# Children as Innovators in Action – A Study of Microcontrollers in Finnish Comprehensive Schools

Esa-Matti Järvinen, Arto Karsikas, and  Jouni Hintikka

In authoritative teaching methods, whereby the teacher controls the social interaction and other classroom activities, the actions of many children are often in response to what they perceive to be the teacher's expectations and the requirements of traditional school evaluation practices, such as examinations and tests (Edwards & Mercer, 1987; Vygotsky, 1997, p. 126). In this kind of school setting, children do not necessarily feel the teaching and its content to be personally important or useful. For this reason, it is difficult for them to make meaningful connections between what they are taught and their everyday life. To make learning more authentic and meaningful to children, it is essential to give them a sense of ownership for their learning (Savery & Duffy, 1995). As epitomized by Biesta (1994, p. 315), it is important that the "contribution of the child is not a pseudo-contribution that is totally dependent upon the intentions and activities of the teacher." In this regard also, von Glasersfeld  (1995, p.14) wrote aptly "[p]roblems are not solved by the retrieval of rote-learned 'right' answers. To solve a problem intelligently, one must first see it as one's own problem." Moreover, it is important that children be able to work in an atmosphere which is low in stress and allows concentration on the task at hand (Futschek, 1995).

Since technology can be seen as a response to "satisfy human needs and wants" (Black & Harrison, 1985; Dugger & Yung, 1995; Savage & Sterry, 1990) and as human innovation in action (see ITEA, 2000), teaching methods in technology lessons should be adjusted accordingly. Problem solving is also considered essential in a technological process (e.g., McCormick, Murphy, Hennessy, and Davidson, 1996).

In technology lessons the problems to be solved should relate to children's real life environment, allowing them to make appropriate and meaningful connections (Schwarz, 1996). Children should be given opportunities to explore and pursue their own needs and interests. They should be encouraged to identify problems and deficiencies in their everyday environment and be given

Esa-Matti Järvinen (esa-matti.jarvinen@oulu.fi), Arto Karsikas (arto.karsikas@oulu.fi), and Jouni Hintikka (jouni.hintikka@oulu.fi) are with the Oulu Southern Institute, University of Oulu, Finland.

opportunities to apply the technological knowledge and skills they have acquired in technology lessons and through previous problem-solving experiences (Adams, 1991).

## Study Purpose

The overall purpose of the study was to help children become familiar with some essential features of microcontroller technology and its possibilities in various aspects of everyday life. Moreover, the study essentially aimed to encourage children to engage in innovative thinking in finding uses for microcontrollers to meet their own needs and purposes. More specifically, the study involved the following:

*Give children opportunities to learn about the human-made environment (technology).*

In accordance with this aim, an effort was made to enhance the children's understanding of the human-made environment "such as it is." This aim is close to the goals of most school subjects, where teaching aims to increase understanding about the world at large. In this respect familiarization with microcontrollers and their programming introduced a very contemporary content area to technology education.

*Give children opportunities to engage in the processes of technology, i.e., to design, make, and apply technology in a creative and innovative manner*

This aim could also be exemplified in the definition: "Technology is human innovation in action" (ITEA, 2000). If the "message" of this definition is the basis for teaching technology, it cannot merely involve the study and consideration of the functional principles of microcontroller technology as an end in itself. Children need to be given opportunities for creative and innovative action as well. This is why the study aimed to focus on the innovative uses of microcontrollers in applications that arose from the pupils' own needs and ideas. Ultimately, the study was directed toward this question: What type of microcontroller applications emerged in the children's own projects?

## Study Methodology

*Instructional and Research Context*

The study reported herein was carried out within a European Union-funded research and development project in technology education at the University of Oulu. It was the first study in Finland to introduce the teaching of microcontrollers in primary schools. The microcontroller system used in the study is based on the Picaxe-08 system developed in England by Revolution Education Ltd. (see www.rev-ed.co.uk/picaxe) and it was modified collaboratively with a Finnish company, Step Systems Ltd., so that it could be better applied to the pedagogical aims of the study. The Finnish Association of Graduate Engineers (TEK) provided support in the purchase of materials and equipment for the study.

The participants consisted of both primary and secondary school teachers who had been taking part in the Technology Education *NOW!* project over a period of years. All project schools were supplied with information about a microcontroller called the "Picaxe" and associated activities. Over 50 teachers were contacted and given the opportunity to participate and 12 elected to do so. The study was carried out during school years 2003-2005.

First, the Picaxe-08 system was introduced to the teachers by arranging a two-day in-service training course. The course consisted of both theoretical and practical aspects of microcontrollers with a special emphasis on the Picaxe-08 system. Another focus of the training was the programming software. Importantly, the teachers were also encouraged to make their own innovative Picaxe applications and this pedagogical advantages of doing so was also emphasized. This perspective was emphasized for the teachers to take into account within the forthcoming Picaxe project with children.

Second, Picaxe software and hardware, including components for children's applications, were sent to the participating schools. Instructions for introducing the microcontroller system to the children were included in the Picaxe package.

The Picaxe-08 system shown in Figure 1 is a relatively new kind of tool for applying microcontrollers in an educational setting and is based on the 8-pin PIC (Peripheral Interface Computer) integrated circuit chip. While programming, children can design the functions desired by means of a flowchart or by using the BASIC language, after which the program is downloaded with a serial cable to the microcontroller on the project (circuit) board. To enable children's innovativeness, a special project board was designed for the study (see Figure 1). First, the children constructed a project board using instructions and diagrams provided (Figure 2). However, the project boards were just 'starting points' and used to familiarize the children with the Picaxe materials before actually beginning the design activity (Figures 3-7). In the end, the idea was that the children could design, make, and program an application rising from their own ideas and needs. To enhance thinking of different possible applications, a wide variety of components were sent to the schools. These included light emitting diodes (LEDs), buzzers, lamps, motors, sound recording modules, miniature water pumps, as well as sensors such as various kinds of switches, passive infrared sensors (PIRs) as well as negative temperature coefficient (NTC) thermistors and light dependent resistors (LDRs). The software is available free of charge from the manufacturer and most of it has been translated into Finnish. One important feature of the Picaxe system is that children can reprogram the device repeatedly, designing new and improved applications to their liking.
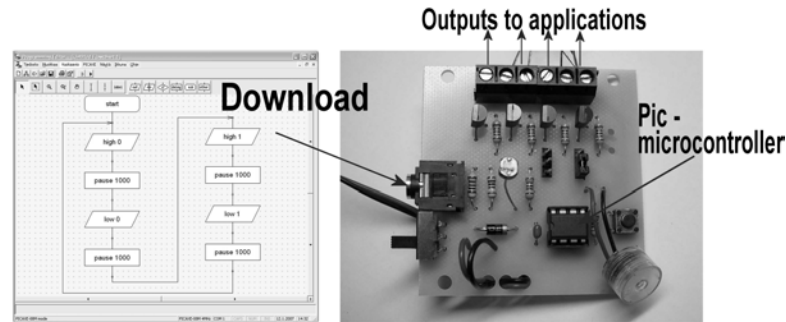
*Figure 1.* The flowchart software and project board used in the study



*Figure 2.* The project board being assembled (left) and being tested (right).

*Study Participants*

Twelve comprehensive (primary and secondary) school classes of grades 5-8 (ages 11-14 years) participated in the study. The number of children involved was 230. The participating schools were located in Oulu Province: Järvikylä School in Nivala, Oksava and Martinmäki Schools in Haapajärvi, Vattukylä, Hyttikallio and Karhukangas Schools in Haapavesi, Ruukki School in Ruukki, Kestilä Central School in Kestilä, Matkaniva and Petäjäskoski Schools in Oulainen, Lintulampi School in Oulu and Kärsämäki Central School in Kärsämäki. All the participating schools were state schools, which is the predominant comprehensive school system in Finland.

*Data collection*

True to the qualitative data collection methods, multiple data sources and strategies were employed, applying the concept of triangulation (Miles & Hubermann, 1994: 266). Data were collected in the following ways: Pictures taken of the children working while making the Picaxe applications, teacher's written reports, researcher's notes of the process and applications, children's written and drawn sketches of their applications, photographs and video clips of

the children's final outcomes, as well as interviews of children documented on video recordings. The interviews were carried out in authentic situations where children explained their applications. The questions asked from the children emerged spontaneously from the situation. Thus, the interviews were not pre-structured and, consequently, there was no "standard" time that they lasted either. Moreover, not every child was interviewed. Some of the children's applications called for more explanation than others. For example if the teacher told the researchers that not all the essential information of the child's application were to be found in the sketches, drawings, etc., an interview session was arranged to deepen the understanding of what the child had actually done and accomplished.

*Data Analysis*

During the first round of analysis, the researchers began to form an idea of the emergent categories relative to the theme of this study. In subsequent analysis rounds the data revealed more organized patterns relative to the research question. During the analysis process, the researchers were continually open to re-exploring the relationship between the data and emergent findings and making revisions correspondingly. They discussed and shared thoughts on several occasions. The data examples presented in this article were considered individually and also in the collaborative discussions (see Ritchie & Hampson, 1996). Finally, the researchers reached the stage where they considered to have investigated the entire body of data sufficiently relative to the research problems. Once the researchers reached the "saturation point" with the data, efforts were redirected to presentation of the results and related analysis.

**Results**

The categories presented in the Table 1 are the result of going through the data several times and searching for emerging patterns. The categories indicate that the systems the children designed and built with the Picaxe were rather varied. Even within one classroom there was a rather large variation in what children made for their Picaxe application (except in the case of Amusement Park Devices, Hydro-Copters and Race Cars). This is an interesting phenomenon in itself, for children tended to be rather independent in pursuing their own idea.

**Table 1**
*Categories and examples emerging from the data*

| Categories and Examples | | | |
|---|---|---|---|
| **Modeling Existing Devices** | **Everyday Needs** | **Competition** | **Just for Fun or Decoration** |
| Amusement park devices | Burglar alarm systems | Race cars | Joe-boy, the talking parrot |
| Traffic lights | Presents for mother | | Fountain |
| Hydrocopters | Name plates using LEDs | | Music applications |
| Low light sensor | Sound recording module | | Map of Finland with LEDs |
| | Fish feeding system | | Logo of the ice-hockey team with LEDs |
| | | | Small bushes/trees with LEDs |
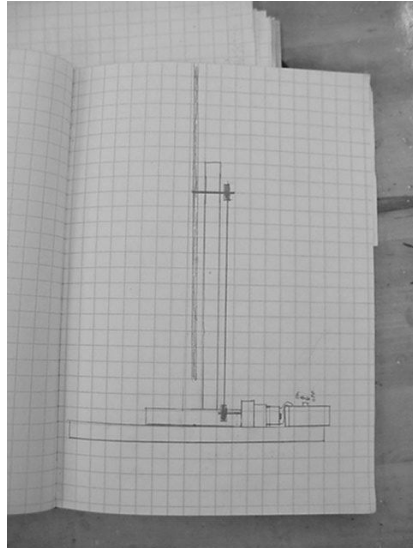
Sketch of Sun Spin

Sun Spin

Dim Light Sensor

Ferris Wheel in the Making

HydroCopter

*Figure 3.* Examples of modelling existing devices (1)

Amusement Park

*Figure 4.* Examples of modelling existing devices (2)

*Modeling Existing Devices*

Some students modeled existing devices. For example, most of the amusement park devices shown in Figures 3 and 4 are what would be found in actual amusement parks. The children have seen them while visiting the parks and modeled the devices accordingly. The other applications, like traffic lights and hydro-copters, involved the same idea of modeling something that already exists. Even though the dim-light sensor shown in Figure 3 has the obvious idea of practical need, it can be regarded more as a model of the existing device, for it was not meant to be used as a "real thing."

There was also an innovative bias in some of the applications in this category. For example, designing the light control system for hydro-copters, and figuring out how to make it function properly inspired children to be problem-sensitive and even innovative. But, the overall process started with the willingness to make miniature models of existing devices. Thus, doing something which would be a response to emergent needs and purposes was not a primary motive.

*Meeting Everyday Needs*



Programming an LED Flower



Presents for Mothers' Day



Making a Burglar Alarm

*Figure 5.* Examples of projects designed to meet everyday needs.

**Excerpts from Video Clips**

*Excerpt 1 – In reference to Burglar Alarm in Figure 5.*

> Researcher:
>  Could you tell me how came up with that idea?
> Child:
>  We came up with this idea…because some unidentified visitors had
>  visited our hut in the woods….and the teachers told us that we'll do
>  these things [microcontroller systems] I got an idea that I can make a
>  kind of alarm system….and actually it has served the need pretty
>  well…
> Researcher:
>  Could you tell me how it works?
> Child:
>  [showing the alarm system to the researcher] here is the on/off
>  switch....and here is a sound recording module on which you can
>  record whatever you want to say….and when the system is activated
>  …and when it [passive infrared sensor] identifies somebody
>  moving…the system switches on the [LED] eyes and plays the
>  recorded message, "unauthorized access denied!"

*Excerpt 2- In reference to Sound Recording Module*
> Teacher:
>> OK, could you tell me what that is?
> Child:
>> If I'm not at home….somebody can leave a message on it [Sound recording module] by pushing a button and when I come home I can listen to the message.
> Teacher:
>> Yes… that is useful.

This category includes more innovative applications which tend to be responses to needs and purposes identified by the children. It was essential among these ideas that the children wanted to solve a practical problem arising from their personal living environment such as the burglar alarm system illustrated in Figure 5 or a fish feeding system. Importantly, the applications were tested in the actual situation in which they were intended to be used. If the application, such as the burglar alarm system, did not function properly it was modified and tested again.

Although there already are many burglar alarm systems in the environment in which the children live, they did not copy these existing systems. Instead they connected components into the applications supplying their own needs, as was the case in "Unauthorized access denied!" In Excerpt 1 the child (12 year old 6th grader) explained both the problem which 'ignited' the technological process and the principle upon which the system operated. In Excerpt 2 the response of the child (12 years old 6th grader) reveals the starting point for the process of performing the application with the Picaxe. It is analogous to a modern version of writing a quick message on a paper. Though the on-site interviews exemplified by the two excerpts above were not conducted with most students, they did provide some details that would not have otherwise been known.

Presents for mother are made every year in Finnish schools, but the Picaxe project and associated materials took the students in a different direction from the greeting cards typical of the past. Some of these new ideas are shown in Figure 5. Importantly, the process started by doing something that would actually operate in response to the needs and purposes identified by the children themselves. This in itself is an important notion and makes creating the technological application real for the student instead of contrived as many school projects can end up being. It is a technological solution that they created even though the hardware and software they used already was in use in "the adults' world." (Savery & Duffy, 1995)
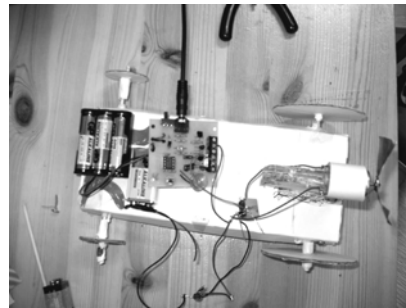
*Competitions*

Despite concerns to the contrary, competitions do seem to be very useful in teaching technology. When competing with each other, children tend to be very motivated and focused in problem-solving. For example, if they do not have the fastest race car, they are motivated to see how they can make it perform better.

Race cars model elements in the real world. However, children are not limited in their thinking to duplicating what already exists. For example, some children supply motive power using propellers instead of using the traditional idea of supply power to wheels. See Figure 6. The creativity of the student can be enhanced and expanded by how the problem is stated. For example, if the problem is to build the "fastest device" instead of the "fastest car," children tend to think differently.



Finishing touches being added to race car

Program downloading to micro-controller chip

*Figure 6.* Projects designed for competition

*Just for Fun or Decoration*

The last category that evolved included projects that were "just for fun" or served decorative purposes. The applications in this category are shown in Figure 7. They did not directly correspond to the children's needs and purposes emerging from their own living environment. At the same time the researchers recognized the need for children to have beautiful and fun things in their environment. In that sense, the projects met the needs of the children. For example, the map of Finland with certain cities highlighted with LEDs has some practical value, but this was not substantiated in either the teacher's report or in other data sources. Moreover, the applications in this category were not intended to just model something already existing. When having fun, children may invent a new, different and even innovative use for technology as well. Joe Boy – The Talking Parrot (see Figure 7) was awarded third place in a national research and invention competition for children in May 2005
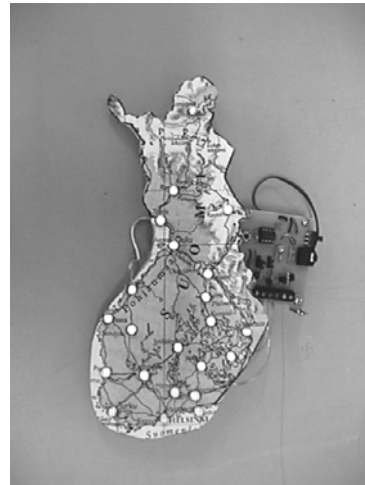
Joe Boy, the talking parrot


Proud creators of Joe Boy


Water fountain


LED map of Finland

*Figure 7.* Projects designed for fun alone

## Discussion

The Picaxe teaching experiment was not really designed pedagogically to teach students how microcontrollers work, as would typically be the case in the upper grades. Instead, the emphasis was on helping students realize their own ideas and needs by applying microcontroller technology in a creative and innovative manner. Moreover, the Picaxe teaching was not directed by traditional school evaluation practices. Even the teacher did not necessarily know what kind of applications the children would eventually create. One of the teachers wrote, "For the first time, there was an electronics project whose final product was not known by anyone at the start of the project. When they were putting the project board together, the pupils acquired information and skills on

basic issues in electronics (components, soldering, etc.), but at the same time they were constantly thinking about the subsequent application and its various possible uses". In spite of the openness of the Picaxe activity, some children had a tendency to copy and mimic the ideas of other children. This raises the question of what is appropriate in the support and encouragement of children to "trust" their own needs and ideas and to take the risk to pursue them. Such risk taking is not often rewarded in traditional school situations. The worry of failure, negatively reinforced by prior experiences in school, may have cause some students to copy ideas from others. At the same time, it does not mean that every student should be expected to be an innovator. The important thing is that each student be able to pursue ideas that meet their personal needs, and those needs might be satisfied from copying a project idea from another student.

This study confirmed once again that children have very fertile minds for coming up with unique ideas. Educators and other adults must make every effort to consider the ideas of children seriously and with encouragement. One never knows when the ideas of children could lead to new kinds of applications and innovations. Ultimately, every effort should be made to assure that a child's experience with technology education positive, builds confidence, and results in directly experiencing "human innovation in action" (ITEA, 2000). The study also reinforced the notion that technological understanding and problem-solving ability is a unique kind of human intelligence (Chen, 1996).

Innovation is not just something carried out in the research and development laboratories of large technology industries, but all of us, including children, can be innovators. As a result of the ongoing research, the authors repeatedly reaffirm that one of the most serious pitfalls of technology education is to underestimate the ability of children to be creative and innovative in technology. As Barlex & Pitt (2000, p.12) stated, "being 'technological' is part of what makes us human."

The possibility to change the human-made world empowers children in a way not usually experienced in schoolwork. Interestingly, this echoes Piaget's thoughts of the principal purpose of education being to encourage children to do new things and not just repeating what previous generations have done – to inspire them to be creative, inventive and discoverers (Piaget, 1970).

### Conclusion

In technology education it is important to engender the idea of how the human-made environment has developed and is still developing through human activity. Ingenuity, innovation, and problem solving are part of the basic essence of technology (e.g. Sparkes, 1993; Järvinen & Hiltunen, 2000; Järvinen, 2001). Consequently, in technology lessons it is essential to also enable children to have ownership of their designing and making processes. The researchers observed that many of the children who took part in the study acted in accordance with the idea put forward by Adams (1991):

> Successful inventors that I know are extremely problem-sensitive. They are
> tuned to the little inconveniences or hardships in life that can be addressed by
> the technology they know. (p. 87)

If a child is able to identify a problem and proves to be successful in solving it in a way that the solution meets personal needs, it results in a very positive experience. It is "serious business" to the child and importantly, in the process he/she goes through the processes truly reflective of technology (Layton, 1993).

It is natural and, in some cases imperative, to provide technology education through an integrative approach that cuts across subject boundaries. The "Human and Technology" theme in the new Finnish curriculum framework is an example. Technology is multidisciplinary by nature and cannot be limited only to applied science or handicraft skills.

In technology lessons, the doing and its understanding are most important. Teaching technology should not begin with the introduction of conceptual jargon, but with design challenges that enable children to come across the underlying technological principles spontaneously while engaged in the learning activity (Papert, 1980).

The authors advocate that children's understanding of technology can be achieved by enabling them to work in the same spirit that real technologists do. This approach brings authenticity to the experience. It is also essential that children are encouraged to work and learn in a way that fosters creativity and discovery. This can be facilitated in an atmosphere that is low in stress and enable children to concentrate on their own problems (Futschek, 1995).

In closing, the authors wish to encourage teachers who are not already doing so to try an open-ended approach to technology teaching. More work and preparation is required, along with open-mindedness and the courage to deviate from the normal school routines, but the rewards are worth the effort. When the final outcome of children's problem solving processes is unknown to them, boredom and disinterest is replaced with thrilling anticipation (Järvinen & Hiltunen, 2000).

## References

Adams, J.L. (1991). *Flying buttresses, entropy, and O-rings. The world of an engineer.* Cambridge , MA: Harvard University Press.

Barlex, D. & Pitt, J. (2000). Interaction: *The relationship between science and design and technology in the secondary school curriculum.* London: Engineering Council.

Biesta, G. (1994). Education as intersubjectivity. *Educational Theory, 44*, 299-317.

Black, P. & Harrison, G. (1985). *In place of confusion: Technology and science in the school curriculum.* Nuffield-Chelsea Curriculum Trust and the National Centre for School Technology. London: Trent Polytechnic.

Chen, D. (1996). Reflections on technological thinking. In: D. Mioduser & I. Zilberstein (Eds.), *The second Jerusalem international science and technology education conference on technology education for a changing future:Ttheory, policy and practice* (p. S3 – 5-6). Book of abstracts. Tel Aviv: Center for Educational Technology.

Dugger, W. E. Jr. & Yung, J. E.  (1995). *Technology education today.* Bloomington, IL: Phi Delta Kappa Educational Foundation.

Edwards, D. & Mercer, N. (1987). *Common knowledge: The development of understanding in the classroom.* London: Metheuen.

Erickson, F. (1986). Qualitative methods in research on teaching. In: M.C. Wittrock  (Ed.), *Handbook of research on teaching*; Third Edition (p. 119-161). New York, NY: Macmillan.

Futschek, G. (1995). Starting learning with computer controlled models. In Tinsley, J. D. & van Weert, T. J. (Eds.), *Proceedings of  the 6th  World Conference on Computers in Education*. Birmingham, UK: Chapman & Hall.

Honebein P. C., Duffy T. M., &  Fishman B. J. (1993).  Constructivism and the design of learning environments: Context and authentic activities for learning. In T. M. Duffy,  J. Lowyck,  & D. H. Jonassen (Eds.),  *Designing environments for constructive learning.* Berlin: Springer-Verlag.

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

Järvinen, E-M. (2001). Education about and through technology. In search of more appropriate pedagogical approaches to technology education. Acta Universitatis Ouluensis: Scientiae Rerum Socialium E50. Oulu, Finland: Oulu University Press. (http://herkules.oulu.fi/isbn9514264878/)

Järvinen, E-M. & Hiltunen, J. (2000). Automation technology in elementary technology education. Journal of Industrial Teacher Education. *37*(4).

Layton, D. (1993). *Technology's challenge to science education.* Buckingham, England: Open University Press.

McCormick, R.; Murphy, P.; Hennessy, S.; & Davidson, M. (1996). *Research on student learning of designing and problem solving in technology activity in schools in England.* Paper presented to the American Research Association Annual Meeting, New York, April, 1996.

Miles, M. B. & Huberman, A. M. (1994). *Qualitative data analysis.* Thousand Oaks, CA: Sage Publications.

Papert, S. (1980). Mindstorms: *Children, computers, and powerful ideas.* Brighton, England: Harvester.

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

Piaget, J. (1970). *Science of education and the psychology of the child.* New York: Orion.

Ritchie, S.M & Hampson, B. (1996). Learning in the making: A case study of science and technology projects in a year six classroom. *Research in Science Education*, *26*(4), 391-407.

Savage, E. & Sterry, L. (1990). *A conceptual framework for technology education.*  Reston, VA: International Technology Education Association.

Savery, J. R. & Duffy, T. M. (1995). Problem based learning: an instructional model and its constructivist framework. *Educational Technology*, *35*, 31-38.

Schwartz, A. (1996). Principles of logic- A learning module for the understanding and implementation of logic at the junior high school level. In Mioduser, D. & Zilberstein, I. (Eds.), *The second Jerusalem international science and technology education conference on technology education for a changing future: Theory, policy and practice.* Book of abstracts. Tel Aviv: Center for Educational Technology.

Sparkes, J. (1993). Some differences between science and technology. In R. McCormick, C. Newey, & J. Sparkes (Eds.), *Technology for technology education.* London: Addison-Wesley Publishing Company.

von Glasersfeld, E. (1995). A constructivist approach to teaching. In: P.L. Steffe. & J. Gale (Eds), *Constructivism in education* (p. 3-15). Hillsdale, NJ: Lawrence Erlbaum Associates.

Vygotsky, L.S. (1997). *Educational psychology.* Boca Raton, FL: St. Lucie Press