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From order to disorder: the role of computer-based electronics projects on fostering of higher-order cognitive skills

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Abstract

This research explored learning and thinking processes enhanced by integrating computers in secondary schools electronics projects. Electronics studies provide a sophisticated learning environment, where computers are simultaneously part of the subject matter learned (Technology Education), and a means for enhancing teaching and learning (Educational Technology), as seen in any other area of education. The follow-up on fifty students working on their final projects showed that students working on computer-based electronics projects tend to adopt flexible strategies, such as creating new ideas, risk-taking, improvisation, using trial and error methods for problem solving, and rapid transition from one design to another. In contrast, students working on non-computerized electronics projects are more likely to progress along a linear path: planning, construction, and troubleshooting. Computerized projects also promote the transfer of knowledge between students, and joint development of ideas. Students who exercise freedom in their project do not express the same independence in their documentation, and prepare portfolios that show how they, supposedly, developed their system in an orderly manner. It is important to educate students, and teachers, that creative design and problem solving requires a balance between openness, flexibility, and intuition, on the one hand, and systematic investigation, discipline, and hard work, on the other hand.

Keywords: Application in subject areas; Cooperative learning; Secondary education; Teaching/learning methods

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1. Introduction

The implications of the rapid development of computer technologies for education are evident on two levels, namely the methods of teaching and learning, and the subject matter. The distinction between the terms "Educational Technology" and "Technology Education" is not always clear (Dugger & Naik, 2001). Educational technology is concerned with the use of technological means to enhance the teaching and learning process, across all subject areas. It was expected that information and communication technologies would encourage schools to shift from traditional teaching to methods that emphasize higher-order learning and develop the students' intellectual capabilities. There is, however, a growing awareness that the mere presence of the latest technological devices within the school does not guarantee the achievement of deep cognitive processes (Jonassen, Peck, & Wilson, 2000; Salomon, 1992). Technology education encompasses such areas as design, problem solving, robotics, control systems, and communication systems (ITEA, 2000). Technological studies deal with the development of artifacts and systems that realize people's aspirations, beyond the fulfilling of basic needs such as food, housing, and transport (Dasgupta, 1996). Thus, technology education provides an especially suitable framework for the implementation 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 courses consist of learning computers and hardware and software, while using computers and communication technologies for instruction and learning, as seen in any other area of education. Since electronics studies expose students to the technology underlying the computer, the integration of computers into electronics studies is a natural process, and is perhaps less revolutionary than for other educational fields. Electronics studies, thus, enable the examination of the impact of computer technologies on learning in an area that is fundamentally rich, refined, and challenging. Electronics studies in Israeli comprehensive high schools are highly developed. A large proportion of the students that study electronics are high achievers, who also study mathematics and other academic subjects at a high level. Naturally, most of the students and teachers involved in electronics are also strongly oriented towards computers and the Internet. How did computers penetrate the teaching and learning methods? To what extent have the expectations that the technological means would contribute to meaningful and in-depth learning been realized? This study examined these questions by following electronics studies in twelve Israeli high schools, over a period of two years.

2. Literature survey

There is a wide consensus that a major goal of modern education is to develop students' higher-order thinking skills, such as the ability to synthesize information, solve problems, combine facts, generalize, hypothesize, and arrive at logical conclusions. These are cognitive processes, involving the application of ideas, analysis, synthesis, evaluation, creativity, and critical thinking (Gentile, 1997). Constructivism regards the learners as active independent participants, who build their own knowledge, organize their experiences, and construct models or representations (Von Glasersfeld, 1996). Constructionism (Papert, 1991) is a theory of learning that asserts the constructivist theories that learners form their ideas and construct their own knowledge structures through actively building technological artifacts, such as mini-robots. Perkins (1986) supports the view that students learn most from design and construction activities, rather than from utilizing ready-made knowledge. Constructivism places a critical emphasis on the social aspect of learning and regards social interactions as the shared outcomes of students' activities.

Encouraging creative thinking in science and technology studies is particularly difficult as teachers emphasize that mathematical-logical thinking is the only valuable thinking, and reward students for giving the 'right answer' rather then for their originality or richness of ideas. A widely accepted definition of creativity is 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; Howard-Jones, 2002). Fostering creative thinking at school requires an atmosphere of openness to experience, tolerance of ambiguity, freedom, and safety (Harman & Rheingold, 1984). Creativity is promoted more by intrinsic then by extrinsic rewards (Hennessey & Amabile, 1998; Sternberg, 1999). Students are unlikely to take on the challenge of complex tasks, to take risks, or to experiment with the unknown when teachers emphasize competition, exams, and grades.

Many educators point out the potential of enhancing learning with intelligent technologies (Scardamalia & Bereiter, 1996; Salomon, Perkins, & Globerson, 1991). Salomon (1998) suggested that information and communication technologies differ from the 'old' educational technologies, such as television broadcasting and multimedia systems means, in four aspects: first, computers and communication systems are not only knowledge-transfer technologies but also knowledge-building technologies. Second, computer technologies are not knowledge-receiving technologies, but rather they facilitate the intellectual partnership between the learner and the sophisticated and intelligent tools (Pea, 1993). Third, computer technologies are not restricted to the individual learner, but rather they present opportunities for shared thinking and knowledge construction. Fourth, novel computer technologies do not constitute tools for structured teaching, but rather encourage open learning, and challenge the learner with enormous knowledge resources when confronting challenging problems. Jonassen et al. (2000) stress that computer technologies promote meaningful learning only when learners are engaged in knowledge construction, conversation, articulation, collaboration, authentication, and reflection.

Technological studies constitute a natural platform for a constructivist learning environment, mainly a project based learning and problem solving. Technological projects present students with the opportunity to confront real-world complexities, to work collaboratively, to develop problem definition and solving skills, and to reflect on their own learning (Johnson, 1997). 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 students' projects, and the extent to which computers affect learning. The present study examines the influence of computers on the ways high school students work on final projects that involved 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 on the quality of the teamwork exhibited by the students.

3. The research

3.1. Participating population

The research presented here is part of a comprehensive study of the teaching of electronics, conducted in comprehensive high schools in northern Israel (Barak, 2002). These schools are located in large, well-established cites, and in peripheral settlements. The students took electronics as an elective subject, in parallel to their general studies. A final project in electronics is optional, but it awards additional credit points on the Matriculation certificate, which affords the student the option to enroll in academic studies. In recent years, schools have been encouraging students to submit final projects, with the purpose of increasing interest in electronics and attracting the best students to this field. The present study closely followed the work of fifty mid-level achieving students, from six schools, who worked in pairs on twenty five projects. Approximately half of the projects combined hardware and software, while the others were based solely on hardware.

3.2. Method

According to the principles of qualitative research, no specific research questions were formulated in advance (Guba & Lincoln, 1994, XXX). The study aimed to collect as much information as possible on the teachers' and the students' activities relevant to the integration of computers into electronics projects. The information was collected as follows:

1. Visiting each school three or four time year, over a period of two years (totalling about 80 visits). During each visit, the researcher met with each pair of students while at work in the laboratory, observed the electronic system they built, their computer files, and the portfolio they prepared.
2. Observing projects' official final exams at five schools. At three school, the researcher talked to the students, the teachers, and the examiners both before and after the exams. At two other schools, the researcher himself served as an official project examiner, and explored students' projects in depth.
3. Observations and conversations were held with students and teachers during countrywide projects exhibitions and prize contest for students, held over two consecutive years.

The collection of data continued as long as significant new facts were found, and was stopped when findings started to repeat themselves. Throughout the process, interim summaries of the findings were made on the students' work methods and on the attitudes of the students themselves toward their own progress on the projects.

3.3. Data analysis

As customary in qualitative research, data analysis was applied to organize the data, to break it down into meaningful units, and to synthesize it, so that critical themes would emerge (Bogdan & Bilken, 1992; Patton, 1990). Thus, the data was first broken down into a range of discrete categories, based on participants' remarks during classroom activities. Then, the categories were reexamined to determine the way in which they are interlinked, and then rearranged to give a more comprehensive picture. These categories are the sub-titles of Section 4. The process of collecting and processing the data was not linear. Every finding or conclusion was re-evaluated through repeated conversations with the research subjects themselves – the teachers and the students – forming a cyclic process. Two colleagues, researchers in scientific and technology education, and three experienced teachers from schools that did not take part in the study, participated in the data processing and drawing of conclusions.

4. Findings

4.1. Overview on the integration of computers in electronics studies

From the interviews and informal conversations held with the teachers, it was found that in order to understand the broader context of the issue of the integration of computers into electronics studies in Israel, one must go approximately thirty years back, to the period before the appearance of computers in the form with which we are familiar with today. Five stages in the development of the field can be discerned:

- The 1970s – *Fundamentals of digital electronics.* Subjects taught in schools included the fundamentals of numeric systems, such as binary codes, number systems, switching algebra, logical gates, flip-plops, shift registers, and counters.
- The 1980s – *Microprocessors and peripheral components.* Students learned the interior structure of the processor and Assembler programming language. This was considered an integral part of the world of electronics, and the word *microprocessor* was better known than the word *computer*.
- The 1990s – *Personal computers*. The first generation of IBM PC and XT computers, which were based on Intel 8088/8086 processors, spread widely throughout the school system. This encouraged the teaching of Assembler programming, relating directly the computer's own processor, Basic programming, Pascal and C.
- Early 2000s – *Computer communications and the Internet*. The current curricula for the teaching of electronics in schools include the study of computer communications and Internet protocols. Students use C++ or Visual Basic programming languages. Additional updating of the curriculum includes advanced topics in the fields of robotics, and voice and image processing.

In this study, we focus only on the integration of computers into students' final projects. Most of the projects are concerned with the computerized control of electro-mechanical systems. The students connect the computers to a range of systems, such as mini robots or computerized greenhouses, by means of interface cards or the standard serial/parallel ports. Programming is carried out in assembler, C or visual basic. Students' projects also employ a range of industrial programmable logic controllers (PLC), based on ladder diagram programming.

In the preliminary conversations, teachers described the way in which computers are integrated into electronics studies. The more senior teachers reminisced about the early days of projects:

- "We spent days and nights learning the hardware and the software, especially assembler language programming."
- "Integrating the microprocessor into the students' projects, such as mini robots or computerized elevators, was exciting, because for the first time we could build truly sophisticated systems."
- "We felt like pioneers, breaking the boundaries of conventional electronics."
- "We walked hand-in-hand with the state-of-the-art industry of those days."
- "When the other teachers were using computers primarily for word processing or for games, we were connecting computers to control systems such as mini robots or computerized greenhouses via digital and analog interfaces."
- "The students wrote programs for the control of practical systems in Basic or in Pascal, languages which caused great excitement since they were much easier and more elaborate in comparison to Assembler programming language."

The appearance of personal computers, and their ease of use, pushed forward the systematic teaching of conceptual topics in electronics and control, such as signal sampling, analog-digital conversion, and feedback control algorithms (Barak, 1990).

4.2. Students' working methods on computer-based electronics projects

In the world of technology, it is customary to present universal models for the design of technological systems or products that include the following stages: identification of a problem or of a need, data collection, research, selection of the optimal solution, planning, construction, evaluation, and improvement (Johnsey, 1995). In the present study, we found that, in their work on projects in the field of electronics, and specifically on computer-based projects, teachers and students follow this model only loosely.

4.3. Choosing the project topic: inventing something new or imitating an existing system?

At the topic selection stage, the students were required also to choose the kind of electronic system and components they would use. These included, for instance, analog or digital electronics, microprocessors, computers, mechanical systems and sensors. Observations and conversations held with the students and teachers in the schools revealed students choose topics for their projects in a brief process. Teachers present the students with a list of topics, each accompanied by a short explanation. Most of the topics are based on components that exist in the school, such as Lego or Fischer–Technik sets, which include building blocks, motors, and sensors. The teachers show the students the available kits or projects from previous years. Many of the topics, such as "traffic lights", "elevator", "greenhouse" or "computerized parking lot", imitate systems familiar to the students from everyday life. Such topics tend to reappear in from year to year and from school to school, in quite similar versions. Only a handful of students from among dozens participating in this study, proposed their own topic for their final project. This was usually due to a personal interest in an area close to their parents' field of occupation. Many students admitted that they chose a topic for their project in a random manner.

4.4. Choosing a solution: are various options examined seriously?

After the students choose the subject of their project, they immediately approach the implementation of the solution they have chosen, including building models, constructing electronic circuits and writing computer programs. Earlier in this paper, we have used the term "imitating existing systems" rather than "improvement" or "enhancement" because the students performed no serious investigation regarding the structure, the properties, or the shortcomings of the practical systems with which they were involved. For example, many students built models of elevators or robots that operate using stepper motors merely because such motors are easy to control using a computer. In reality, stepper motors are inappropriate for the operation of elevators, and even in robotics their use is very rare. During the early stages of students' work, no evidence was found of activities that characterize creative thinking, such as a search of multiple ideas, lateral thinking or brainstorming. Within dozens of projects examined, it was rare to find indications that students seriously compared several solutions or used pre-defined criteria for decision-making.

4.5. Ongoing modification and refinement of the systems

At a certain point of working on the project, after the students realized that the systems they had designed worked, a difference was discernable in the work methods of students working on conventional projects and those working on computerized projects. Most of the students who were involved in non-computerized projects continued to work on the system they had built and made only minor changes or improvements to it. Some of them decreased their efforts or completed their projects before the official due date. In contrast, most of the students who were working on computerized projects tried to refine or enrich the systems they had built. Following are some quotes from conversations held with students who had repeatedly modified their systems:

- "A computerized project holds a special challenge... It was the first time that I felt I was not trapped between the keyboard and the screen."
- "What is appealing is that one can step out of the boundaries of the square box (the computer) into the outside world... write programs that operate all kinds of apparatus and immediately see the results..."
- "The computerized systems challenge you... The more advanced you are in the project the more you want..."
- "The project grows and develops and every day there are new ideas.... You have the freedom to try out your ideas... You can try out more and more ideas."

4.6. From a "school solution" to an original design

During the initial stages of the projects, the students relied mostly on knowledge that they had acquired and practiced during electronics and computer classes in school. Such topics include analog electronic circuits, digital electronics, and computer programs. While developing their computerized projects, the students changed significant portions of both the software and the hardware, and at times rebuilt the entire system. Students described this work process as follows:

- "In the beginning you go according to what you know... The electronic circuits that we built in the project are very similar to what we learned in class... On the other hand, when writing the programs, you go deeper and deeper... sometimes you even become entangled."
- "In the beginning, we write simple programs but gradually we change and add more and more on to them... In the end, parts of the programs are not at all similar to anything we have learned... This is why it is also sometimes hard to explain to others what we have done or to receive help."

4.7. Improvisation and patching

When closely observing students' work, over the critical 4–6 weeks of system development, it could be seen that the students' progress was not linear, but seemed at times to be an improvisation, a "sewing" of patch over patch. Many of the students spontaneously raised more and more ideas for the refinement of their system. In some cases, the students 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 in hardware, changes in software are easier to check, adopt, or withdraw. The work method adopted by many of the students is similar to the rapid "zapping" between television stations, or to fast surfing of Internet websites: checking out for a moment and deciding whether to stay or to try something else.

4.8. Knowledge transfer and joint development of ideas

The observations made in class and the conversations held with the students showed that the students who worked on computerized projects cooperated among themselves significantly more than students who worked on non-computerized projects based on conventional electronics. Students exchanged ideas or solutions to hardware and software problems. The researcher found identical portions of computer programs in files belonging to different students, from the same school or from different schools. For instance, one of the more useful functions in computerized projects is reading information from the keyboard. In their projects, many students had initially used software segments that were similar to whose they had learned in their electronics class. After a group of students wrote a different algorithm that seemed to be more efficient, students from other groups copied it and changed their own programs to incorporate it. Sometimes the ideas travelled from one place to another aided by teachers who were guiding students from different schools. Students and teachers adopted the approach that it is not appropriate to copy physical models or electronic circuits from others. On the other hand, software is perceived as shareware and it is legitimately transferred from one to another. This presumably is an indirect effect of downloading a variety of software from the Internet. The knowledge transfer among students was not limited to the transfer of ideas. When a certain idea was "thrown" into the air, it spread among the students and took on new shapes and versions. The following example illustrates how students received an idea from one domain, and refined and adapted it to fit another domain. One of the more prevalent formats in writing programs for the control of computerized systems is a

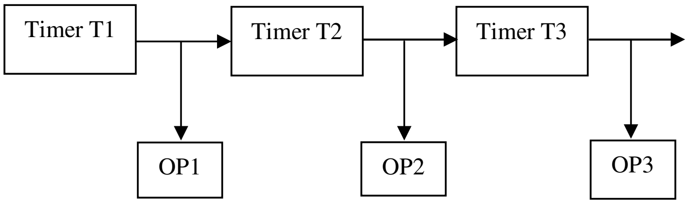

Fig. 1. Execution of a sequence of operations using a chain of timers.

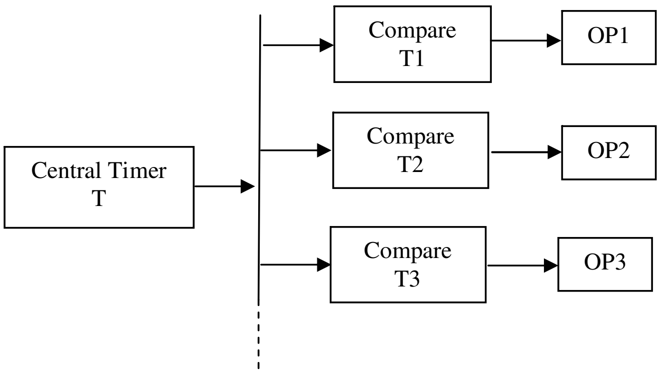

Fig. 2. Execution of a sequence of operations using a central timer.

series of delayed operations, such as an illumination sequence of red, yellow and green lights in a traffic light or operations for the preparation of coffee using an automatic coffee machine. The common method for the programming of a sequence of such operations is using a chain of timers that activate each other, as shown in Fig. 1. This principle can be applied to all kinds of digital systems, such as discrete hardware components, microprocessors, high-level languages, or programmable controllers. The drawback of this structure is that any change in the time delay of one of the timers affects all of the timers positioned after it in the chain.

One of the students came up with the idea that each operation should be controlled separately and thus recreated his program using a central timer and a series of "compare" operations, as illustrated in Fig. 2. This idea rapidly spread among the students, and several of them rewrote their programs using the same method.

Students who had built a "lights game' project using a PLC took the idea several steps further: They defined a number of timers, which ran at different speeds, and central counters, which counted forwards or backwards. Thus, they created varied possibilities for the lights sequences.

The cooperation between the students was at times accompanied by negative phenomena. Cases were found in which students who did not meet the project deadlines, or who encountered difficulties, used portions of computer programs copied from others at the last moment, without even understanding the programs and without contributing to them in any material way. When dealing with software it is very difficult to determine the fine line between joint work, imitation, and outright copying.

4.9. From unstructured work to ordered documentation

We have discussed how students advanced in their work on the project and gained confidence, adopting work methods that seem to break the accepted school conventions: improvisation, copying ideas from others, and performing unplanned changes in the projects. These work patterns, which look like loss of control over the students' work on the part of the teachers, are in fact an expression of creativity, flexibility, and openness of the students. The students, however, tried to show that they had developed their product or system in a systematic way, based on ordered planning. Of the dozens of projects examined, rarely the students pointed out in their portfolios that their final product differed much from the original design or that they had improvised solutions. One student expressed himself in a conversation as follows:

- "The examiners (in the matriculation exams) expect us to show how we worked in an orderly manner..."
- "Imagine me writing in my project book that I changed my project several times or that I took ideas from others..."
- "Although I decided only towards the end how the machine I built would look, I'm not including the versions I tried in my project book."

4.10. The teachers' perspective: an example of a teacher's proposal for a computerized project

The example presented below reflects the advantages of computerized projects, as teachers see them. A teacher, from a school that did not initially participate in the study, prepared a project proposal for young students. The proposal consisted of a circuit that activates LEDs in various combinations, a kind of computer-controlled light game. The teacher posted the proposal on his private website and teachers from the schools in the study referred the researcher to the website. The proposed system included an infrared remote control, a receiver connected to a computer through five input terminals in the printer connector, and eight LEDs that are activated through eight output terminals of the printer connector. The student is required to build all of the system's components and to write computer programs that receive the signal from the remote control and activate various combinations of LEDs. On his website, the teacher posted all of the technical information required to build the electronic circuits, and examples of computer programs in Assembler language. The following are original quotes from the Introduction written by the teacher:

"In this project, the students build a "game", with which they can have some fun... Since I am in the midst of the process, I can already report that I, as a teacher, am enjoying the process... I have to "kick" my students out of the laboratory... The spontaneous joy of the students when something "works" is worth the effort... Although all of the students build identical circuits, the LEDs can be positioned differently and the structure of the remote control can be designed according to the creativity... They can be expected to be original and creative in writing segments of the software and the effects of the lights."

This example illustrates several of the points mentioned above: a great deal of information about the projects is distributed among teachers and students while working on the projects; copying ideas or design details of various systems is legitimate; the expectation of student creativity focuses on the programming more than on the hardware aspect of the project.

5. Discussion

This study examined the implications of the integration of computers into electronics projects, in particular on the development of significant learning and the imparting of high cognitive skills. Students' electronics projects handled topics in digital electronics, computer hardware, and programming. Electronics studies facilitate a constructivist learning approach, in which students work in teams on the design and building of artifacts and complex systems, in a rich learning environment. The main question is how computers affect the way in which students work on their projects and how computer-based electronic projects develop independent learning, creative thinking, and team work.

The follow up on students work on their final projects revealed differences in ways of working on analog electronics projects, in comparison to working on computerized projects. Most of the students who work on non-computerized projects tend to progress linearly: planning, construction, and troubleshooting. On the other hand, the flexibility and abundance of possibilities afforded by computerized projects encourage students to change or improve the planned system, adding to it layer by layer. The students who work on computerized projects have a greater tendency to adopt the following kinds of strategies in their work:

- Spontaneous raising and immediate examination of new ideas.
- Risk-taking.
- Improvisation.
- Development of computer programs by way of trial and error.
- Rapid transition from one solution to the next.

Computerized projects allow the students freedom of action and independence, beyond those that usually exist in the context of the school. Teachers fulfil a central role in the initial stages of the projects, primarily in the selection of the project topics and in securing the technical means, such as construction kits, sensors, interface to computers and software. Students 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 students from modifying or improving their system, and they usually continue along the course outlined by the teacher. Those students working on computerized projects, on the other hand, are much less dependent on the teacher's guidance and tend to take their own initiative. Many of them drift away from the initial design suggested by the teacher and develop their projects in unpredicted directions. Working on computerized projects produces unique patterns of cooperation and teamwork among students: information and knowledge are rapidly transferred from one to another; new ideas, especially regarding computer programs, are distributed among the students, developed and refined, and become their common property.

Students who take more freedom in their project do not express the same freedom in their documentation. They believe that they are expected to work in a systematic manner. Consequently, they create a portfolio that shows how they, supposedly, developed their system in an orderly manner. They have learned from experience that those who evaluate their work, teachers or examiners, give credit for more orderly work then for an abundance of ideas, semi-random experiments, and improvisation. These work methods do not receive legitimization in the school, despite the fact that research in the area of the history of science indicates that a significant number of scientific discoveries and technological inventions arose in an unplanned manner, based upon intuition or the performance of experiments with no pre-structured theory. According to Kantorovich (1993), scientific novelty generated through events dominated by serendipity, tinkering, or random variations, is not a marginal phenomenon. Systematic design characterizes novice engineers and students, whereas experts tend to ignore rules and act intuitively, automatically adjusting their behaviour to the perceived constraints (Dreyfus & Dreyfus, 1986). When students cross the line from fully teacher-guided work to free initiatives and trials, it does not imply they have become experts, but it indicates that they have developed into confident and independent learners.

6. Concluding remarks

Computer-based technology projects encourage creativity and the growth of knowledge out of spontaneous cooperation between the students. It is important to teach the students that a creative, but efficient, solution to an engineering problem requires a constant balance between openness, flexibility, playing with ideas, and use of intuition, on the one hand, and an aspiration towards profundity, logical-mathematical thinking, systematic investigation, discipline, and hard work, on the other hand. Just as it is important to teach students the theoretic basis of the topics they are dealing with, so there is a need to teach them systematic work and creative thinking in planning and in solving problems.

References

Barak, M. (1990). Imparting basics in technology through an instructional system for computerized process control. *Research in Science and Technology Education, 8*(1), 5367.

Barak, M. (2002). Learning good electronics, or coping with challenging tasks? Priorities of excellent students. *Journal of Technology Education, 14*(2), 20–34.

Bogdan, R. C., & Bilken, S. K. (1992). *Qualitative research for education: an introduction to theory and methods* (2nd ed.). Boston: Allyn and Bacon.

Csikszentmihalyi, M. (1996). *Creativity: flow and the psychology of discovery and invention*. New York: Harper Collins.

Dasgupta, D. (1996). *Technology and creativity*. Oxford: Oxford University Press.

Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over machine: the power of human intuition and expertise in the era of the computer*. New York: The Free Press.

Dugger, W. E., & Naik, N. (2001). Clarifying misconceptions between technology education and educational technology. *The Technology Teacher*(September), 1–6.

Gentile, J. R. (1997). *Education psychology* (2nd ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

Guba, E., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin, & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 105–117). Thousand Oaks, CA: Sage Publications.

Harman, W., & Rheingold, H. (1984). *Higher creativity*. Los Angeles: JP Tarcher.

Hennessey, B. A., & Amabile, T. M. (1998). Reward, intrinsic motivation, and creativity. *American Psychologist, 53*, 674–675.

Howard-Jones, P. (2002). A dual-state model of creative cognition for supporting strategies that foster creativity in the classroom. *International Journal of Technology and Design Education, 12*, 215–226.

International Technology Education Association (ITEA) (2000). *Standards for technological literacy: Content for the study of technology*, Reston, VA: Author.

Johnsey, R. (1995). The design process – does it exist?. *International Journal of Technology and Design Education, 5*(3), 199–217.

Johnson, S. D. (1997). Learning technological concepts and developing intellectual skills. *International Journal of Technology and Design Education, 7*, 161–180.

Jonassen, D., Peck, K., & Wilson, B. (2000). *Learning with technology: A constructivist approach*. Upper Saddle River, NJ: Prentice Hall.

Kantorovich, A. (1993). *Scientific discovery: logic and tinkering*. Albany: State University of New York Press.

Papert, S. (1991). Situating constructionism. In I. Harel, & S. Papert (Eds.), *Constructionism*. Norwood, NJ: Ablex Publishing Corporation.

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognition* (pp. 47–48). NY: Cambridge University Press.

Perkins, J. (1986). *Knowledge as design*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Salomon, G. (1992). New challenges for educational research: Studying the individual within learning environments. *Scandinavian Journal of Education, 36*, 167–182.

Salomon, G. (1998). Novel constructivist learning environments and novel technologies: some issues to be considered. *Research Dialog in Learning and Instruction, 1*(1), 3–12.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: extending human intelligence wit intelligent technologies. *Educational Researcher, 20*(3), 2–9.

Scardamalia, M., & Bereiter, C. (1996). Engaging students in a knowledge society. *Educational Leadership, 54*, 6–10.

Sternberg, R. J., (Ed.). (1999). *Handbook of creativity*. Cambridge, MA: Cambridge University Press.

Von Glasersfeld, E. (1996). Introduction: aspects of constructivism. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspective, and practice* (pp. 3–7). New York: Teachers College Press.

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