Implications of Computer-Based Projects in Electronics on Fostering Independent Learning, Creativity and Teamwork

Moshe Barak, Science and Technology Education Program, Ben-Gurion, University of the Negev
& Beer Sheva, Israel
Tel: (972) 8 6461987, Fax: (972) 8 6477487
Email: mbarak@bgumail.bgu.ac.il

Abstract: This research aimed to explore the impact of computer-based projects, within the framework of high school electronics studies, on pupils' learning. Technology studies provide a sophisticated learning environment in which computers are simultaneously part of the subject matter learned and a means for teaching and learning. In the beginning stages, pupils highly depend on teachers' instructions and help. Pupils working on non-computerized projects in electronics are likely to progress along a conventional path: planning, constructing, troubleshooting and improving. In contrast, pupils working on computer-based projects tend to modify their systems, drift away from the initial design suggested by the teacher, take risks, improvise and make progress through trial and error. Computerized projects impart flexibility, freedom of action and independence to the pupils beyond that usually found at school. Computerized projects encourage cooperation and teamwork among pupils through the Internet. Under "Internet culture," pupils quickly zip between sources of information, download programs from different sources and exchange ideas with friends. New ideas, especially regarding computer programming, are distributed among the pupils, developed and refined, and become common property. Computerized projects encourage pupils to cross the line from fully teacher-guided work and become confident and independent learners.

Introduction

In recent years, educators expected that computers and communication technologies would encourage schools to shift from traditional teaching to methods emphasizing higher-order learning and developing the pupils' intellectual capabilities. Technology education encompasses such areas as design, problem-solving, robotics, control systems, and communication systems (ITEA, 2000; Dugger, 2001). Technological studies deal with the development of artifacts and systems that realize people's aspirations, beyond fulfilling basic needs such as food, housing and transport (Dasgupta, 1996). Thus, technology education provides an especially suitable framework for implementing pedagogical ideas that promote significant learning and foster the development of higher cognitive skills, such as problem-solving abilities, critical thinking and creativity (Johnson, 1997).

Electronics studies in Israeli comprehensive high schools are highly developed. Computers and communication technologies are at the same time part of the subject learned in electronics studies and a means for teaching and learning, as seen in other areas of education. The integration of computers into electronics studies and pupils projects has a history of over three decades. Since the mid-1970s, the electronics curriculum has included the teaching of the fundamentals of numeric systems, such as binary codes, number systems, switching algebra and digital hardware. During the 1980s, the study of microprocessors and the Assembler programming language become a central part of electronics studies. During the 1990s, personal computers, mainly IBM and Apple, spread widely throughout the school system and encouraged the use of higher programming languages such as Turbo Pascal and C for pupils projects.

In recent years, more and more projects are involving the use of digital hardware and advanced programming tools, such as C++ and Visual Basic, for real-time measurement and control. Most of the electronics laboratories are equipped with computers permanently connected to the Internet. Since teachers and pupils dealing with electronics studies have almost unlimited access to computerized means, they are among the heaviest users of computers and the Internet in their schools. Electronics studies thus enable examining the impact of computer technologies on learning in an area that is fundamentally rich, refined and challenging.

How do computers affect pupils' work on their projects? To what extent have the expectations that technological means contribute to meaningful, in-depth learning been realized? This study examined these questions by following electronics studies in six high schools during one year.

Theoretical Framework

A major goal of modern education is to develop pupils' higher-order thinking skills, such as the ability to synthesize information, solve problems, combine facts, generalize, hypothesize and arrive at logical conclusions. Over the past few decades, science and technology education has been influenced significantly by constructivist learning theories emphasizing that learning is a process of knowledge construction, not of passive acquisition of facts and roles (Von Glasersfeld, 1989; Cognition and Technology Group at Vanderbilt, 1997). Learners actively construct their knowledge based on their prior knowledge and experience. The idea of situated learning (Brown, Collins & Duguid, 1989) means that meaningful learning is closely related to the situation or the context in which it takes place. Learning occurs when pupils address subjects meaningful for them in a real-world setting. The importance of active experience with objects as a means of developing thinking was stressed by Dewey (1963). Constructionism is a theory that expands on the concept of constructivism by placing critical emphasis on the construction of knowledge through designing and building artifacts and systems that are personally meaningful and that can be shared with others (Kafai & Resnick, 1996; Papert, 1991). In technology studies, this can be, for instance, a mini robot, a model of a computerized house or a sophisticated alarm system.

Information and communication technologies, mainly computers and the Internet, can contribute to deeper learning and the development of thinking skills (Scardamalia & Bereiter, 1996; Salomon, Perkins & Globerson, 1991; Salomon, 1998). Computer technologies are knowledge-building tools, and not just a means for knowledge-transfer. The novel technologies encourage open learning and confront the learner with enormous knowledge resources when facing challenging problems, and are not just tools for structured teaching. Communication technologies present opportunities for shared thinking, cooperation and joint knowledge construction by individuals distant from one another. Computer technologies promote meaningful learning only when learners are engaged in knowledge construction, conversation, articulation, collaboration, authentication and reflection (Jonassen et al., 2000; Krajcik et al, 1998). Technology studies constitute an adequate framework for the realization of these ideas, mainly through project-based learning. Technological projects present pupils with the opportunity to confront real-world complexities, work collaboratively, develop problem solving skills, and reflect on their own learning (Johnson, 1997; Barak & Doppelt, 2000).

Creativity is often defined as the production of an idea, an action or an object that is new (unusual, original, novel, unexpected) and valued (useful, adaptive and appropriate) (Csikszentmihalyi, 1996). Encouraging creative thinking in science and technology studies is particularly difficult as teachers emphasize that mathematical-logical thinking is the only valuable thinking, and they reward pupils for giving the 'right answer' rather than for their originality or richness of ideas. Fostering creative thinking in school requires an atmosphere of openness to experience, tolerance of ambiguity, freedom and safety (Harman & Rheingold, 1984). Creativity is promoted more by intrinsic than by extrinsic rewards (Hennessy & Ambile, 1988; Sternberg, 1999). Pupils are unlikely to take on the challenge of complex tasks, take risks or experiment with the unknown when teachers emphasize competition, exams and grades. According to Solomon (2000), technology studies that comprise practical work seem to offer some measure of creativity. Quite unlike science lessons, all pupils complete their technology studies with their own individual artifacts. Variety and creativity are the essence of this sort of learning

Project-based learning has been common in electronics studies prior to the extensive use of computers, and computers are a natural component in the world of electronics. Questions then arise as to the benefit of integrating computers into pupils' projects and the extent to which computers affect learning. The present study examines the influence of computers on the ways high school pupils work on final projects that involve both hardware and software. The emphasis is on the development of independent learning, the encouragement of creative thinking and problem-solving skills, as well as the quality of the teamwork exhibited by the pupils.

The Research

This study closely followed the work of 50 Grade 12 pupils from six schools, who worked in pairs on 25 projects over a period of 10 months – about four hours a week during school hours and during their free time in the afternoons at school or at home (Barak, 2002). Approximately half of the projects combined hardware and software, while the others were based solely on hardware. A final project in electronics is optional but awards additional credit points for the matriculation certificate, which provides the pupils with the option to enroll into higher Israeli academic studies. The study adopted a qualitative research methodology (Guba & Lincoln, 1994). It aimed to collect as much information as possible on teachers' and pupils' activities regarding the integration of computers into electronics projects by visiting each school three to four times during one year. During every visit, the researcher interviewed each pair of pupils working in the electronics laboratory for about fifteen minutes, observed the electronic system they built, their computer files and the portfolios they prepared. Each school visit comprised informal talks with the teachers during and after the meetings with the pupils Data analysis aimed to organize the findings, to break them down into meaningful units and to synthesize them so that critical themes would emerge (Bogdan & Bilken, 1992; Patton, 1990). Every finding or conclusion was re-evaluated through repeated conversations with the research subjects themselves – the teachers and the pupils – forming a cyclic process.

Findings

Getting Started: Pupils' Dependence on their Teachers

Conversations held with the pupils and teachers in the schools revealed that the teachers play a central role during the first two to three months of the pupils' work on their projects. The process starts when the teacher presents the pupils with a list of optional subjects for their projects, each accompanied by a short explanation. Most of the topics are based on the teachers' experience with pupils' projects and rely on components that currently exist in the school. These include, for example, Lego or Fischer-Technik sets consisting of building blocks, mechanical components, motors and sensors. The teachers present the pupils with the available kits or examples of projects from previous years. Many of the topics, such as a "robotic arm," "traffic lights," an "elevator," a "glass house" or a "computerized parking lot" reappear from year to year and from school to school in slightly different versions. All of the projects involved the design and construction of hardware electronics, such as analog circuits (consisting of transistors, operational amplifiers or oscillators) or digital circuits (consisting of logic gates, counters or micro-controllers). About half of the projects involved computerized control. The hardware circuits were connected to the computer through the printer port, or special I/O cards installed inside the computer. Pupils used programming languages such as Assembler, Visual Basic, Pascal or C.

Only a few pupils from the dozens participating in this study proposed their own topic for their final project. The pupils admitted that they had accepted the teachers' suggestions or chosen a topic for their project in a random manner. After deciding their project, the pupils soon planed their system structure and immediately approached the design of electronic circuits, the construction of mechanical models and the preparation of computer programs. During the early stages of their work, the pupils depended greatly on the teacher's instructions and got most of the information they needed from the teacher. It was rare to find pupils who seriously searched for multiple ideas, compared several solutions or used pre-defined criteria for decision-making.

Moving towards Original Design

During the initial stages of the projects, the pupils relied mostly on knowledge that they had acquired and practiced in their electronics studies, mainly the design of analog and digital electronic circuits and programming. At a certain point of working on the project, after the pupils realized that the systems they had designed worked, a difference was discernable in the work of pupils dealing with hardware-based projects and those working on computerized projects. Most of the pupils who were involved in non-computerized projects continued to work on the systems they had built and made only minor changes or improvements to them. In contrast, most of the pupils who were working on computerized projects tried to refine or enrich their systems. Pupils' progress was not linear, but seemed at times to be an improvisation, a patchwork of solutions. At least ten pupils spontaneously raised new ideas to refine their system. Pupils described this work process as follows:

- "Our first programs were quite simple. After everything worked together, we started to improve our system, expand on it, and make it more interesting and elegant."
- "We write programs and immediately see the results. This challenges us."
- "The computer gives you the possibility of trying out your ideas… you sees the results and can decide."

- "We see what our friends are doing. We learn from them and help each other. There are no secrets."

In some cases, the pupils were not certain that the solution they had chosen would work. They worked intuitively and performed a large number of experiments. This was, in their eyes, a legitimate way to work. The computerized environment enabled them to perform such experiments relatively easily. In comparison to changes made in hardware, changes made in software are easier to check, adopt or remove. The work method adopted by the pupils is similar to the rapid "zapping" between television stations or to surfing on Internet websites, checking out a site for a moment and deciding whether to keep it or try something else.

The following example demonstrates how the flexibility of computerized systems promoted independent learning and teamwork. In one of the schools, two groups worked separately on different projects: a robotic arm and a conveyor, both controlled by computers. The robot consisted of two axes controlled by electric motors and a pneumatic gripper. The conveyor also comprised a light sensor detecting the presence of an object, a weight sensor and a metal sensor. The teacher helped each group a great deal with the construction of their electronic system, programming and troubleshooting, up to the point whereby each project just about worked properly. At a fairly late stage, the teacher suggested that the two groups link their systems by connecting the two computers via the serial ports. At that point, the teacher became much less involved, leaving the pupils to make their own decisions. The pupils invested great efforts and changed significant parts of their original programs in order to synchronize the robot and the conveyor, and program the robot to pick out objects from the conveyor and sort them according to weight or material.

Collaboration through the Internet

All the pupils started their programming with segments similar to those they had learned in their electronics lessons. Pupils gradually developed their original solutions for specific applications in their system, such as algorithms for reading data from sensors through the computer input port, controlling the system through the output port and screen graphics. The communication abilities, mainly the ICQ (peer-to-peer instant messaging system) and e-mail, encouraged collaboration between pupils from different schools. For example, some pupils used stepper motors in their projects digitally controlled by transmitting pulses to four coils in a cyclic sequence A, B, C, D, A, B… Each electronic pulse moves the rotor shaft one "step," i.e. 1.8^{o} (200 pulses per revolution). The total angle of the mechanical move is determined by the number of pulses transmitted to the motor, and the rotation speed depends upon the pulse frequency. One of the pupils developed an efficient algorithm for controlling two motors in parallel. Another pupil suggested increasing the motor resolution by providing "half a step" each time, using the sequence A, AB, B, BC, C, CD, D, DA, A… These kinds of ideas spread quickly among the pupils, and were found in pupils' projects in different schools. Some of the pupils modified or enhanced the programming solutions they received from friends; others just copied parts of the programs into their work. The borders between carrying out original work and copying ideas from others are not always clearly defined. Pupils and teachers often see the exchange of files through the Internet as being more legitimate than, for example, duplicating models of mechanical systems or copying electronic circuits.

Using Computer Simulation

Observing pupils working on their projects revealed a problematic aspect of using simulation software in electronics. While working on their projects, pupils were expected to build a prototype of their circuit on a board and exam it using conventional instrumentation, such as an ammeter, voltmeter or oscilloscope. In the world of electronics, a variety of design packages exist, such as Spectrum Software (2003), Pspice (2003), Circuit Maker (2003) and Electronic Work Bench (EWB) (2003). These professional programs were developed primarily for engineers but are also used extensively in high schools and institutes of higher education. Aside from the educational potential of using simulation for teaching and learning (Milrad, 2002), Israeli pupils tend to use the simulation as a substitute for practical lab tests. In the interviews with the pupils, most of them quickly "built" a circuit using the simulation, which involved locating components on the screen, connecting them to each other, adding measuring devices and "running" the circuit. On the other hand, the pupils had much greater difficulties building their circuit on an actual electronic board. Some made wrong connections, used the power supply improperly or encountered problems when using the measuring instruments. This reflected the fact that during their previous years in school (Grades 10 and 11), the pupils had used simulation for circuit analysis instead of carrying out practical lab experiments. Many teachers complained that "the simulation draws the pupils away from the real electronics world." In their projects, all the pupils started their work by drawing their circuits using the simulation and carrying out preliminary checks. However, later on they spent most of their time constructing the real circuits, troubleshooting and programming. The simulation became a marginal tool, mainly for documentation. All the pupils included professional drawings of their circuits made by the simulation tool in their portfolios.

Using the Internet as a Source for Technical Data, or Cover for Superficial Activities

Teachers and pupils dealing with electronics have just about free access to the Internet in their schools, and almost all of them have Internet at home. The web comprises a large selection of sited on electronics and physics, such as analog circuits, digital circuits, principals of communication, or theory of control systems. Manufacturers like Motorola, Intel, Philips or Hewlett-Packard provide data sheets of their products. Almost all the pupils demonstrated good experience on finding technical information on the Internet, but could not give specific examples of how the Internet helps them to increase their understanding of electronics phenomena or to design electronic circuits.

In some cases, the use of the Internet became as a pseudo symbol of serious learning and investment of efforts by the pupils. In examining twenty five project portfolios, it was found that those pupils who had prepared original or complicated projects had devoted most of their portfolios to presenting their design, the problems they had encountered and how they had solved them. On the other hand, pupils who had worked on simple projects placed pictures, graphs or tables in their portfolios they had retrieved from the Internet, some of which were specifically unrelated to their work. For example, one pupil constructed a simple model of a robotic arm using Fisher-Technick building blocks controlled by a computer. He included in his booklet figures of robots, mentioned that he had retrieved the figures from the Internet, but did not refer to these items in his work. While teachers appraised high-achievers for their efforts in system design and problem-solving, they praised the lower achievers for using the Internet to prepare their portfolios.

Discussion

This study examined the impact of computer-based projects in electronics on learning. Electronics studies in high schools, being an elective subject for pupils majoring in technology, provide a rich and sophisticated learning environment in which pupils work in teams on the design and construction of artifacts and systems relevant to their daily lives. Pupils' projects integrate mechanical elements, sensors, analog electronics, digital electronics and programming. The main question is how computers affect pupils' work on their projects, and to what extent the project work promotes the development of independent learning, creative thinking and teamwork. While pupils who work on hardware-based projects tend to progress in a conventional path of planning, construction, troubleshooting and improving, pupils dealing with computerized projects work differently in three aspects. First, computer-based projects afford the pupils flexibility and a wealth of possibilities to change or improve their systems, or expand on them layer by layer. Pupils who work on computerized projects have a greater tendency to suggest and examine new ideas spontaneously, take risks, improvise, make progress through trial and error, and move rapidly from one solution to another. Second, computerized projects provide the pupils with freedom of action and independence, beyond those that usually exist in school. Teachers fulfill a central role during the initial stages of the projects, primarily in the selection of the project topics and in securing the technical means. Pupils inexperienced in the design and construction of complex systems depend greatly on the teacher's initial guidance. Projects based solely on hardware or analog electronics inhibit pupils from modifying or improving their system, and they usually continue along the course outlined by the teacher. Those pupils working on computerized projects, on the other hand, are much less dependent on the teacher's guidance and tend to take their own initiative, drift away from the initial design suggested by the teacher and develop their projects in unpredictable directions. Third, working on computerized projects produces unique patterns of cooperation and teamwork among pupils: information and knowledge are transferred rapidly from one to the other; new ideas, especially regarding computer programs, are distributed among the pupils, developed and refined, and become their common property. The "Internet culture" influences the ways pupils work on their projects: they quickly zip between sources of information, download programs from different sources and exchange information with friends.

Concluding Remark

Design and the search for efficient solutions to engineering problems require a balance between openness, flexibility, playing with ideas and the use of intuition, on the one hand, and an aspiration towards profundity, logical-mathematical thinking, systematic investigation, discipline and hard work, on the other.

Tough systematic design characterizes novice engineers and pupils, whereas experts tend more to ignore rules and act intuitively, automatically adjusting their behavior to the perceived constraints (Dreyfus and Dreyfus, 1986). When pupils cross the line from fully teacher-guided work to free initiatives and trials, it does not imply they have become experts, rather it indicates that they have developed into confident and independent learners.

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