.

The Type of Projects the Students Dealt with and How Did They Chose Their Projects

In the current study, the 53 students in the four schools worked on 29 different subjects. The projects were defined as an individual task for each student, but two or three students commonly worked together on the same subject. All of the projects included the design and construction of an electro-mechanical system; 28 projects were interfaced to a computer and the students programmed these systems using software tools such as Assembler, C, HTML or Visual Basic. A typical product of a student's project is illustrated in Fig. 1.

To deal with a project of the type illustrated in Fig. 1, a student must address topics in digital and analog electronics, and concepts of control systems and programming. It must be noted, however, that while some of students' projects consisted of compound hardware and software elements, others were simpler, such as constructing and improving a given electronics circuit. This situation reflects the diversity among the students participating in the study, as demonstrated later in this paper.

How did the students choose their projects? Since technological systems surround us virtually everywhere, one could expect that the students themselves would come up with ideas for their projects. The current findings, however, showed that this is not exactly the case in the schools. Let us see what three teachers from different schools said in the interviews in this regard:

> Teacher 1: "I told them—bring your ideas, we'll study them together and see what can be done… the truth is that no one suggested something realistic…"
> Teacher 2: "We (the teachers) prepared a list of project ideas and gave it to the students during the summer; we asked them to think about these ideas and come up with some of their own… they suggested unrealistic projects such as building a Stradivarius violin having one chord… we had to bring them back to earth—there is a limit as to what we can do in school… the final result was a synthesis between what we had suggested to them and what they wanted to do…"
> Teacher 3: "I had a bunch of project ideas that I got from exhibitions and competitions… we took an existing project idea and upgraded it… If a student came up with his own idea, I did the best to accept it… but we often had to compromise…Each year we have one or two cases like this."

The students echoed what the teachers had said. For example:

> Student 1: "The teacher gave us a list of project ideas… we chose something that looked attractive… something that would work."
> Student 2: "We understood that the project must cover what we had learned (in theory)."
> Student 3: "I had an idea but the teacher did not understand it… it was really crazy… Two weeks later we decided together on a suitable idea…"

In summary, since the students often have only limited knowledge both about the subject matter and the practical aspects of designing and constructing technological systems, they depend heavily on the teacher on choosing their projects. Later in this paper we will return to the question of how to engage the students more in the process and prepare them for dealing with compound technological projects upon graduating from high school.

The Extent to Which the Projects Promoted Independent Learning

As previously mentioned, during the school year in which the students worked on their projects, the students and the teachers filled in two questionnaires. The first questionnaire, to which we refer in the next sections, consisted of six items touching on issues such as the extent to which the students worked independently on their projects and the connection between project work and theoretical studies.

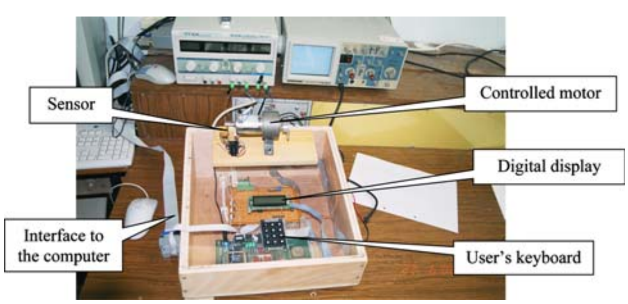

Fig. 1 A typical student project in electronics—a computer-controlled motor

The participants answered the questionnaire using a specific scale for each question (for example, very much/much/little/very little), and also explained or justified their answers to each question in their own words. The contents and outcomes of four items from this questionnaire are hereby presented.

In one item in the questionnaire, the students were asked to grade to what extent they depended on their teachers on their project work; in parallel, the teachers were asked to grade to what extent the students depended on them. The results are presented in Table 1 and Fig. 2.

From the students' and teachers' answers seen in Table 1 and Fig. 2, we can see that while 78% of the teachers marked that the students depend on them 'very much,' only 23% of the students felt this way; in contrast, 75% of the students indicated that they 'depend a little' on the teacher or 'work independently.' How can we explain this contradiction? During the classes, the teachers were often seen sitting with the students, helping them out to construct their system or in troubleshooting. For example, a relatively less capable student, whose project was a "snooker guide," received the electronics circuit design from the teacher; in the interview, this student said:

> "I didn't construct (design) the circuit at all. What does it mean to build (design) the circuit? The teachers explained this to me, and I did what he told me."

On the other hand, the more competent students worked independently; one of these students, whose project was a "computerized parking lot," said:

> "I decided where the entrance and exit for the lot would be, whether to use a touch sensor or an optic sensor, and how to construct the system's main board."

In our experience, the teachers are busy most of the time helping the less capable students while the more talented students require less help, do a significant part of the work at home, and often help out one another. This point is discussed below.

Peer Learning in the Classroom

Fostering cooperative learning and teamwork is certainly a major objective of introducing projects into science and technology studies. Teachers' and students' views on the extent that peer learning exists in the project work are shown in Table 2.

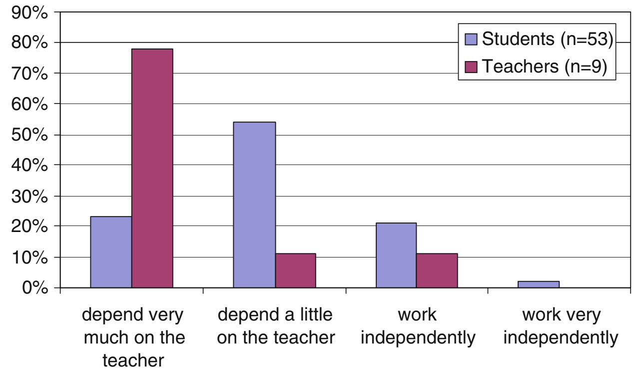

Fig. 2 Students' (n = 53) and teachers' (n = 9) views about the degree of independent learning in the project

In referring to teamwork in the class, we see that about two-thirds of the teachers and half of the students think that there is 'some' or 'a great deal' of mutual help among the students. In the observations in class, the students were very often seen working in groups and helping out one another.

The Contribution of the Projects, the Theoretical Lessons and the Dedicated Laboratory Experiments to Learning Technology

As previously noted, the teaching of electronics in school consists of conventional lessons and pre-designed laboratory experiments. Since the students in the current study were in their third year of electronics studies in high school, they could sense how the theoretical studies, the conventional laboratory work and the projects contribute to learning. Table 3 shows the students' and teachers' views on this matter as expressed in the questionnaire.

Table 3 shows that the majority of both the students and the teachers regard project work as being the most important source for understanding content in electronics. It is also important to note that 29% of the students and 22% of the teachers consider conventional theoretical lessons as being an important factor in learning, but only 15% or less consider conventional pre-designed laboratory experiments as being important. These results agree with

Table 1 Answers to the question: "In working on the project, to what extent do you depend on the teacher or work independently?" (Teachers' version: to what extent do the students work independently or depend on the teacher in the project work)

	Depend very much on the teacher (%)	Depend a little on the teacher (%)	Work independently (%)	Work very independently (%)
Students (n = 53)	23	54	21	2
Teachers (n = 9)	78	11	11	0

Table 2 Answers to the question: “In working on the project, to what extent did you get help from friends or work alone?” (Teachers’ version: To what extent did the students get help from friends or did they work alone?)

	Very little help from friends (%)	Little help from friends (%)	Some help from friends (%)	A great deal of help from friends (%)
Students (n = 53)	23	28	40	9
Teachers (n = 9)	0	33	67	0

Table 3 Answers to the question: “What contributes more to understanding the subject matter in electronics?”

	Theoretical lessons (%)	Laboratory experiments (%)	Project (%)	All combined (%)
Students (n = 53)	29	15	51	5
Teachers (n = 9)	22	11	67	0

other studies held regarding electronic studies in Israel (Waks and Sabag 2004; Barak 2005). Actually, many students attend technology education because they hope to construct sophisticated technological systems. Performing conventional laboratory experiments, such as measuring the parameters of a diode or transistor and describing the results in a table or graph, is of little interest to them. Lately, a growing number of schools (including one out of the four observed in this study) combined most of the laboratory work into the students’ projects rather than using the traditional method of a series of separate experiments. This approach is in line with the notion of starting students’ projects earlier in high school, as suggested in the Discussion section.

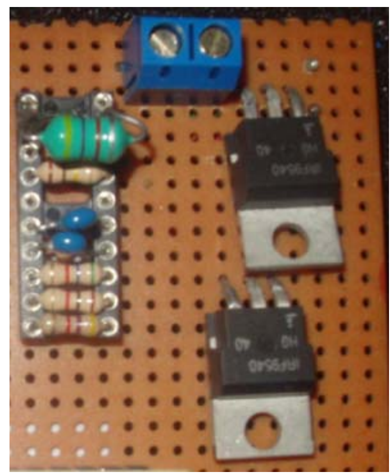

Fig. 3 Transistors, resistors and capacitors on an electronics circuit board

The Types of Knowledge the Students Dealt with Throughout Their Project Work

As previously noted, it is helpful to distinguish between four types of knowledge related to the design and construction of technological systems: *declarative knowledge, procedural knowledge, conceptual knowledge and qualitative knowledge*. To explore how these types of knowledge are expressed in students’ projects in the current study, let us consider a small component of an electronic circuit shown in Fig. 3 and the schematic diagram of an electronic amplifier illustrated in Fig. 4. Students often use components and circuits of these types in projects dealing with sound amplification, control systems or communication systems.

Declarative knowledge means, for example, that a student can identify a basic component in an electronic system or declare that the aim of a transistor is to amplify the current, but cannot develop this idea or show how it applies to his project. This level of discussion was rarely observed in the current study. Although in engineering, designers sometimes use a given integrated circuit as a black-box, this approach is commonly used in dealing with relatively

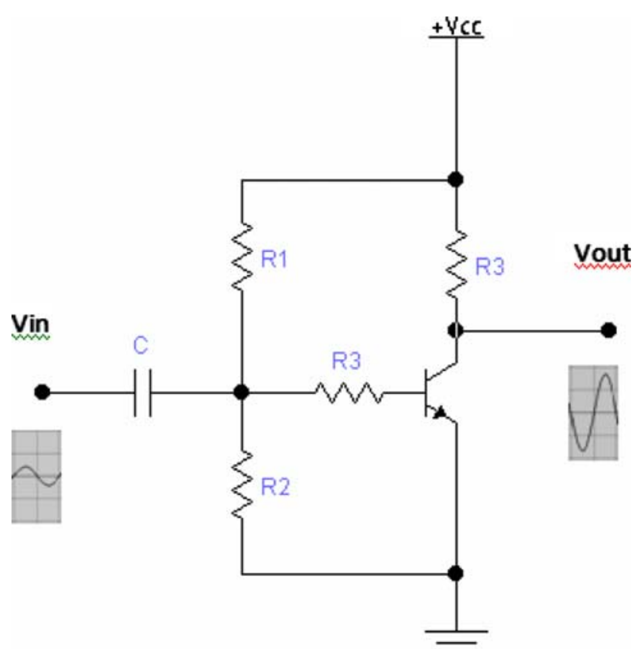

Fig. 4 A typical electronic circuit in a student’s project: a transistor-based AC amplifier

sophisticated systems and was rarely found in the observed schools.

Procedural knowledge can be, for example, when a learner draws a circuit like the one shown in Fig. 4, calculates the currents in each of the resistors R1–R4, and determines the voltage amplification ratio A = Vout/Vin In the current study, the students demonstrated this level of discussion only when addressing the basic circuits they had previously learned well. In practice, the teachers frequently challenged the students by engaging them in hardware and software beyond what they learned in class; this limits the learners from showing the procedural design of their electronic system.

Conceptual knowledge about circuits of the type we are discussing here exists when a student broadly understands the concept of electronic amplification, can compare different types of amplifiers, or can analyze the factors determining the amplifier's performance such as efficiency, linearity or bandwidth. Conceptual knowledge also deals with system thinking, namely understanding the structure and function of a compound system. In the current research, many students exhibited knowledge of this type. For example, developing a robotic arm required the learner to integrate mechanical systems, electronic circuits and programming.

Qualitative knowledge in electronics design means, for example, that a student can qualitatively explain how changing the capacitor C or each of the four resistors R1–R4 would affect the output voltage Vout, or why the phase of the output signal is opposite to that of the input signal. Additional examples of qualitative knowledge are when a student knows how to check a transistor and determine if it works properly or if it is faulty, or when the learner can touch a transistor in a working circuit and determine if its temperature is correct. In the current study, the observations in the classrooms clearly revealed that most students' and teachers' discussions were of a qualitative type. All of the 29 portfolios that the students prepared on their projects consisted mainly of qualitative explanations of specific components, circuits or computer programs they used, with few examples of systematic calculations or full detailed design.

To explore the students' and teachers' views of the role of knowledge that is not learned in the classroom, a specific question on this issue was included in the questionnaires filled in by the participants. Since the students and the teachers rarely used terms such as procedural or qualitative knowledge, we instead used the phrase "things that are difficult to explain in theory," as shown in Table 4.

Table 4 shows that while 57% of the students felt that they learned from their project work 'very little' or 'little' things that are difficult to explain in theory, all of the teachers marked that the students gained 'much' or 'very much' knowledge of this type. While the students see the projects as a continuation of learning electronics, the teachers see things differently. Let us examine what a group of students working on a remote-controlled robot said about their system:

Table 4 Answers to the question: "In working on the project, did you learn things that are difficult to explain in theory? (Teachers' version: In the project work, do the students learn things that are difficult to explain in theory?)

	Very little (%)	Little (%)	Much (%)	Very much (%)
Students (n = 53)	8	49	28	15
Teachers (n = 9)	0	0	78	22

> "We work using the modular method… We have four modules in the project: one is responsible for the transmitting-receiving system, one for the motor (its speed), one for the parking, and the body (the module) for the control."

In the above case, each student was responsible for one of the four sub-modules. Towards the end of the school year, the students had to connect the four separate modules to construct the entire system. In the final exam, they had to explain how the sub-modules connected to one another and how the entire system worked. From the students' point of view—all this is part of learning electronics. The teacher, on the other hand, understood that by working on this type of project, the students gain higher-level knowledge, namely conceptual knowledge, on issues such as control and system thinking. Moreover, the students learned how to work as a team not only in constructing the compound system but also in documenting the design and preparing for the final exam.

A second example is the case in which a teacher and a group of students were observed trying to reduce the effect of noise in a system by adding a capacitor to the electronics circuit. The teacher said:

> "There are things in electronics that look clear on the paper but don't work in practice… it is difficult to explain in theory how a capacitor reduces noise… until you put it in the circuit, you can't see how it works… a student understands this, but does not know to explain it exactly."

The above example demonstrates the notion of 'qualitative knowledge' in technology that we referred to in the literature review (McCormick 2004). This case also reminds us that expert designers and problem solvers often use heuristic methods or 'rules of thumb' in solving a problem rather than sticking to theory (Barak 2007).

Table 5 Students' and teachers' assessments of a project's degree of complexity on Problem-Solving Taxonomy (1 = very little; 2 = little; 3 = much; 4 = very much)

Level	Description	Teachers (n = 8)	Students (n = 47)
Routine	The project consists mainly of electronics parts (components, circuits, software) that the student is very familiar with, without and need for change or further learning	2.11	2.34
Diagnosis	The project includes electronics parts (components, circuits, software) that the student is familiar with but has to change or modify his/her system	1.94	1.91
Strategy	The project includes problems that can be solved using diverse methods that the student is familiar with, and he/she has to choose the optimal one	1.66	1.56
Interpretation	The project includes a poorly defined problem, for which the student must define what is given on his/her own, what is required, and the criterion for success	0.91	1.13
Generation	In the project work, the student invents parts such as circuits or software that are new to him/her	1.45	1.69

It is worth mentioning that educators commonly believe that merely engaging students in challenging tasks develops their higher knowledge and thinking skills. The educational literature, however (Swartz et al. 1998), advocates that in order to foster a specific learning skill, a teacher must: (a) Present this skill to the students; (b) Allow them to gain significant experience in using it; and (c) Encourage them to reflect on it. In other words, to foster students' competencies such as system thinking or teamwork, the teachers must talk with them about these concepts and make them reflect on their learning. Unfortunately, these elements of instruction are rarely found in the classroom.

Degree of Problem-Solving in Student Projects

Earlier in this paper, we referred to the common problem-solving model that appears in the literature on technology education consisting of a sequence of stages such as: identifying a problem or a need to be resolved; investigating and setting specifications for a required solution; suggesting several alternative solutions and choosing the optimal one; planning; constructing; evaluating; and improving. The observations in the schools, however, indicated that this model is rarely manifested in electronics studies in Israeli high schools. For example, the students frequently start planning and building the electronics circuits or computer programs for their projects immediately; they only superficially define the problem or the need, and seldom carry out a meaningful investigation about the subject or systematically or analytically consider alternative solutions. Indeed, many student projects are about inventing new artifacts that fulfill human needs, such as aides for people with physical disabilities or instrumentation to reduce road accidents. However, the focus in schools is on the electronics design, i.e., the procedural knowledge, as is common in faculties of electrical engineering in higher education.

In the current study, we sought to explore to what extent the participants regarded the projects as being challenging tasks rather than technical work. To this end, the participants were asked to fill out a questionnaire based on the five-level Problem-Solving Taxonomy (PST) we presented earlier (see the Data Collection and Analysis section). The five items in the questionnaire, as well as the average scores of students' and teachers' answers, are marked in Table 5 and illustrated in Fig. 5.

The findings observed in Table 5 and Fig. 5 show that in general, the students and teachers answered the PST questionnaire fairly similarly; both groups sensed the increasing hierarchy of the first four levels defined in the questionnaire and ranked them in decreasing order; they gave the lowest grade to the type of task level called 'interpretation,' referring to a poorly defined problem that requires the student to decide about the parameters or the

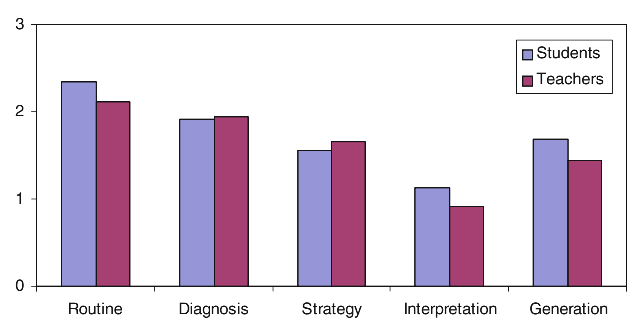

Fig. 5 Outcomes of the Problem-Solving Taxonomy (PST) questionnaire (1 = very little; 2 = little; 3 = much; 4 = very much)

specifications for the required solution. In the participants' eyes, the task of Generation, namely creativity, occurs more often in the projects. Yet, the fact that both the students and the teachers gave rather low grades to all of the categories in the questionnaire is in line with other findings in the present study showing that the concept of problem-solving is not the focus of project work in the schools.

Discussion

The present study aimed at exploring the role of project work in technology education in fostering meaningful learning and developing students' higher-order thinking skills such as independent leaning and problem-solving. The findings provide a comprehensive outlook on the practice of project-based learning, as well as students' and teachers' conceptions on the method. One the one hand, the study revealed that project work in technology education indeed enables a meaningful shift from traditional schooling and provides the students with a real opportunity to learn differently. On the other hand, the study exposed some difficulties and limits in utilizing the project method in schools, mainly when the project work comes as summative task or exam at the end of high school studies. A further discussion on these points follows.

In the literature review of this research, we pointed to a range of characteristics of a learning environment essential for promoting meaningful learning and fostering the development of higher-order intellectual skills (Brandt 1998; Bransford et al. 1999). Let us see how and to what extent projects in technology fulfill some of these conditions for promoting good learning.

One important condition for encouraging significant learning concerns the notion of '*contextual leaning*,' which means linking what is learnt in school to real-life contexts and issues that interest students and affect their daily lives (Dewy 1910; Resnick 1987). The kind of projects observed in schools in the current study, such as a traffic-light system controlled by the Internet or a computer-controlled parking lot, certainly fulfill this notion; moreover, these projects not only address peoples' needs or solve specific problems but also leave room for the students to use their imagination and suggest original ideas.

How should we regard the fact that the students depend quite a lot on the teachers in choosing their projects? In our opinion, the concept of 'authentic learning' means that the project topics are meaningful to the students; however, this does not necessarily mean that the students themselves come up with the project ideas. Only a few of the students have enough knowledge or practical experience to suggest realistic projects to work on. Sometimes the teacher a takes a student's initial idea and develops it into a project that fits his/her prior knowledge and experience; in other cases, the teacher suggests a variety of projects for the students to choose from. Our research experience shows that the vast majority of the students immerse themselves almost immediately in the project work, while the question of who originated the project or where the idea came from is less important.

A second requirement for enabling meaningful learning in school is *adapting the curriculum to students' prior knowledge and cognitive development level*. In the present study, even though all of the students were considered high-achievers in their schools and all took the most advanced courses in the exact sciences, there were significant gaps among students in the same school or from different schools in terms of prior knowledge in electronics, self-learning abilities or commitment to investing efforts in completing their projects. As noted above, the project framework allows the teachers to adapt the range and complexity of the task to each student, and provide more help to the less competent students.

A third important feature of a valuable learning environment is *giving the students freedom to learn in their own way and have control and responsibility for their learning* (Brandt 1998). In the current study, the teachers and students expressed contradicting views on this point: while the majority of teachers marked that the students depend on them a great deal in the project work, most of the students felt that they depend only a little on the teacher, or work independently. As already noted, one explanation for this is that the teachers commonly spend much of their time helping the less competent students in their project work; the more competent students, on the other hand, tend to work independently and help one another. The fact that the projects take place as part of the matriculation exams and afford the students credit points in their high school diploma serves a dual purpose: on the one hand, it encourages many students to take a project, despite the hard work it entails; on the other hand, formal rules and exams are not the best way to foster openness and creativity; also, they cause the teachers to see themselves as being responsible for ensuring that the students complete their project in time and succeed in the final exam.

An additional essential character of a constructivist-guided schooling is encouraging social interaction and peer assistance in the class. In the case discussed, the students worked on their projects in the technological lab individually or in groups, helped one another and utilized the teacher's assistance in a completely informal atmosphere. It is worth mentioning that in technological projects, much of the cooperation between students revolves around the practical work, such as constructing the system, programming and troubleshooting. This provides a natural atmosphere in which the students help one another to complete a task rather than to compete among them or seek high grades.

A fifth significant ingredient of reform-based instruction *is providing the students with helpful feedback and furthering reflection and meta-cognition in the class*. In a technological activity, the students get feedback first from their success or failure in building and improving the system they are working on, rather than feedback from the teacher. In documenting their projects and presenting them orally in a formal exam, the students describe the process they went through in developing their system, the difficulties or problems they encountered, and how they overcame them. So far, however, these aspects of reflection in the project work take place intuitively, and are stressed only slightly by the teachers; further work is required, therefore, to make meta-cognition a routine ingredient in technological projects.

How to Make Project Work a Central Ingredient in Learning Technology?

The fact that the students start their projects only in their third year of high school after learning technology for 2 years in the traditional method is perhaps the major barrier in realizing the educational advantages of project-based learning. To summarize this discussion, we suggest engaging the students in open tasks or mini-projects from their first day of learning technology. This method has many advantages: first, project work enhances students' interest and motivation more than any other activity at school; second, the teacher can link the theoretical subjects the students learn, such as analog electronics or digital electronics, to the projects they work on during the school year; third, the students can do all the lab work in the context of their projects rather than as separate experiments; fourth, the projects are a natural platform for encouraging students to engage in reflective thinking; and fifth, by gaining experience in a range of projects of increasing scope and complexity in 10th and 11th grades studies, the students acquire the knowledge and experience required to handle a sophisticated project upon graduating from high school. Indeed, other programs for project-based learning in science and technology in Israeli schools in which all the theoretical lessons and lab work were linked to student projects were significantly successful in promoting students' motivation and learning abilities, both with the competent students (Barak and Raz 2000) and the less competent students (Barak et al. 2000). In electronics studies as well, there is a growing tendency in schools to combine project work with traditional instruction; the students and teachers still prefer conventional class lessons for learning new theoretical subjects.

Concluding Remarks

Educators and educational researchers often point to a range of factors that are likely to impede the application of reform-guided schooling such as: the curriculum; the disconnection of school from real-life context; the lack of instructional means at school; the shortage of learning hours; the need to prepare students for conventional pencil-and-paper exams; the objection of students in investing efforts in learning; or the teachers' difficulties to change. Apparently, the current model of technology studies in Israeli high schools consisting of a combination of theoretical studies, and project-based learning provides good conditions for overcoming the above-mentioned difficulties: the content learnt closely relates to subjects that could interest students and enhance their imagination; the learning takes place in a rich and sophisticated physical environment consisting of advanced component, tools, scientific-technological instrumentation and computers; the vast majority of teachers have a good background in engineering and often update their professional knowledge; and project-based learning has been integrated into the formal matriculation exams the students take. Though this is a good framework, the potential educational advantages of project-based learning are utilized only partly in regular schools, mainly because technology educators often regard project work as a means for increasing students' knowledge in the subject matter, while the notion of enhancing students' aptitudes like independent learning, problem-solving and creativity is frequently regarded as side effects or natural outcomes of technology education. Consequently, further work is required in teachers' initial and in-service training to make the promotion of students' self-regulated learning a central goal of technology education. It is especially important that teachers having a strong engineering orientation also acquire pedagogical knowledge on issues such as encouraging independent learning, creativity, peer learning and reflective practice in the technological classroom.

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