Articles

Defining and Measuring Technical Thinking: Students' Technical Abilities in Finnish Comprehensive Schools

Ossi Autio and Ron Hansen

The terms "technical" and "technology" are widely used by educators, workplace practitioners, and the general public. Seldom, however, is there a written explanation of a technologist's or technician's attributes (Hansen, 1994; Ropohl, 1997). What do technicians know and do? Also absent from public consciousness is a sense of what constitutes the design or problem-solving process which precedes any technological act. By comparison, media depictions of technology as computers, electronics, and tools are widespread and the public appetite for these depictions is extensive. In teacher education and in schooling itself the subject through which technical skills and knowledge are imparted suffers from confusion about definition as well. What is technical thinking? What is technical aptitude? Why is it that technology teachers can recognize this ability when it is observed in students but they, and educators generally, have difficulty documenting the essence of it in writing?

To expose what it means to be a technologist, the investigators in this research project examine what students in Finland's schools learn in their study and practice of technology. Why, you might ask, would the authors attempt to better understand what it means to have a technical orientation or technical ability by studying school children, in this case Finnish children? The answer has two parts. First, from a research perspective, children's responses to adult inquiries are often more informative and authentic than those of adults. Secondly, teachers of technology have had to think about their field, especially how to teach it. In doing so, they have to know about the substance of their subject. By comparison, practicing technicians and technologists may not have been required to think through what they know and do, much less express it.

The case of Finland's children and schools is especially timely. This country of five million people has a reputation for cherishing inventiveness and aesthetics. The essence of the creative and rational process of technology and design in Finland is found in the connection between nature and people. Our

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instincts as human beings to observe, appreciate, and respect/disrespect the patterns/cycles of the natural environment is a particularly important issue in Finland. The eye of the trained and untrained observer absorbs many facets of the physical and manufactured worlds. The combination of these activities (to see, touch, think, and do) is called "technology." It is, itself, the inherent capacity of the technologist. The degree to which students experiment with regard to the physical world is the degree to which each is a prospective technologist. In Finland the connection between technology and culture is a deliberate part of the school curriculum.

The Finnish Context

Technology as a school subject in Finnish schools has a long and rich history dating back to the 1800s when Uno Cygnaeus defined "sloyd" (Kantola, Nikkanen, Kari, & Kananoja,1999). It has evolved and is still evolving in such a way that examination of its essential elements is particularly informative. In particular, the attention to technical thinking which emerges from this history and which is the focus of attention in this study, informs readers about a host of important issues. Policy regarding the importance and place of technological education in schools, how best to recruit and prepare technology teachers, and what to teach students in the school curriculum, head the list of issues that are associated with understanding "technical thinking."

Finland's tradition in craft education is unique. For years students have engaged themselves in creative and reproductive handwork using a variety of craft and machine tools. In the early years of the last century workshop learning focused on reproduction handwork as a pedagogical strategy for developing student insight into the technological world. More recently, the curriculum has included creative handwork, textbook learning, and innovative technology (see Figure 1). The curriculum was and is geared mainly toward the development of starting-level technical thinking skills. For boys this involved crafts handiwork; for girls, textiles handiwork. In 1994 the new Finnish curriculum (National Board of Education, 1994) specified that technical craft and textile craft should be combined into one subject, taught to both boys and girls over their entire comprehensive school lives. Craft learning was designed as a comprehensive curriculum to develop psychomotor skills, "technical thinking" (knowledge), and work ethic.

"The student learns to appreciate work, to master the lifespan of the product, and to adopt the principle of sustainable development by using different planning and problem-solving methods. During the production process both a student and a teacher are continuously considering environmental, cultural, and nature values" (National Board of Education, 1994, p. 115). The value of craft teaching is described in the national curriculum as the appreciation of work in respect to ethics, ecology, aesthetics and economy, safe working habits, responsibility, consideration for others, and the all-round development of the student.

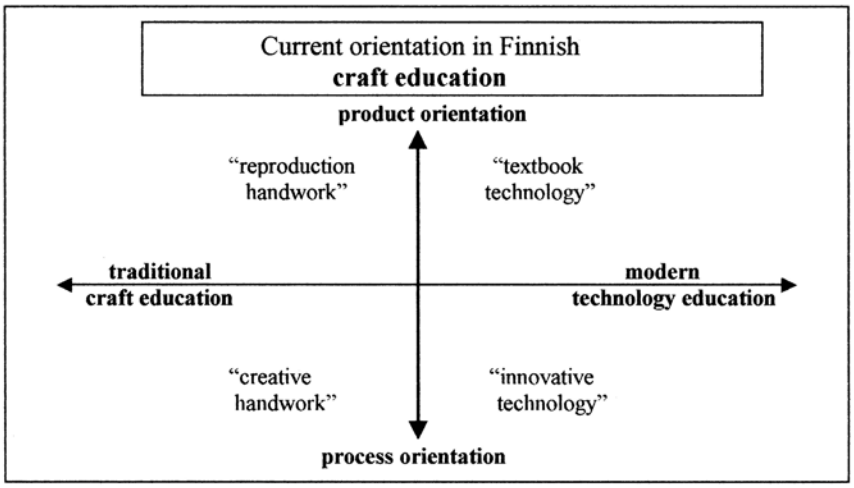


Figure 1. Current orientation in Finnish craft education (Autio, 1997, p. 32)

The Finnish national curriculum of 1994 requires that students learn to apply theoretical information to practical work. "In planning, making, and choosing the craft products, the student learns to apply theoretical information to practical work. The aim of the subject is to live through the work process where, between the start of an idea and reaching the final result, there is growth in creativity, thinking, and the development of self-esteem" (p. 113). The aim is to have students acquire the essential skills needed to manage their everyday lives. Learning, in its pedagogical sense, is experiential. The study of craft is, above all, practical rather than academic. Outcomes from learning include individual responsibility, initiative, creativity, perseverance, and a positive picture of oneself. Self-esteem, the report suggests, is built on practical rather than academic achievement.

The post 1994 curriculum proposes new approaches to students' all-round development. Technology education as a term is seldom mentioned in government documents; however, it's shadow, as cast by a growing number of middle school level technology education curricula in other countries, is evident. The fact that technology in Finland continues to be taught using formal workshop methods, with less emphasis on computer simulations, may be significant. Finland is often mentioned as a country where innovative technology, e.g., cell phone products, is prominent, yet that reputation appears to be attributable, in part, to a traditional curriculum unlike that being espoused in many contemporary school systems around the world. Finland may be the only country in the world that has a compulsory stand-alone technological arts subject in its primary schools, and a system of teacher preparation for that subject. Finnish comprehensive schools do not have a subject equivalent to technology education in the United States. Technology education, to the extent

that it has evolved in Finland, has been taught as a part of the instruction in science and craft education (see Figure 2). Only in 1994 was technological literacy introduced as a national educational objective. This study addresses the Finnish "case" by investigating how students become technical thinkers, through traditional and contemporary craft curricula with a technological literacy emphasis.

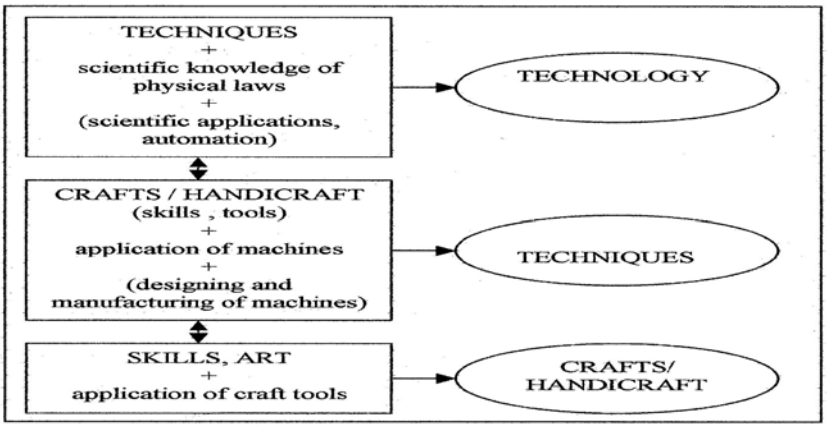


Figure 2. Conceptual foundation of technology (Parikka, 1998, p. 40)

Evidence (Alamaki, 1999) suggests that instructional goals and methods in Finnish schools are changing: Reproduction handwork and design are being merged with general knowledge of craft tools and technological literacy. Historically, technological education in Finland fulfilled the requirements of an agricultural society. The emphasis was on tool and machine use. Today, like many developed countries, it seeks to meet the requirements of a post-industrial society, complete with scientific knowledge of physical laws and automation. Parikka's conception (Figure 2) of the relation between technology, techniques, and crafts is helpful in describing one vision for something other than technological arts in Finland's schools.

In spite of Parikka's proposed reconceptualization, Alamaki points out that woodwork is still the most popular technological activity in Finnish primary schools. "It is clearly more popular than other activities such as plastic work, metal work, service and repair of technical equipment and construction of electronic equipment. Least popular are construction kits, internal combustion engines, and familiarity with technological equipment" (p. 143-144). Computers are not commonly used in these programs, although usage is expected to increase in the near future. Could the fact that Finland reveres a practical pedagogical tradition in the teaching of technology be related to this country's apparent success in both the design arts and in the new technology fields?

The changes that have occurred in Finnish classrooms and workshops are encouraging. Much work is being done to introduce the principles of creative problem solving. However, the search for clarity, confirmation, and definition of technology education is on-going. A formal definition of "technology education," for example, has not been articulated. More important, an understanding of the elusive aptitude known as "technical thinking" and its roots remain a source of debate. The fundamental issues are as follows: Can "technical thinking" be defined and measured? What is the relation between an experiential pedagogy and developing the ability to think technically?

The Research Design

Defining and measuring technical thinking as a construct was achieved by extending the work of Dyrenfurth (1990) and Layton (1994). They identified three components that correspond with what the authors considered to be the dimensions of technical thinking. The first is technological knowledge. Citizens in a democratic society, according to Dyrenfurth, know something about technological concepts, principles, and connections, as well as the nature and history of technology. This kind of "knowing" is often referred to in the educational sciences literature as the cognitive domain. The second dimension of technical thinking is skill or "competence." Technical and technological skills are part of most human activity and are essential for the survival of humankind. These skills are often labelled by psychologists as "psychomotor" skills and are an important component of technical thinking. These skills involve tactile or kinaesthetic ability and practical intelligence. The third dimension is technological will or "being active and enterprising." Technology is determined and guided by human emotions, motivations, values, and personal qualities. Thus the development of technology in society is dependent on citizens´ technological will to participate in, and have an impact on, technological decisions (individual and/or societal). This is the affective or emotional aspect of technical thinking. Technical thinking, in short, involves a balance of knowledge, competence, and emotional engagement. In its fullest sense it is the act of using human ingenuity or, being ingenious.

After extensive pilot work, three test instruments were developed, one to measure each of a) competence/motor skills, b) technological knowledge, and c) emotional engagement. The test of motor skills is called X-boxes and was based on the theory of Powell, Katzko & Royce (1978, p. 194) and Fleishman & Hempel (1954, p. 248) (see Figure 3). In this test all the elements of bodily orchestration, precision, vocalization, motor reactivity and dynamism are involved. The reliability of this test was 0.819 as measured with the Cronbach Alpha.

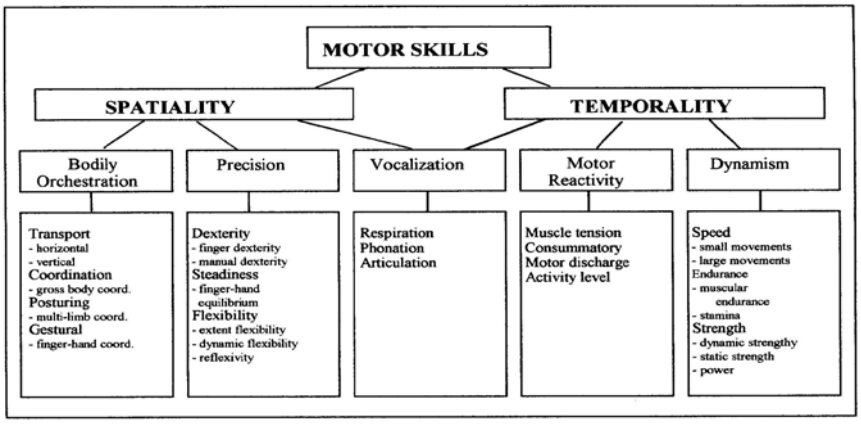
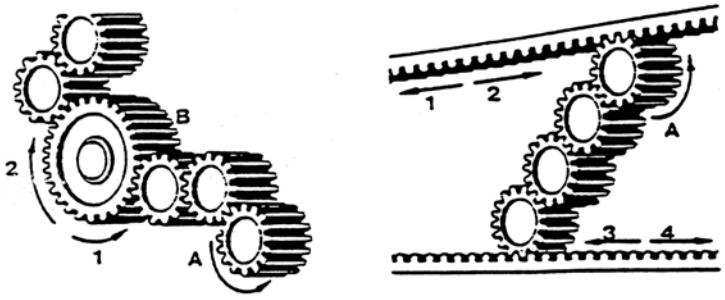


Figure 3. The hierarchical structure of motor skills (Powell, Katzko & Royce, 1978, p. 194)

To detect and measure the cognitive dimension of technical thinking, the instrument used was a test of "technical knowledge." It consisted of three different parts with twenty-eight questions. The questions deal mainly with physical laws, often observed in simple machines. Other aspects of technical knowledge are also involved, e.g., tool design and application. The reliability of the test, measured with the Cronbach Alpha, was 0.881. Figure 4 provides some example questions.



If cogwheel A rotates to the direction of the arrow, in what direction does cogwheel B rotate?

a) direction 1
b) direction 2
c) cogwheels can not rotate

Cogwheel A turns to the direction of the arrow. In what direction do the coglevers move?

a) direction 1 and 3
b) direction 2 and 4
c) direction 1 and 4
d) coglevers can not move

Figure 4. Example technical thinking questions

Emotional engagement was measured with a questionnaire based on the PATT (Pupils Attitudes Towards Technology) material designed and tested by Raat & de Vries (1986) and van de Velde (1992). The designers tested the questionnaire on several occasions. From their studies six factors associated with technical attitudes were found: interest in technology, favourite role models, understanding that consequences are a reality, some aspects of project work are difficult, attitudes towards school and technology, and career aspirations. These factors were used to establish the final test B, a questionnaire with fourteen Likert scale statements. Although attitudes are not best measured with paper and pencil tests, the test worked quite well, especially in detecting differences between the control and experimental groups. Test reliability was 0.853.

Evidence that the new curriculum in Finland either fostered or discouraged technical thinking in students would require that these three instruments be applied in the classroom. Each instrument was used three times over four years (pre-measurement, intermediate, and final measurement). Data were collected on 267 students in grades five to nine. The experimental group consisted of four classes from university training schools in Helsinki. Male and female students were given a new curriculum that combined technical and textile craft projects at the grades five to seven level (two classes), and an additional technology component at the grades seven to nine level (two classes). This curriculum included the teaching of problem solving with computer animations, as well as "hands-on" projects. The control group included classes from four local schools in Helsinki. Each class used the traditional crafts curriculum and pedagogical methods. Boys worked on technical craft projects, girls on textile craft. These four classes worked on projects that included wood and metal work, with some electronics. The grades seven to nine boys received a slightly greater emphasis on computers and electronics. The textile craft curriculum included mostly handwork and machine sewing. The classes were organized according to grade level and craft subject. In textile craft ninety-nine percent of the students were girls and in technical craft/technology ninety-five percent were boys.

Technical achievement was assessed using three tests that correspond to the conceptualization of technological thinking described earlier: 1) psychomotor domain (human competence/motor skills), 2) cognitive domain (technological knowledge), and 3) affective domain (emotional engagement). The research design is described in Figure 5.

From this research we wanted to explore, in a preliminary way, whether or not a curriculum which combines or retains traditional textile and technical crafts, or new technology education, would enhance technical thinking. Our hypotheses, while not formally stated, were that technical thinking as a construct could be defined and measured, and technical thinking could be linked more directly to technology education than to crafts education. The important research questions were: a) could/can student achievement in technological knowledge, competence, and emotional engagement be identified and measured? b) could/can technical thinking ability in students be attributed to

different treatments, i.e., traditional curriculum versus technology enhanced combined crafts curriculum? c) are there any differences in development between boys and girls as a result of these different treatments? d) is individual student technical ability evenly distributed across motor skills, technological knowledge, and emotional engagement? and, e) what impact, if any, can be attributed to the pedagogy practiced in traditional craft education compared to the emerging pedagogy practiced in more contemporary classrooms/workshops?

Groups	**Pre-Measure-ment**	**Treatment**	**Interme-diate Measure-ment**	**Treatment**	**Final Measure-ment**
Experimental group Combined craft (*n*=116)	O_1	X	O_2	X	O_3
Control group (*n*=151) Technical & textile craft	O_1	X	O_2	X	O_3
Test Instruments/Areas	-motor skills -technical knowledge -attitudes/ emotions	-combined technical/ textile	-motor skills -technical knowledge -attitudes/ emotions	-com-bined -technical/ textile	-motor skills -technical knowledge -attitudes/ emotions

Figure 5. The research design

The Results

The results show that in the psychomotor area (motor competence), student technical abilities improve quite a lot even with a small amount of practice. Significant improvement ($p < 0.001$) was found in both control (textile and

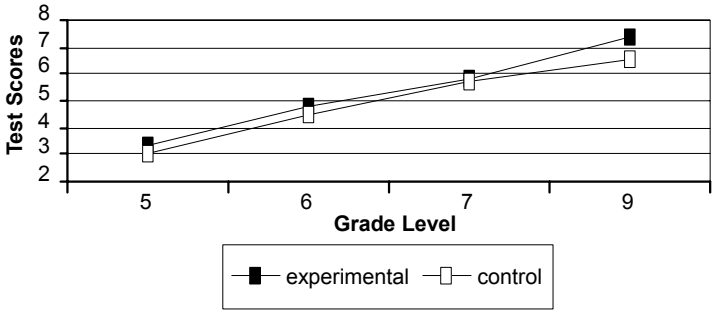


Figure 6. Development of psychomotor skills ($n = 267$, $p < 0.001$)

technical craft) and experimental groups (combined craft). Students excel at psychomotor activities in craft related projects. Figure 6 shows how psychomotor development increases from one grade level to the next.

According to the data there were no significant differences between the motor competencies of boys and girls, although, in the final measurement (grade nine), a significant difference was found ($p = 0.01$, see Table 1). Differences from one grade level to the other were also significant ($p < 0.001$), i.e., between children in grade five versus those in grades seven, and between grades seven and nine. Interestingly the experimental group achieved better results in every measurement. When technical and textile craft are combined, competence and motor skills receive more emphasis than technological knowledge. The wider range of experiences with different materials and projects may be an important factor.

Table 1
Average Scores in Motor Skills

Group	Pre-Measurement	Intermediate Measurement	Final Measure-ment
Experiment group (*n*=116)	4.17	5.58	6.68
Control group (*n*=151)	3.80	5.00	6.29
Boys (*n*=161)	4.05	5.26	6.58
Girls (*n*=106)	3.83	5.23	6.28

In the cognitive (technological knowledge) domain, achievement is similar between the control and experimental groups (see Figure 7). Even when students reach the grade seven to nine level their technological knowledge increases at a steady rate.

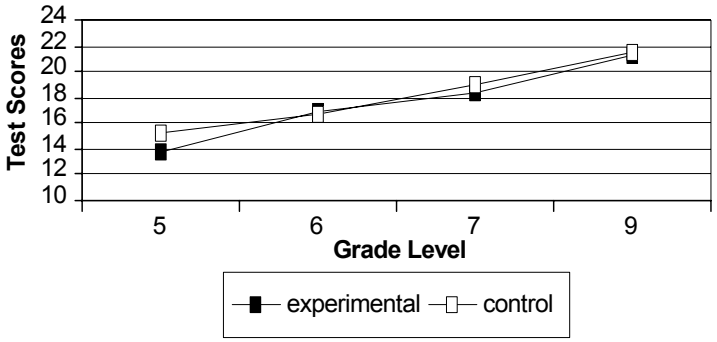


Figure 7. Development of technological knowledge (n = 267 $p < 0.001$)

According to the data (Table 2) there are significant statistical differences in the cognitive domain between boys and girls ($p < 0.001$). This finding corroborates results in other studies that look at cognitive development (Autio, 1997; Halperin, 1992; Kalichman, 1989). By contrast, there were no statistical differences between the control and experimental groups on test scores. This is due to the fact that in the cognitive area, the older girls had much better results in the combined craft than in textile craft. It seems that the girls in combined craft benefit from technical craft lessons even though some project work was not technological. Among younger boys the result was the opposite. Boys in the control group (technical craft) scored better than boys in the combined craft (experimental group).

Table 2
Average Scores in Technological Knowledge

Experiment/Control Group	Pre-Measurement	Intermediate Measurement	Final Measurement
Experiment group (*n*=116)	16.16	17.33	20.24
Control group (*n*=151)	16.15	17.53	20.61
Boys (*n*=161)	17.38	18.87	21.72
Girls (*n*=106)	14.29	15.27	18.52

In the affective domain (emotional engagement) change over time was not distinguishable. Only in the higher grades, when students are able to concentrate more seriously on activities in which they were genuinely interested, do attitudes towards technology change (see Figure 8 and Table 3). It may be that another variable intervenes in this area of human development. For example, students could be developing attitudes about technology outside of school as Sherif & Sherif (1967) found in their research.

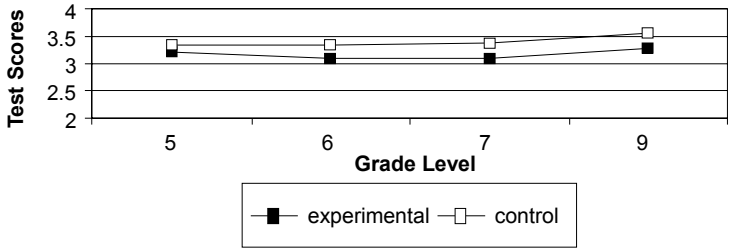


Figure 8. Development in attitudes toward technology (n = 267)

The data show there are significant statistical differences in the affective domain between boys and girls ($p < 0.001$) (see Table 3). The pattern is the same as in the cognitive area. Little change occurs until the middle school years, at which point interest in, commitment to, and respect for technology, increases. The difference between the control and experimental group may be due to the fact that the commitment among boys is higher when they can fully concentrate on the craft area which interests them most and for which they have the greatest capacity. Also, in combined craft, every class (except for the older boys) had similar pre-and-final measurement scores. Attitudes towards technology (emotional engagement) scores remained constant for boys, except for a modest increase after grade seven. Girls' scores, when the new curriculum was introduced, actually went down (2.88 to 2.72), but improved in grade nine when they could concentrate in their own area.

Table 3
Average Scores in Attitudes Toward Technology

Group	Pre measurement	Intermediate measurement	Final Measurement
Experiment group (*n*=116)	3.20	3.09	3.15
Control group (*n*=151)	3.31	3.35	3.51
Boys (*n*=161)	3.51	3.57	3.70
Girls (*n*=106)	2.88	2.72	2.84

Conclusions

The results show that in the psychomotor area, technical thinking achievement improves steadily over the four years. It seems that students excel at psychomotor activities in all project areas, perhaps because they see meaning in their accomplishments, even with small amounts of practice. The research design did not control for normal maturation so it is not possible to state unequivocally that the new curriculum caused these achievement levels.

In the area of technological knowledge (cognitive domain), the results were not as supportive for the post-1994 model of craft education. Remarkable differences were found especially between boys and girls in the younger age group. This finding suggests that a heavier or different emphasis on technical thinking for girls may be required in the curriculum. They (girls) should have equal opportunities to develop their technical thinking at primary school and earlier. One area of need for the Finnish school curriculum is early emphasis on technological knowledge. By comparison, the results in the affective domain followed the same pattern as those in the cognitive. The impact of the post-1994 curriculum on attitudes is problematic. Differences were found between boys and girls in all age groups. Male attitudes toward technology, i.e., emotional

maturity, occurred earlier and more quickly than that of girls. This finding corroborates with results found in teacher training (Autio, 1997).

The data from this study suggest that the definition of technical thinking as human ingenuity in problem solving is measurable. Furthermore, motor skill development (spatiality and temporality) is an aspect of technical thinking and human development that can be taught successfully in crafts and textiles programs within schools. In every psychomotor exercise there is a lot of thinking and with every thought and action there is emotion. The combination of all three involves a cleverness, competence, and emotional will. The data, above all, suggest that the relationship between cognitive ability, motor development, and emotional development is one that needs to be recognized and valued in pedagogical terms. What is the relationship between these three inseparable areas of student development, and what are the implications for our understanding of how children learn and develop?

The data also suggest that boys and girls differ in their interests and development with respect to technology. The difference between boys and girls in the affective domain has an influence on girls´ motivation for learning about technology and even on their future career decisions (Byrne, 1987; Halperin, 1992). In developing technology-related education programs, the cognitive differences between boys and girls need to be taken into account. The extent to which girls can improve their technical thinking in the future may hinge on how school programs are designed and implemented.

When curriculum specialists attempt to provide a good balance among attitudes, motor activities, and technological knowledge in teaching technology they should pay much more attention to the pace at which boys develop versus girls. The fact that it is difficult to sustain student commitment to practical problem solving questions through formal education is important to understand and respect. Young students may feel, because of the time and effort it takes to complete a project, that they are not learning quickly enough at this stage of their development. Later, as their competencies and technical thinking improve, motivation and subsequent achievement increase.

Discussion

The 1994 Finnish curriculum of crafts specifies that technical and textile craft should be combined into one subject, which should be taught to both boys and girls over their entire comprehensive school lives. This study suggests that such a recommendation is supportable but that some topics should be taught in homogeneous groups. If girls do require more time for development, they should have some opportunity to learn independently from the boys, perhaps as a pedagogical strategy, e.g., in the design and completion of projects. They should have more opportunities to concentrate on materials and projects with which they are familiar and comfortable. Craft is described as a comprehensive school subject that offers all-round education, develops the skills of the hand and thinking, and teaches pupils to work. Several years after the new curriculum, the tradition of teaching technical craft to boys and textile to girls is

as entrenched as ever. Renewal in the curriculum has not changed much but could if curriculum planners understood how a pedagogical strategy and curriculum content are distinctive but complementary. In other words, organize the curriculum and instruction so that students have a personally meaningful experience.

The vision of technology education as a subject of its own at the national level, evolving either partially or entirely from crafts, is a realistic one. Parikka's (1998) three alternatives for implementing technology education in Finnish comprehensive schools could be a possible curriculum conceptualisation. It would be useful though, to classify knowledge in a practical rather than scientific way. For the senior secondary schools this conceptualisation would have to be more experiential and accommodate local community culture and heritage. The tendency for comprehensive secondary schools to be university preparation sites that perpetuate an academic milieu is already widespread. While the study did not directly solicit anecdotal information in this regard some observations and recordings were noted. Some of the boys, for example, made their feelings clear about their learning in crafts compared to other school subjects. They found the learning activities in non-craft subjects to be mindless and meaningless. Interestingly, these boys were the ones who often had the best results in the test of motor skills. Perhaps the preference by some students for experiential pedagogy practiced in craft classrooms warrants investigation relative to the didactic pedagogy characteristic of other subjects. Further study is required.

Given the results of this study, every student in Finnish schools should be given a balanced curriculum that draws deliberately upon examples from everyday life situations as well as from textbooks from the educational sciences. In addition, every student should also be given an opportunity to concentrate more seriously on the craft area that most interests him or her. In light of the different interests held by boys and girls for motor skill development, technological knowledge, and emotional engagement, designing technological studies curricula for different genders in a particular age group is crucial in the policy and planning process. As early as in nursery school, teachers may need to concentrate more on crafts that place equal emphasis on textiles and mechanics, drawing judiciously on projects that are relevant and of prime interest to students.

De Luca (1993) and Williams & Williams (1997) argue that creative problem-solving activities should be an integral part of craft-and-technology education in contrast to teacher-directed reproduction handwork. Others (Wu, Custer, & Dyrenfurth, 1996) suggest that problem solving itself should determine the content and teaching method employed. This is an issue that will require further study and thought in the opinions of the authors. An especially important aspect of education in, about, and through technology, and teacher education, is the opportunity of utilizing fresh ideas and approaches. For example, by adopting alternative pedagogical strategies at the university and comprehensive school levels, it is possible that more could be learned about the

value of teaching problem-solving strategies and the relation of those strategies to psychomotor skills and emotional development.

This study shows that a better understanding of what children learn when they exercise their minds and bodies concurrently is important. Learning takes place upon completion of a product but also through reflection in every phase of the technological process. But does current research acknowledge and address this connection? Above all, do children understand that technology (the combining of body, spirit, and mind) is directed by human needs and wants, including their own? Technological and social development, can be reconciled. Every generation needs to understand how its technological culture and its human evolution process interact. The kinds of artistic and technological/ practical experience needed to enhance meaningful social progress and to design school curriculum exist. Needed now, in Finland and beyond, is the willingness to further define and commit to an experiential pedagogy and heritage in school programs.

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