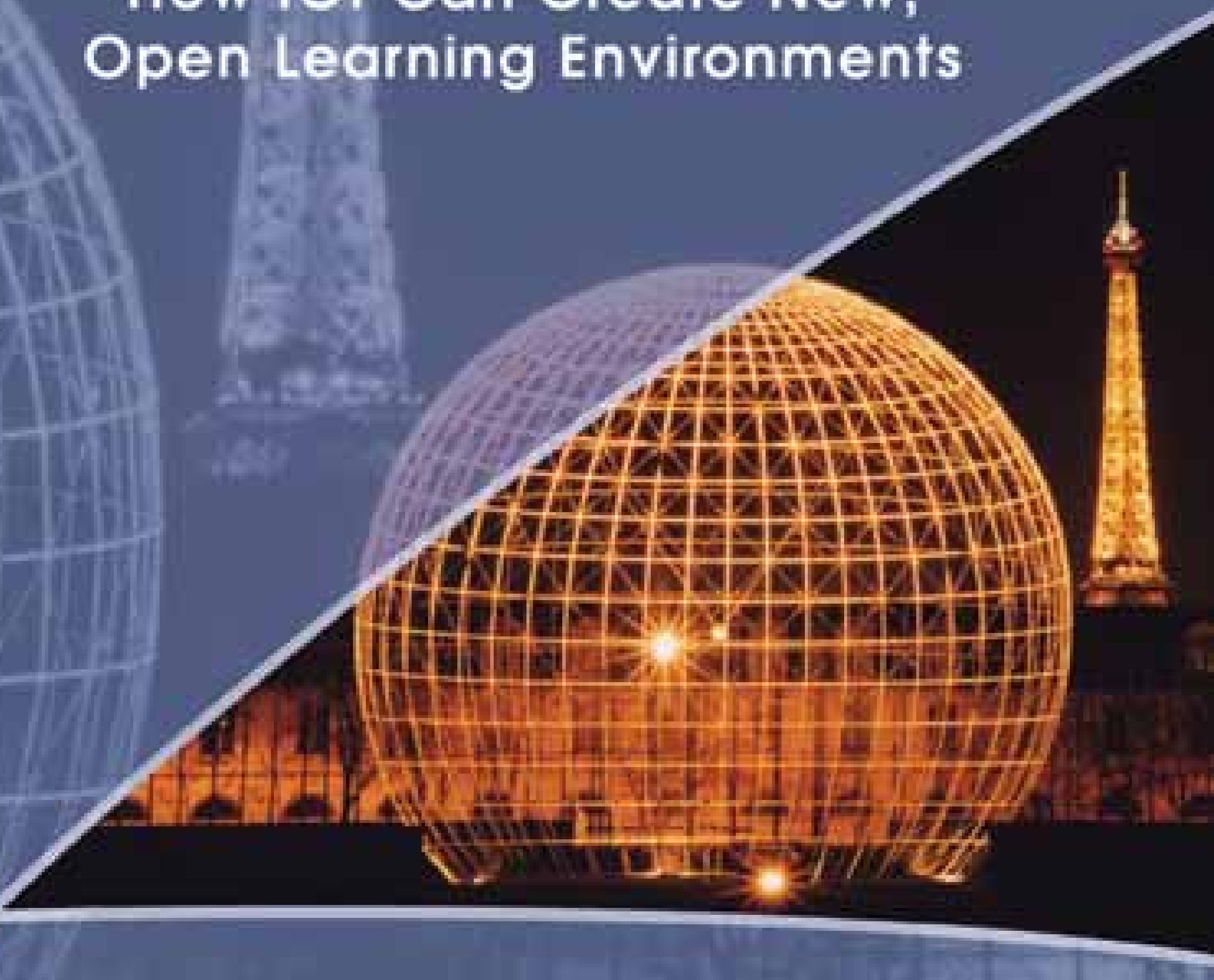
United Nations
Educational,
Scientific and Cultural
Organization

INFORMATION AND COMMUNICATION TECHNOLOGIES IN SCHOOLS

A HANDBOOK FOR TEACHERS

or

How ICT Can Create New, Open Learning Environments



INFORMATION AND COMMUNICATION TECHNOLOGIES IN SCHOOLS

A HANDBOOK FOR TEACHERS

or

How ICT Can Create New, Open Learning Environments

UNESCO, 2005

Co-ordinator: Mariana Patru, UNESCO

Author: Alexey Semenov, Moscow Institute of Open Education,
Russian Federation

Other Contributors:
Leonid Pereverzev, Institute of New Technologies, Russian Federation
Elena Bulin-Sokolova, Centre of Information Technologies and
Learning Environments, Russian Federation (Chapters 3, 4, 5 and 7)

Editor:
Jonathan Anderson, Flinders University, Australia

Reviewers: Evgueni Khvilon, Consultant, UNESCO
Boris Berenfeld, The Concord Consortium, USA

Cover design: Bertrand Ambry, UNESCO
Cover photo credit: Tatyana Khvilon, Institute of New Technologies, Russian Federation
Picture design: Anna Roschina, Institute of New Technologies, Russian Federation

For further information, please contact:
Mariana Patru
Division of Higher Education
UNESCO
7, place de Fontenoy
75352 Paris 07 SP, France.
Phone: 33-1-45 68 08 07

Fax: 33-1-45 68 56 26
E-mail: m.patru@unesco.org

Printed in France
ED/HED/TED/2

FOREWORD

All governments present at the World Education Forum in Dakar, Senegal, April 2000, pledged to achieve a number of essential goals aimed at ensuring Education for All (EFA). I will mention only two of them that are particularly relevant for, and lie at the basis of, the development of this new publication - *ensuring that the learning needs of all young people and adults are met through equitable access to appropriate learning and life-skills programmes* (Goal 3) and *improving all aspects of the quality of education […] so that recognized and measurable learning outcomes are achieved by all* (Goal 6).

This new publication, initiated by the Division of Higher Education, entitled "*ICT in Schools: A Handbook for Teachers or How ICT Can Create New, Open Learning Environments*", should be seen as complementary to the ones already published by the Division in the 2002-2003 biennium devoted to the use of information and communication technologies (ICT) in teacher education. The present handbook is principally designed for teachers and teacher educators who are currently working with, or would like to know more about, ICT in schools.

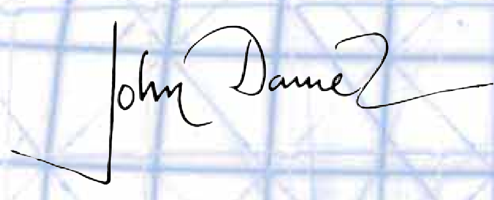
A major theme in the book concerns how ICT can create new, open learning environments and their instrumental role in shifting the emphasis from a teacher-centred to a learner-centred environment; where teachers move from being the key source of information and transmitter of knowledge to becoming a collaborator and co-learner; and where the role of students changes from one of passively receiving information to being actively involved in their own learning.

Evidence over the past years has clearly indicated that efforts to ensure equal access to educational opportunities and quality education for all must be accompanied by wide-ranging education reforms. Such reforms are not likely to succeed without addressing the new roles played by teachers in preparing students for an emerging knowledge-based and technology-driven society. Teachers must have access to adequate training and ongoing professional development and support and be motivated to use new teaching and learning methods and techniques.

Information and communication technologies must be harnessed to support EFA goals at an affordable cost. They have great potential for knowledge dissemination, effective learning and the development of more efficient education services. This potential will not be realized unless these technologies serve rather than drive the implementation of education strategies. To be effective, especially in developing countries, ICT should be combined with more traditional technologies such as books and radios and be more extensively applied to the training of teachers.

Education must reflect the diversity of needs, expectations, interests and cultural contexts. This poses particular challenges under conditions of globalization given its strong tendency towards uniformity. The challenge is to define the best use of ICT for improving the quality of teaching and learning, sharing knowledge and information, introducing a higher degree of flexibility in response to societal needs, lowering the cost of education and improving internal and external efficiencies of the education system.

I sincerely hope that this new publication will be both informative and useful for a wide range of users who all believe in, and pursue, a common goal - *Quality Education for All*.



John Daniel
Assistant Director-General for Education

CONTENTS

PREFACE

This handbook is designed for teachers and all educators who are currently working with, or who would like to know more about, information and communication technologies in schools. The technologies involve much more than computers, and so the abbreviation we use for information and communication technologies - ICT - is a plural term to denote the whole range of technologies associated with processing information on the one hand and, on the other, with sending and receiving messages.

However, this handbook is not primarily about hardware (the term applied to computers and all the connecting devices like scanners, modems, telephones, and satellites that are tools for information processing and communicating across the globe): it is about *teaching*, and, more particularly, *learning*, and the way that all these technologies that we group under the acronym ICT can transform schools as we currently know them.

ICT have already impacted on the economies of all nations and on the fabric of society at every level within which teachers and students live and interact. In so far as ICT have the potential to impact similarly on every aspect of the life of a school, the coverage of this handbook is very broad and includes - to mention just one topic from each chapter - educational technology of the mind, multimedia presentations, multiple intelligences, wearable computers, goals of education, and information objects.

Although the handbook coverage is necessarily broad, much of the content is quite specific and directed to teaching and learning activities with ICT in the classroom. Thus there are sections on modelling forms and meanings of reading, writing, and oral communication, or the *new literacy*, as we prefer to call them. Other sections embrace science experiments, foreign language learning, research in social sciences and humanities, and the mathematics of informatics.

The handbook, then, is for teachers at all levels, from kindergarten through elementary, middle, and high school. Further readers who should find this handbook useful are those in pre-service teacher education courses at colleges and universities who are preparing to become teachers. Classrooms that they will enter promise to be very different environments from those when they themselves went to school, thanks largely to developments in ICT.

A major theme of this handbook is how ICT can create new, open learning environments. More than any other previous technology, ICT are providing learners access to vast stores of knowledge beyond the school, as well as with multimedia tools to add to this store of knowledge. ICT are largely instrumental, too, in shifting the emphasis in learning environments from teacher-centred to learner-centred; where teachers move from being the key source of information and transmitter of knowledge to becoming guides for student learning; and where the role of students changes from one of passively receiving information to being actively involved in their own learning.

Two other recent UNESCO publications complement this handbook nicely. These are *Information and Communication Technologies in Teacher Education: A Planning Guide* (UNESCO 2002a); and *Information and Communication Technology in Education: A Curriculum for Schools and Programme of Teacher Development* (UNESCO 2002b). Both publications are available online (see References for full details).

This handbook consists of seven chapters that together provide a comprehensive treatment of ICT in schools within the context of broader movements in society and the world at large.

The first chapter, *Society, Learning Imperatives, and ICT* is intended to provide basic perspectives of:

- society, peoples, individuals, and their needs;
- educational systems to serve society and individuals; and
- ICT as a powerful and versatile means to support socio-cultural development, especially in the field of education.

The second chapter, ICT: *New Tools for Education*, is devoted to technical matters. ICT are described here on the basis of little prior knowledge. However, this chapter should be useful for ICT-using educators as well.

The third chapter, *Schools in Transition*, contains a systematic overview of the traditional or *classical* school with its strong and weak points, its problems, prospects and possible solutions for further development. Some of the solutions we suggest can be implemented with the help of ICT; other solutions should be taken into consideration while introducing ICT into schools.

The fourth chapter, *ICT in Learning and Teaching*, investigates the elements, or atoms of teaching and learning activities in view of different kinds of support, improvement, and extension made possible by ICT. From *atoms*, the chapter moves to more complex teaching and learning activities or *molecules*.

The fifth chapter on *Structuring the School Continuum* covers the problems of practical use of ICT in schools and offers possible solutions.

The sixth chapter on *Mathematical Fundamentals of Information Science* focuses on the fundamentals of computer science and technology (or educational informatics). These fundamentals are relevant for different ICT applications and belong to what we call the *new literacy*.

The final chapter on *ICT and Educational Change* brings together the several key themes that underlie this book: the need to restructure schools, strategies of change, and dimensions of ICT development. A final section puts forward practical suggestions for planning.

References to all works cited, a *glossary* of key terms, and an *index* for ready reference complete this handbook.

1

SOCIETY, LEARNING IMPERATIVES, AND ICT

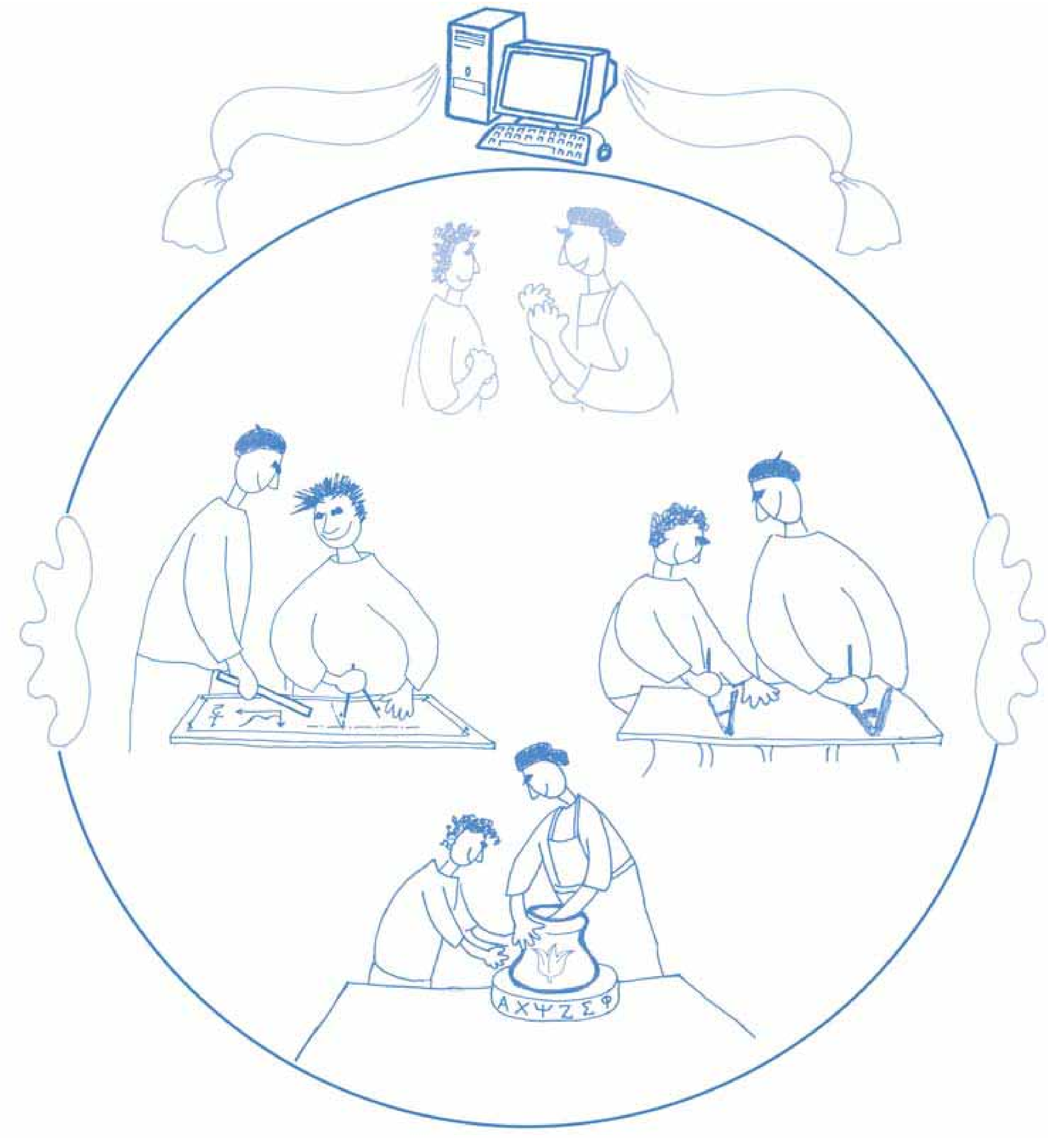
SOCIETAL PERSPECTIVES

The shock of the future

Modern civilization is characterized by the growing pace of change. The economy now undergoes a radical transformation (including the structure of the labour market and requirements for job qualifications) within a single generation. Because of the enormous difficulty in understanding, appreciating and even surviving change, we talk about the impact of these changes as future shock. On the other hand, these fundamental shifts do not appear suddenly, as bolts from the blue: they are always a part of a longer historical evolution, in which technological development plays a part.

It is not out of place to cite Alvin Toffler who coined the term *future shock* about forty years ago:

> In dealing with the future, at least for the purpose at hand, it is more important to be imaginative and insightful than to be one hundred percent "right". Theories do not have to be "right" to be enormously useful. Even error has its uses. The maps of the world drawn by medieval cartographers were so hopelessly inaccurate, so filled with factual error, that they elicit condescending smile today…Yet the great explorers could never have discovered the New World without them. (Toffler 1970)



We believe that ICT will be a key factor in future positive change – provided they are in the possession of people who use them creatively and for the common good.

Mindcraft economy

The economy has classically been divided into agricultural, manufacturing and service sectors. Today, these sectors have been joined by a fourth category: the booming *knowledge sector* consisting of *knowledge workers*. In an increasingly 'smart' automated environment, mental work is moving from crunching and tossing data to creating information and knowledge, and then communicating, exchanging and sharing it with fellow-workers. In short, as it was already noted more than decade ago, *mindcraft* is replacing *handicraft* (Perelman 1992). The ubiquitous computer and its related ICT devices have become critical tools for much of the world economy.

At the same time, *knowledge work* has become, not just another sector but a cross-sectional drive, a main carrier, and a cutting edge for contemporary economic activities. Observers talk about the emerging *mindcraft economy* of the 21st century, an economy that presupposes continuous learning within elaborate systems that combine human agents and intelligent ICT-based machines.

Globalization and ICT

One of the major trends in the global economy is the movement of material industries from developed to developing countries. This process involves information industries as well. While this change is positive in many ways, the distribution of wealth is unequal and much of the world continues to suffer from severe problems of poverty, hunger and illiteracy. At the same time, more countries have a chance to take leading roles in the new information or knowledge society, which generally assumes a multi-centrist and multi-cultural worldview. ICT can help educators achieve this kind of society by creating opportunities for:

- greater individual success, without widening the gap between the poorest and the richest;
- supporting models of sustainable development; and
- more countries to build and use information space, rather than having a few countries and mass media monopolies dominate dissemination of information and culture.

The world's most serious problems – the growing demand for food, shelter, health, employment, and quality of life – cannot be solved without highly efficient new technologies. With the advantages of being nature-protecting, non-polluting, less energy consuming, and more human-friendly, ICT applications are becoming indispensable parts of contemporary culture, spreading across the globe through general and vocational education.

Technology – a double-edged sword

ICT already influence the social and political life of all nations. However, their influence is not always for the better. The use of message-forming and transmitting technologies in some cases impedes justice and concentrates power by reducing reciprocity in communication. Emergence of huge media conglomerates is vivid evidence of this.

Even more impressive lessons, both warning and encouraging, can be drawn from the recent history of the fall of great totalitarian states. One might suggest that the fall of the Soviet communist empire had already begun when Joseph Stalin died in 1953. Not coincidentally, the change to a more liberal regime coincided with the proliferation of TV broadcasting and the introduction of home tape-recorders in the USSR. The impact of those types of ICT was equally significant but different in its directions and consequences. Television, owned by the state, became, and for the next forty odd years remained, another tool for *vertical* brainwashing and manipulation of public consciousness, exercised by the totalitarian regime.

The same historical period was marked by a rising tide of underground dissemination of the written word (and, if caught, severely punished). Forbidden manuscripts of prose, poetry, political philosophy, social critique, and reports on violations of human rights were duplicated on mechanical typewriters that produced four carbon copies at a time. Photostat copying was too complicated and demanded special skills to be used widely. In the early 1970s, the old fashioned photostat copier was supplanted by the electrochemical xerox copier, which was extremely fast and easy to operate, but kept under strict police surveillance in governmental offices and inaccessible to private persons. Fax machines followed a decade later, giving additional impetus to the already visible process of decay and disintegration of the totalitarian stronghold. Toward the end of the 1980s, communication barriers (censorship, radio jamming, and all that) went tumbling down along with the Berlin Wall.

Future generations of historians may be tempted to interpret ICT as the main leverage for all these cataclysms. Needless to say, it would be an obvious exaggeration. History paves its way through time by much more complicated trajectories. In fact, Mikhail Gorbachev ascended to power and launched his famous *Perestroika* (re-building) before such novelties as the Internet, and even phone-fax, had become common commodities in the USSR.

Nonetheless, it would not be too strong an exaggeration to say that the personal computer (with printer and modem to connect the Internet), neglected by short-sighted Soviet authorities, hammered the last nail into the coffin of communist ideological and political rule in Russia and Eastern Europe.

Similarly, we believe that the worldwide proliferation of ICT will help offset cultural imperialism, ideological totalitarianism, and information monopoly. The Internet and desktop publishing will play a crucial role in democratizing the dissemination and use of information. In addition, ICT create new options for the preservation and revival of indigenous cultural traditions and spiritual values. Even a teacher with a class of students, can design a set of fonts for their native language, make a multilingual dictionary, record folk songs and dances, make pictures of handicrafts, and put everything together as an Internet page. We hope that linguistic barriers such as the historically and politically imposed dominance of a few languages may be weakened by the worldwide availability of ICT and its thoughtful application for educational purposes.

Finally, ICT also change age and gender distribution and opportunities in the work place. Women and young people can learn to use ICT and work in ICT environments as well as men.

Individual needs and expectations of society

Life in the new knowledge society demands more independent and responsible behaviour and much less routine execution of orders. To prosper, and sometimes even to survive, people now need to be able to make responsible decisions in new and unexpected situations. Most of all, they need to continue to learn throughout life. Individuals seek to use ICT for personal growth, creativity and joy, consumption and wealth. They also need to be able to analyze mass media information critically and to use it productively.

These individual needs require knowledge and skills to search for information, to analyze, synthesize, evaluate, channel, and present it to others, and to exercise judgment in order to predict, plan, and control fast changing events. The skills noted above are indispensable to ICT-supported and non-ICT learning environments. However, more and more industrial, professional, and business occupations call for knowledge-based and skilful intellectual work. A worker's ability to use ICT fluently is necessary in more and more occupations. Former skills have become obsolete. The abilities to make pen-and-paper arithmetic calculations, for example, or to write in calligraphy, are now viewed as specialized abilities (though both are still useful in the education of students).

At the same time, it is now vital for every child, adolescent, and adult to have at least a general notion of their technological surroundings at home and at school, on the street, in the office and work place. To be sure, any new technology brings dangers and temptations. A recent example of such risks is encouraging a *grasshopper mentality*, as seen in much of the Internet surfing across content, and the pollution of the Internet environment.

Now, what can we as educators do in carrying out our mission, and how can ICT be used to enrich learning opportunities in our schools?

It is essential to develop a vision of the future. This is true, not only because the world is becoming a knowledge society, relying heavily on new knowledge, skills and experiences, but also because we live in a technologically dominated socio-economic milieu that is based on short-term consumer-driven goals of production, and only secondarily on holistic, long-term concern for sustainable development. With our minds fixed narrowly on the technology that supports a comfortable life – even school life! – we may forget, or even act in conflict with, humane and democratic values.

Radical changes needed in school

In the 21st century, the ever-increasing needs of individuals and society are placing a heavy burden on established educational institutions. At the same time, traditional structures and modes of teaching appear less and less responsive to the challenges of our turbulent times. There is a clarion call for innovation and transformation among educators everywhere, especially in the elementary school, the most crucial stage in the development of a human being. Furthermore, the internal problems of schooling are inseparable from external changes on a global scale, and must be seen in the context of contemporary world problems. These, in turn, will not be solved unless approached and treated educationally, as well as economically, politically, and socio-culturally.

Students who enter school are communicative, curious, creative, and capable of learning many things. They have proved this already by mastering a mother tongue, physical motion, complicated games, and many other life skills. However, we believe that the traditional school of the 20th century, which is still very much with us, diminishes these abilities over the period of learning. We need a new kind of school for the 21st century.

EDUCATIONAL TRENDS

From a consideration of societal perspectives, we turn now to an examination of educational trends over recent centuries.

Ancient legacy and modern trends

Trinity of education

There is a venerable tradition, extending at least from Jan Amos Comenius in the 17th century to Max Scheller in the 20th century of subdividing general education into three domains (see Pick online; Scheler 1958)[1]. This approach stemmed from the old tripartite notion of the human creature consisting of:

- a body that needs food and shelter, physical comfort, and fleshly pleasures, as well as other material goods and man-made things, available only in an artificial environment;
- a soul, suffering from solitude and searching for another soul, longing for sympathy and understanding, willing to give love and be loved in joyful communion with the universe; and
- a spirit, striving to orient itself towards the Initial Cause (Prime Mover, Life Source, Perennial Wisdom, Ultimate Truth, and Final Goals) of human existence, transcending all temporal and spatial boundaries.

The corresponding educational (i.e. cultural) domains have been designated by various words. In summarizing (very roughly) their essential meanings, we might call them:

[1] For a fuller account, see Murphy (1995).

- **Labour-technological education**, aimed at mastering arts and crafts, logic and mathematics, engineering, natural, social and behavioural sciences, and other activities enabling individuals to fulfill their needs and desires by efficiently processing, governing, and controlling matter, energy, and information in a world of objects and objective phenomena.
- **Communitive (interpersonal) education**, aimed at learning the ways and means of subjective-emotional relations and interactions between human beings (and, to a degree, non-humans). This can be done through ethical and aesthetic teaching, caring for those in need, playing games, dancing, singing, and story-telling; ritual and myth, folk-lore and philosophy, poetry and theatre, music and fine arts; discussing and solving problems of civic life, thus actively participating in public endeavours of social concern.
- **Transpersonal education**, aimed at the catechization and initiations of neophytes into the creed, mysteries, and sacraments of a particular religious confession or ideology; helping individuals to pose a question of their relations to the Absolute; or just endowing a person with a sense of belonging to something infinitely greater and more potent.

Diversions and estrangement within the educational whole

The so much talked about education-and-culture crisis (often labeled as the *Conflict of Two Cultures*, or the *Snow-Leavis controversy* – see Stange 1988 and Bissett 2002) has resulted, to a large extent, from the historical schism between the educational domains described in the preceding section. In the 17th century, Western Europe hailed the advancement of scientific learning and technological inventions, based on newly discovered mechanical laws of motion. Water-, and later steam- and electric-driven machines, self-acting and labour-saving, relieved man of gaining his daily bread by the sweat of his brow, and promised to turn his life into an earthly paradise. Believers in science and engineering did not foresee that the humanization of the machine would have the paradoxical effect of mechanizing humanity.

Rationalism backfired

Since the mid-19th century, we have witnessed the dominance of the rational and technological aspects of culture over the spiritual and cultural. Ironically, the rational domain has itself begun to suffer from the severing of its vital connections with the spiritual and cultural domains. The system of mass education –

one of the really miraculous inventions of that era, along with medicine – itself falls victim to the triumphant march of Reason.

Religion, philosophy and art, once so nourishing to humane values, have been made arid and sterile, incapable of counterbalancing and complementing rational and intellectual development. Meanwhile, the latter has encountered increasingly loud callings to fight against the proliferation of advanced technologies and even to penalize efforts to make new ones. This kind of debate has had led nowhere.

The 20th century witnessed, on the one hand, the highest degree of techno-scientific refinement such as, for instance, magnetic resonance imaging, among numerous examples. On the other hand, the 20th century also saw the creation of the most sophisticated devices to exterminate millions of defenceless people by, for instance, self-guided ballistic missiles with nuclear warheads. Examples here are numerous as well. Rationality, devoid of humane values, runs the risk of stagnating, or running wild, to our own destruction.

From schism to convergence

We need to envisage measures and take modest, practical steps toward restoring a lost balance and creative interconnectedness, which might be achieved by making each domain more perceptive and responsive to the true nature, needs, and aspirations of each. Perhaps the best advocate of such a convergence in the 20th century was the Russian philosopher Nikolai Berdyaev. Here are a few key points, extracted from his works, *Spirit and Machine* (1915) and *Man and Cosmos. Technics* (1990):

> The role of technology is two-fold. It has both positive and negative meaning.
>
> Technicalization dehumanizes man’s life, while being in itself a product of the human spirit. But the relationship between spirit and technics is more complicated than it is usually thought of. Technology can be a force capable not only to de-spiritualize, but spiritualize as well.
>
> When obeying only the law of its own, technology would lead to the technicalized world wars and to an exorbitant etatisme, the absolute Supremacy of the State. The state gets omnipotent, even more totalitarian – and not under totalitarian political regimes only; it doesn’t want to recognize any limits to its authority and does treat the man as his own means and tool.

Berdyaev's views suggest a healthy ground upon which educators of the labour, communitive, and transpersonal domains might collaborate productively. A hopeful future lies, not in the further adaptation of human personality to the machine, but in the re-adaptation of the machine to the human personality for truly noble, humane purposes.

Just as the autonomous nervous system liberates the mind for its higher functions, so the new technology can bring about a similar release of creative energy. To achieve this end, we must go beyond technicalities and tackle the more profound issues of education.

Liberal and vocational education

A false dichotomy

The rift between academic schooling and master-apprenticeship training goes back to the classical age of ancient Greece, when the liberal arts curriculum was originally designed as vocational education for politics. The first goal of such instruction was apprenticeship in the skills of rhetoric, in preparation for a career in political argumentation. At that time, the ability to do or to make something, and the ability to talk about doing or making it, were literally one and the same thing.

However, with the vast expansion of academic institutions since the early 19th century, rhetoric came to be seen as a means, not an end of teaching. As a result, rhetorical methods of academic vocationalism have been misapplied to a range of non-political crafts and skills which, to be learned effectively, need doing to be mastered.

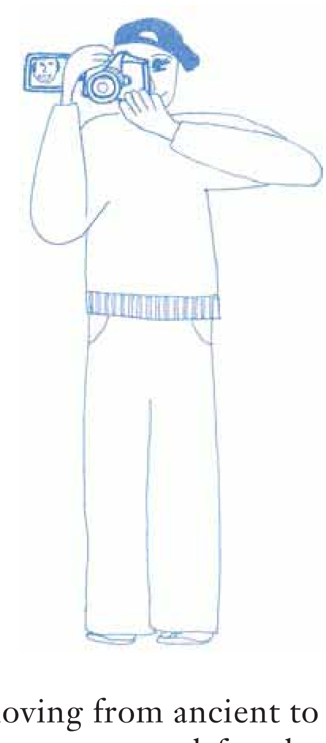
We believe that rhetoric, as a fully-fledged ICT-supported subject matter, could provide a collaborative community of practice built in the classroom. There, students, through assisted participation in rhetorical activity, could undertake what is now often called *cognitive*, or *semiotic apprenticeship*. That is, they could individually reconstruct the resources of culture as tools for creative and responsible social living in the classroom, the school, and the wider community.

A long time ago, distinguished voices were pointing towards this false dichotomy of technical and liberal education. Alfred North Whitehead entitled his 1917 Presidential address to the Mathematical Association of England *Technical Education and Its Relation to Science and Literature*. He wrote:

> There can be no adequate technical education, which is not liberal, and no liberal education, which is not technical: that is, no education which does not impart both technique and intellectual vision. [...] Geometry and mechanics, followed by workshop practice, gain that reality without which mathematics is verbiage. (Whitehead 1963)

ICT demonstrate that technical-vocational and liberal education can be taught together; they need not suffer from an impenetrable barrier between them. In vocational-technical education, essential knowledge and skills are transmitted, not by means of lecturing from a position of authority, but through a working interaction between master and apprentices. For a long time, vocational learning was looked upon as unquestionably inferior to academic instruction. Today, however, educators are reconsidering vocational learning as a useful basis for schooling.

Smarter people for smarter machines



We can sum up our argument so far by offering three points:

1 The post-industrial mindcraft economy and global society depend on smart machines AND a smart workforce, using high-end technologies with even greater competence.

2 Training and skill enhancement are part of a lifelong learning process.

3 Adolescent schooling, techno-vocational education, and actual work need to be interrelated. These truths apply to technologically advanced societies and to developing countries alike. Indeed, nations moving from ancient to modern agrarian economies must be even more prepared for the accelerating pace of change, because their youth will have even more to learn and master over their working life span. Befriending ICT in the initial stages of education will help young people come to terms with what lies ahead.

The only true education

Our aims as educators must go beyond specialized training of craftsmen or factory workers. The only true education is one where all arts, crafts, sciences, and technologies are linked and facilitate mutual cognitive development, productive creativity, and personal growth. The *new literacy*, a term used more than a decade ago (Anderson 1993) to embrace the changed literacy demands resulting from the new technologies in schools, and ICT offer educators, perhaps for the first time, an opportunity to create such an ambitious scheme.

The question is how can we create both the educational framework and the technologies to carry on a project of such proportions?

Continuous educational development

We need to build a continuing mechanism for the uninterrupted development of new curricula and new modular courses in an increasing variety of different learning environments. Furthermore, this needs to be extended from earliest childhood education through to adult education. Deep questioning is taking place regarding general schooling in our society:

- What should a student be required to know and do to succeed in the 21st century?
- What should a teacher be required to know and to do to help students acquire the desired knowledge and abilities?
- What role can ICT play in helping both teachers and students perform these new tasks?

New activities to be learned and new learning activities

Memorizing is not enough. The old pedagogy was justly criticized for presenting content in lecture format, as a series of abstract notions and formal rule-following to be memorized and reproduced by a student orally or in written or behavioural form. In many schools, little has changed. Much teaching is still conducted on this basis, while insufficient attention is paid to learning strategies (the tools and procedures a person uses to learn). A small percentage of students (those usually called bright or gifted, who are capable of building their own learning strategies) learn best under these conditions. However, most young people — and we would add, adults, too – need concrete, visualized, experiential, self-initiated, hands-on, and real-world learning opportunities. Yet many of these students are typically pushed aside and labeled *weak*, *poor* or *lagging behind*.

There is a movement in many countries, and within different education systems, to allow more variability and flexibility in the initiatives of individual teachers and local educational communities.

Changes are needed in the status and functional role of teachers. Contemporary teachers do not have to pretend that they know everything in order to formulate problems and ways to solve them. At the same time, teachers are taking on the increasingly important roles of advisor and learning facilitator. The new focus is on the process of learning and providing environments and tools that encourage everyone to become successful and responsible learners.

Three Rs for the 21st century

The new kinds of activities to be learned and new learning activities lead inevitably to a drastic revision of the idea of literacy, considered for many centuries the main goal of primary education.

The traditional notion of literacy (including so-called numeracy) was based on the Three Rs (Reading, wRiting, and aRithmetic), together with accurate handwriting (preferably calligraphic), and memorizing certain excerpts from textbooks and classical poetry by heart.

Now, we see an urgent need for a *new literacy* that is ICT-based and can be presented in three components corresponding to the traditional Three Rs:

- [Reading] – finding information by searching in written sources, observing, collecting, and recording;
- [Writing] – communicating in hypermedia involving all types of information and all media; and
- [Arithmetic] – designing objects and actions.

To sum up, we must reshape drastically both educational content and learning procedures. The new literacy shuns memorization of facts and rules. It stresses the ability to find facts and imagine unprecedented options. A capacity to understand and invent rules, posing problems to oneself, planning and designing one's own activities, come to the forefront. The goal of this kind of education is not a narrow technical fluency, but personal development alongside the core competencies for high-level thinking and acting.

Calling for new dimensions of teaching

Modern society needs educated citizens who can make decisions and implement them in a rapidly changing world. Individuals, organizational structures such as corporations and governments, and educational institutions, should be prepared for life-long learning. Information processing and communication are becoming major activities in daily life, and effective citizens and leaders of the 21st century will be required to understand and fluently use the latest sophisticated tools to manage an enormous amount of data, information, and messages. *Future shock* means there is an urgent necessity to solve unexpected or ill-defined problems. Therefore, lifelong learning will be the normal state for a modern individual.

One of the major changes in education can be described as a general shift from teaching to learning. This does not mean that the teacher is becoming any less important. Rather, the teacher's role is increasingly to assist students to become good learners. At the same time, teachers must help create stronger relationships between the subjects of study and concrete reality, putting them in a more relevant context for students. In many cases, this implies an integration of disciplines and cooperation among teachers of different subject areas.

Global awareness and cooperation

Educators all over the world have been working for decades to reform their local school systems according to their specific conditions, aspirations, and traditions. These educators are becoming aware that their local endeavours need the support of the global educational community to succeed.

Global awareness is greatly encouraged by the progress of modern information and communication technologies. ICT offer a wide array of materials for building new schooling systems that allow long-distance exchange and interaction between geographically spread groups of teachers and their students. These materials are flexible and responsive to the changing needs of learners of all ages.

Meeting this challenge, in turn, requires collaboration across national, cultural and institutional boundaries, and among individuals and groups who have been isolated. Electronic mail, bulletin board systems, teleconferences, and virtual communities on the World Wide Web (WWW) allow reciprocal communication among individuals and groups with common interests. Education researchers can team up with classroom practitioners to form research collaborations. Working together, regardless of where they live, scientists, teachers, and students are already finding once unimaginable freedom to investigate and understand powerful ideas that may have a global impact. A UNESCO-IBE document puts it this way:

> Current trends such as worldwide economy, the information technology revolution, the crisis in traditional ideological paradigms, massive migration, the growing concern with global problems such as the environment, drugs and AIDS, have modified not only traditional social relationships, but also culture's role in the development process. Two apparently contradictory trends dominate modern society, or, more correctly, many societies that are now in transit: standardization of cultural patterns and the search for basic reference points for cultural identity. The tensions, the imbalances and, in many cases, open conflicts have worsened to such point that some analysts estimate that future conflicts will take on cultural character…
>
> Education, both formal and informal, is at the centre of this renewal of methods for cultural dialogue. (UNESCO-IBE 1995, p. iii)

INFORMATION PROCESSING AS CORE ACTIVITY IN SCHOOLS

This chapter commences with a discussion of various societal perspectives – the accelerating pace of global change, globalization and ICT, and so on – concluding that radical changes in schools are needed. Next, we touch on key educational trends and suggest that a new literacy is required for the 21st century, calling for a different kind of teaching. The final section of this chapter argues that ICT can meet many of the major challenges of society and ultimately transform schools, as we currently know them.

Technologies and tools

As a wise man noted centuries ago, neither a bare hand nor an intellect alone can get jobs done. We need tools. And ever since the dawn of human history, people have been inventing and using tools – stone axes and hammers, potter's wheels and furnaces, levers, and pulleys – to process food and materials and to harness the energy needed for their physical survival and well being.

Similarly, people have used tools for information processing and communication exchange. The invention of language made our far-off ancestors capable of processing and controlling their own thoughts, feelings, and behaviour. Words can be considered as the tools of our mental activities, and the first and foremost of the latter is the activity of learning.

Until recent centuries, these activities have been manifested almost entirely through the organic functions of our minds and body (i.e. speech), and slightly supported externally by rather primitive tools and techniques (e.g. writing stylus and pen, or abacus). Then the printing press appeared.

During the 19^{th} and 20^{th} centuries, new tools for storing and transmitting information appeared. Today, computer-centred ICT are extending and amplifying our capacity for computational operations, logical reasoning, heuristic search, and grasping of coherence and hidden interconnectedness in chaotic signals and disparate data. That is, a computer is never autonomous but, rather, connected to a growing number of electronic digital devices, aggregations and networks for data and information acquisition, storage, processing, distribution and multimedia delivery. All these entities are subsumed under the generic name of ICT.

Educational technology of mind

We turn now to the educational technology of the mind, or an analysis of what is involved in learning. In most learning activities, the following phases can be recognised:

(a) Accepting and analyzing a problem.

(b) Making sure we have no ready-made solutions for it.

(c) Deciding to launch a project, setting the main goals and objectives, weighing our mental and material resources.

(d) Discovering that we are not equipped enough to cope with it successfully.

(e) Seeing what additional specific knowledge, skills, or experience we must obtain to arrive at a solution.

(f) Going through a corresponding process of research learning, training, drill and practice.

(g) Designing a set of possible solutions (generating options, comparing alternatives, evaluating), and then choosing the one that seems most suitable.

(h) Imagining what will happen if the chosen design is implemented. What changes will it make to our immediate surroundings and broader physical and socio-cultural environment? What consequences and side effects might it cause? How could we prevent, avoid, or repair them? Re-assessing the overall approach to tackling the problem.

(i) Reflecting upon what we have done: repeating mentally the road taken and actions made; describing the essentials; scheming about if, and how we could use our newly acquired knowledge, skills, and experience to address other problems in the future.

This pattern of learning activity phases, which we might call the basic educational technology of mind, can be developed and supported with various software, hardware, and courseware technologies of computer simulation, email networks, interactive multimedia, and other advanced uses of ICT.

Learning as information processing

Generally speaking, information is the content of all messages we receive from other people and the world at large, as well as those we originate ourselves and send back in exchange.

Information manifests itself wherever and whenever we find or create any patterns. A pattern is such a distribution of events in a time or space continuum that we can recognize and nominate, then compare to some other pattern and, finally, discern the former from, or identify with the latter. One may draw a parallel between the notion of pattern and the notions of order, organization, and form, as opposed to anything disordered, chaotic and formless; in this perspective, information can be understood literally as *putting into form*.

Human information processing – be it purely organic or instrumentally supported and extended by the most sophisticated machines – encompasses collecting, storing, retrieving, sorting out, assembling and disassembling, re-working, and transmitting patterns used in thinking and communication, as well as inventing, designing, constructing, and manufacturing any tangible object.

Any learning begins with seeking for, finding, and testing patterns – coherent clusters of information – favourable to our survival, comfort, and unfolding of our hidden potential. Even infants strive to explore their immediate surroundings by trial and error; they imitate adults' actions (e.g. smiling) and see whether something is edible, pleasant, amicable, hostile, or good as a tool to reach something desirable. The information gathered, interpreted, and evaluated during such explorative and imitative-reconstructive behaviour is stored in children's memory as mental models for their future purposeful actions, both physical and intellectual, including all kinds of consecutive learning endeavours.

ICT make natural tools in education because of the simple and fundamental fact that learning is largely based on dealing with information. Listening, talking, reading, writing, reassuring, evaluating, synthesizing and analyzing, solving mathematical problems, and memorizing verses and state capitals, are all examples of off-computer information processing. Even more importantly, ICT can be used for other types of information processing, previously marginal in the traditional school, but now becoming more and more essential, like project planning, or the search for new information outside school textbooks, as well as in the processes of so-called creative writing (drawing, constructing). In many other school activities (such as sport, for example), different kinds of interaction between students and teachers can gain from using ICT. The human dimensions of ICT manifest themselves in providing powerful means to open dialogue, fruitful interaction, and synergy between a teacher and a student or, rather, between Master and Apprentice, as well as among apprentices themselves – whether in close contact or by long-distance.

Historically, information processing and communication have been major school activities. These occurred mainly between the teacher and student with the very modest external support of pencil, paper, and chalkboard. Now, the extensive use of computers, with versatile sensors, peripherals and extensions, allow teachers a whole new degree of sophistication and flexibility.

2

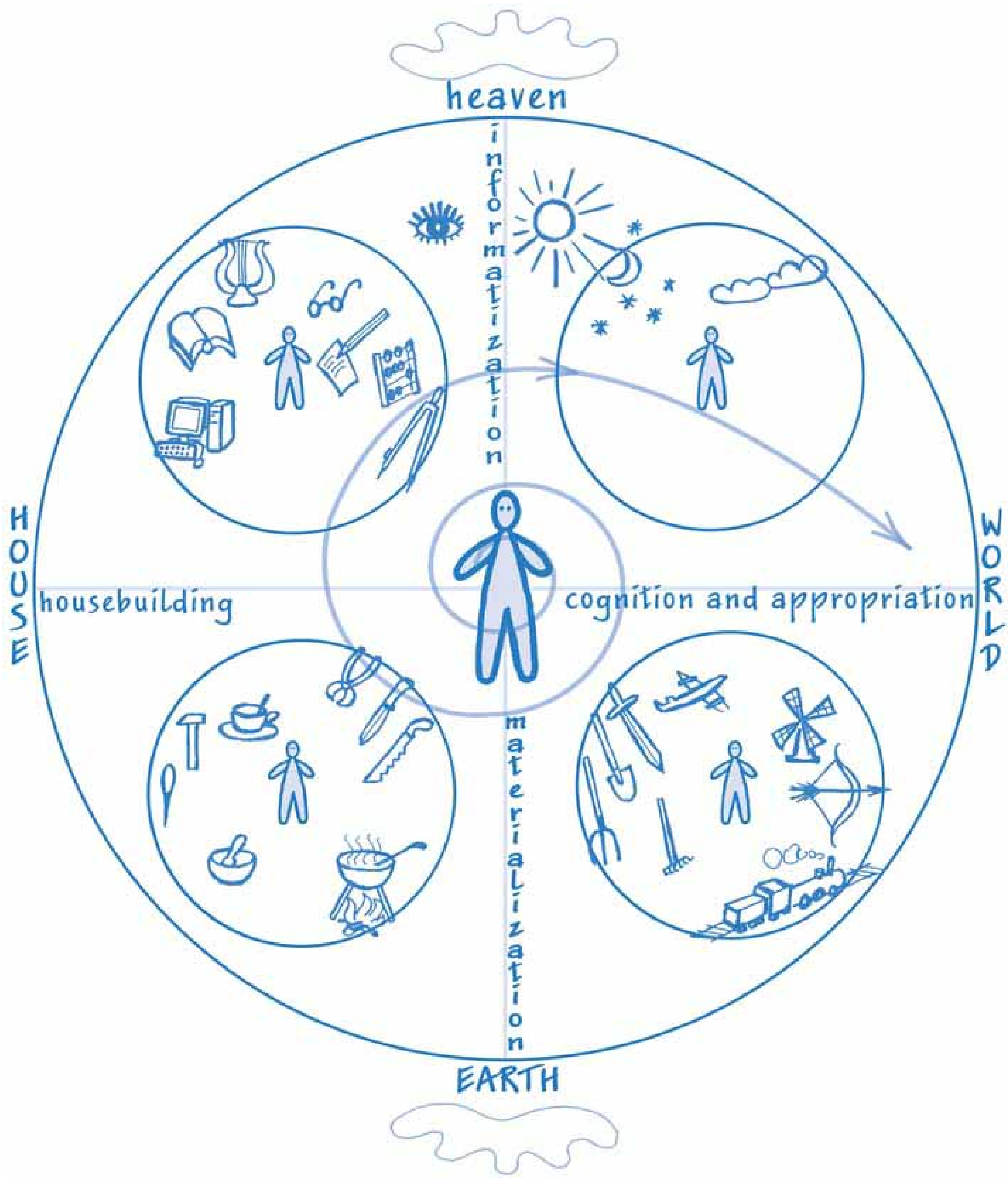
ICT: NEW TOOLS FOR EDUCATION

METAPHORS FOR COMPREHENDING ICT

A computer and its peripherals are often likened to an organism able to interact purposefully with its surrounding realities, which are perceived and modified through various receptors and effectors. This view helps to explain the principles of industrial robots, guided missiles, and similar automata, but the metaphor leaves out many other important applications of ICT.

One could also describe these complex hardware and software systems as sets of smart tools or, rather, as teams of highly disciplined, indefatigable, semi-self-governing artificial agents ready to execute strictly defined tasks. By wisely commanding, controlling, and managing the work of those tools or agents, we can increase:

- the sensitivity of our senses, which enable us to perceive events and communicate with other humans and machines over long distances;
- the amount of data, information, and symbolic expressions that can be processed and logically analyzed in a split second;
- the efficiency, accuracy and precision of our manipulations of both symbolic and material objects of the most diverse kind; and
- our capacity to make sound decisions based upon intuitive judgments and tacit knowledge.



Still another way to understand ICT is to imagine them as extensions of human organs and systems, including perceptive, reacting, thinking ones. These extensions operate mostly in the created (artificial or virtual) reality,, presented mostly by visual images. So we can use digital tools to clarify our inner picture of the outside world, as well as to enhance our ability to manage space and time while operating personal computer – a machine that works in permanent contact with a human. Co-ordination between the human body, our senses, and the personal computer is a critical issue in the effectiveness of using ICT. This coordination is similar to that required by other artifacts designed and targeted to human needs: tools for handicraft, furniture, eyeglasses, and many other material objects.

INFORMATION BASICS

In this chapter, we start with an approximate explanation of what an information object is and explain some basic facts about storing, transmitting, and processing information. After a discussion of the different types of information processing devices, we return to information objects and related learning and teaching activities in Chapter 4 and following chapters.

Information objects

Technology can provide our eyes with a static image (or picture) or a dynamic (changing) video image. It can also present us with an audio (always dynamic) sound. And both can be combined in video recording and playback. These are the basic types of information objects.

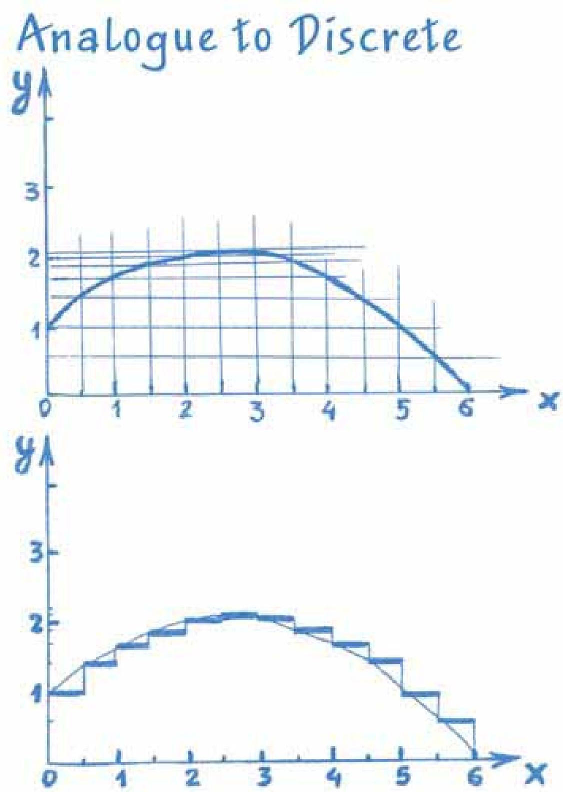
Humans can also structure information objects. For example, we invented languages and characters for their communication. Texts (sequences of characters) are formed information objects. There is also the possibility of making complex objects from simpler ones by means of links. A link is an imaginary connection, association, or arrow going from an element of one object (for example, a word, or a piece of an image) to another. The complex object constituted by such linked objects is called a hyper-object. ICT provide us with tools to transfer immediately from one object to another, or between hyper-objects.

Information space

As humans, we store a huge amount of collected information outside the human brain, in libraries and archives, and in other types of storage, and increasingly in ICT digital devices. These might include an individual, personal information space (like a personal library). Similarly, groups and organizations build their own information spaces. Thanks to the Internet, most of these information spaces are now parts of single global information space, in theory accessible to everyone.

Digital transformation

Signals and images in the physical world are either continuous or analogue. To be stored, transmitted, and processed by modern ICT, they must be transformed into digital, or discrete, signals. The simplest example of discretization is measurement. When you measure length, weight, or time, you transform an analogue value into a digital one: the result is a finite sequence of digits. In the following graphs, temperature is presented as a continuous curve. It is approximated by measurements in fixed moments, one an hour with an accuracy of one degree.



Words for big numbers

In the world of ICT, some very big numbers appear in measuring amounts of information, speed of transmission, and processing of information. To name these numbers in a human language, we need further words, and for this special Greek prefixes have been adopted:

K = Kilo = 10^3	T = Tera = 10^{12}
M = Mega = 10^6	P = Peta = 10^{15}
G = Giga = 10^9	E = Exa = 10^{18}

The same words are also used for powers of 2, exploiting the approximation $10^3 \approx 2^{10}$.

Storing information, memory and compression

When we store information (in a computer memory or in another way), we measure the needed memory size using specific units. To store the simplest piece of information, a '0' or '1', we need 1 bit. One byte equals 8 bits, and can store up to 256 different symbols – for example, the English alphabet (in upper and lower case), plus digits, and punctuation marks. Therefore, when we say that the memory size of a computer is 6 gigabyte, this means that the memory can store approximately 6,000,000,000 symbols. Bits are abbreviated as b, bytes as B.

In some cases, information can be compressed to occupy less space, and then de-compressed (decoded) to restore it close to, or often identical to, the original. Compression requires less memory volume for storage, and allows quicker transmission time. A popular format today for compressing video and sound is MPEG (in different versions: MPEG-1, MPEG-2, MPEG-4, and so on).

Here are some figures on the size of information objects given in orders of magnitude:

1 page of text occupies 1-10KB

1 picture of the screen of a modern computer of a good quality occupies about 1-10MB

1 minute of digitized sound of good quality occupies approximately 10MB (or, if compressed, with a minor loss of quality, it takes about 100KB)

1 minute of digitized video of good quality occupies approximately 100MB (or, if compressed, with a minor loss of quality, it takes about 1MB).

Transmitting information

Information is transmitted between people in different continents or inside the human brain in the form of signals. The signals are dynamic changes, or waves. Two major types of waves around us are: sound waves in solid, liquid or gaseous media; and electromagnetic waves transmitted in a vacuum (in any mediuma transparent for them), or channelled in a wire or optical fibre. The most important kind of waves is constituted by periodic changes (oscillations) in a medium. These periodic changes are transformed, distorted, reshaped or modulated, to transmit a signal. The frequency of the changes is measured in Hertz (abbreviated as Hz). One change per second is 1 Hz. In the case of sound, the frequencies that can be perceived by humans are in the range of 20 Hz to 20 KHz. In the case of electromagnetic waves, the frequencies used to transmit information are:

Visible light between 430THz (Red) and 750 THz (Violet)

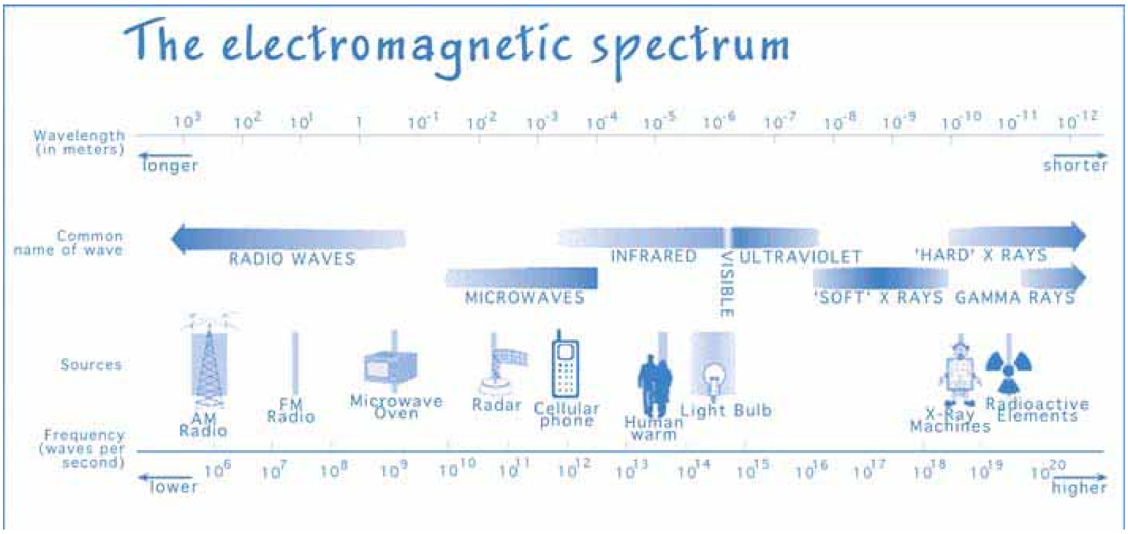
Radio (RF) in the range 100 KHz to 10 GHz (including frequencies for AM, FM, TV, cellular, and satellite transmission)

Microwave between 10 GHz and 1 THz

Infrared (IR) about 10 THz – visible light (Red)

Ultraviolet is visible light (Violet) – 100 THz

X-Ray is 100 THz

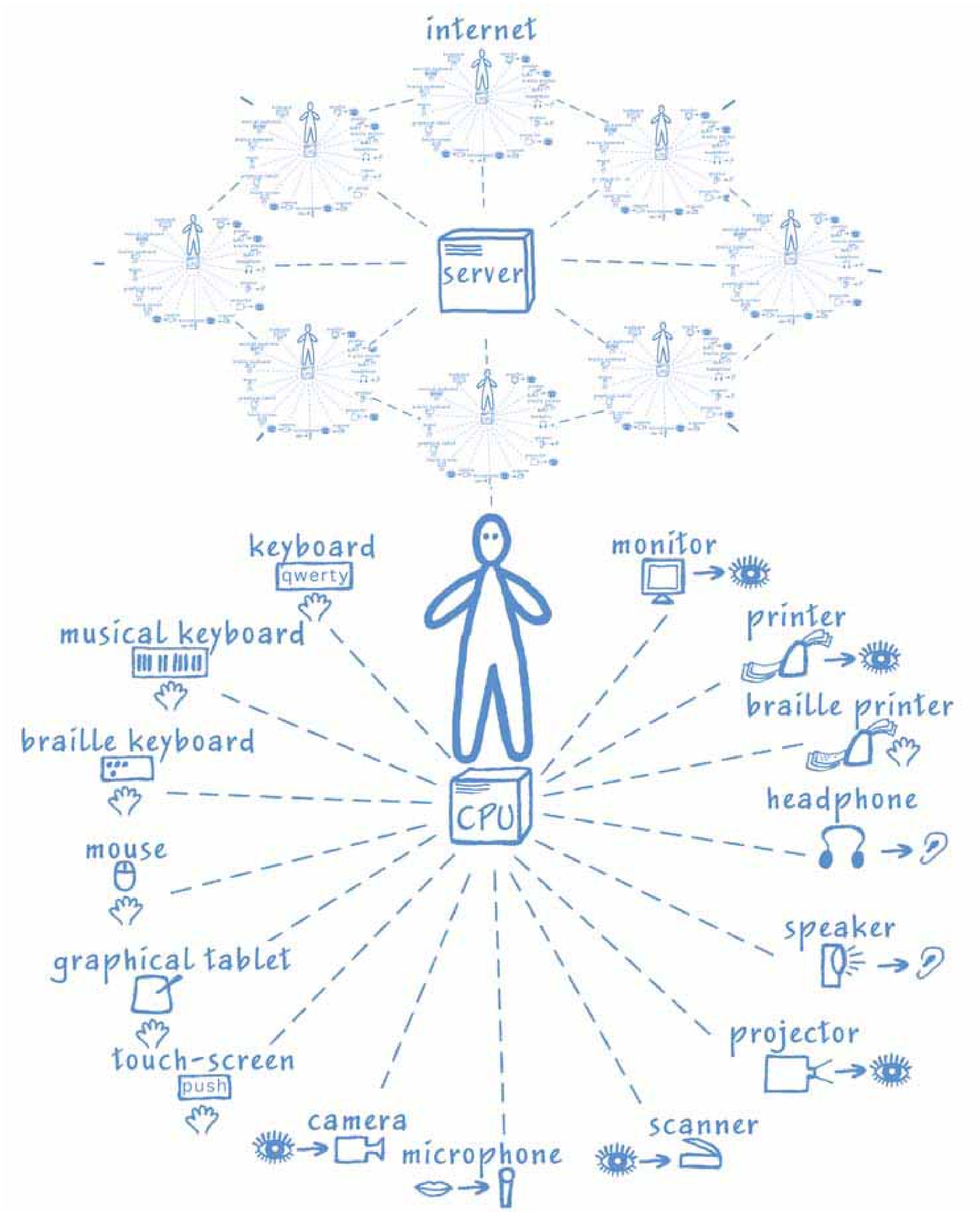


Visible light is limited by the physiology of the human eye. The limits indicated for visible light are not conventional but *natural* – starting with red and going to violet. Other borders are more a question of terminology.

In the process of information transmission, when modulating a wave of a given frequency, we actually occupy, not a single frequency for transmission, but a band of frequencies. With a wider band, we can transmit more information. In simple cases of wireless transmission, we cannot use the same band in the same geographic area for two simultaneously transmitted signals. Instead, we use higher and higher frequencies for transmission. For wired transmission signals in the RF range, we use in metal (copper) wires, while for visible light we use special plastic optical fibres.

HARDWARE COMPONENTS OF ICT

In this section, the focus is on what is termed *hardware* – the components of ICT like the computer itself, storage media, and input and output devices.



Computers

The computer is a universal information processor. In theory, any kind of information processing can be done on any computer but, in reality, this is not true. A specific task for a specific computer may require too much time, or the computer's memory may be too small. Computers process information in the form of electric signals. In other existing technologies, simple information processing can be done also in the form of air or liquid streams. There are attempts to produce computers that use light processing, or biochemical mechanisms similar to that of living organisms, but these approaches are at a premature stage.

CPU

Information processing is done by computer hardware. The most important components of computers are (electronic) semiconductors, similar to the components of radio or TV, but much more sophisticated. The number of electronic elements inside these components can be counted in millions. These elements are joined together to form integrated circuits (IC), commonly referred to as *microchips*, or simply *chips*. The core device in any computer, called the *central processing unit* or *CPU*, does all information processing. Today the CPU occupies a metal box in which you can see dozens of integrated circuits, wires, and cables connecting them. (Yesterday's computers were much bigger and occupied a full room, or even a whole building.) The main IC in the CPU is the processor itself, which does most of the active task of processing, including adding numbers, comparing strings of symbols, sending information to memory (see below), retrieving it from memory and, very importantly, reacting to signals from the outside.

The work a computer depends not only on its constitution as an electronic device, but also on the information stored in it or that it receives while in operation. This information can be considered as instructions that tell the computer what to do, and is called *software.*

Information is stored, transmitted, and processed in the form of strings of zeros and ones. The input of information into a computer usually involves the transformation of images or sounds into digital and discrete strings. The output involves the reverse transformation. These components of hardware and software responsible for these transformations and making them perceptible to the human senses, are called *interfaces*. Computer information is stored in special types of IC, called *storage* or *memory chips*. A computer's speed is an important factor in its performance. It is measured in MHz, which refers to the number of changes inside a computer that can take place in one second.

Monitor

An important component of any modern computer used by a human being (and for this reason called a *personal computer*), is the *screen or monitor*. Monitors not only display information but can also support direct interaction. For example, if you need to make a technical drawing of a particular detail with a computer, you move your hand equipped with one of many input devices (see *Peripherals* below), to create a line or activate a detail on the screen. The whole system of using physical movements to manipulate information and present this manipulation in intuitive screen images is called *graphical user interface* or GUI.

Connections

The CPU is connected with other ICT devices via communication channels. The most common communication channel is a cable plugged into a computer at one end, and to another device at the other end. The cables and sockets can cause problems, including incompatibility of sockets in the case of connecting your computer to a local telephone line abroad. A popular alternative to cables is wireless (radio-frequency or infra-red) connection. To simplify the graphic presentations, we do not include cables in the pictures, and say more about these connectors in the sections that follow.

Computer sizes

Computers that are placed on the desk of a clerk, student, or teacher are called *desktop computers*. Sometimes, however, the computer itself is placed under the desk with the monitor and keyboard on top. These computers usually weigh several kilograms, with the monitor usually being the much heavier component. Other computers are portable or mobile. Their weight and size permit them to be carried comfortably. Computers of a size and weight of a large notebook, which is easy to carry, are called *notebooks* (formerly, *laptops*). Today's notebooks weigh as little as 1–4 kg. Computers the size of one's palm, and weighing less than 1 kg, are called *palm computers*, *handhelds*, or *palms*. All such computers are called *personal computers*, or *PCs*, because they are intended for individual usage.

CPUs today are very small. We can say that for most school applications the size of a typical CPU is not a limitation. On the other hand, in some classroom situations, the size of the whole computer matters. If we place a monitor on a student's desk, it must be large enough to be comfortably visible, yet small enough to leave space for student work.

Energy for computers

Electricity is needed to run a computer and its related devices. The power consumption for a desktop computer is typically 100–500 watts. In many countries, this resource is widely available, but in others it is still a problem. For them, alternative power sources such as solar batteries, wind generators, and accumulators (rechargeable batteries), as well as UPS (Uninterruptible Power Supply), should be considered in the planning of ICT implementation. Solar batteries, for example, cost a few dollars and can supply a palm computer with energy, provided they are exposed to sunlight a couple of hours a day.

Portable computers can use the same power line as desktop computers. However, it is much more convenient to have a portable computer that can function, for a while at least, with rechargeable batteries. These can support the computer for a few hours, and then need to be recharged from a power source. In the best cases, recharging takes much less time than the computer needed to use up its power, and recharging can occur while the computer is in use. A bad aspect about accumulators, apart from their weight and considerable cost, is that, if used intensively, they last only a few months. Even in the best cases, a rechargeable batteries' life is much shorter than the life of the computer itself.

In many cases, the modern processors that have appeared over the last few years require more energy to run than the older ones. Roughly speaking, every action of the CPU needs a minimal amount of energy to be used. If the processor works faster, the same amount of energy is used in a shorter time. As the computer runs, this energy dissipates in the outside environment in the form of heat, and so computers come equipped with special cooling mechanisms like fans.

Peripherals

For the best utilization of ICT in education, a teacher needs a wide range of devices connectable to a computer, and these are referred to as *peripherals*. The major categories of peripherals are devices for:

- Input: alphanumeric keyboard, musical keyboard, microphone, tape-recorder, tablet and stylus, scanner, digital photo camera, video camera, sensors, and probes.
- Output: monitor, printer, projector, headphones, speakers.
- Control: motors, lights for robotics construction kit, and sensors.
- Communication: modems, communication lines, satellite and local network equipment, and wireless networks.

Having a wide range of peripherals for educational and general use is more important in a school than the number of computers. We consider these categories of peripherals in a little more detail in the sections that follow.

Different components of a computer as well as peripheral devices need to be connected via channels for information flow. In most computers today, cables do this, but wireless connection is increasingly possible as well, which then requires, of course, that the device has its own source of energy (usually, power line or batteries).

Storage

Information is stored in *integrated memory circuits* or *memory chips* in the computer's CPU. However, there are other ways to store information. These other means differ in capacity (the amount of information they can store) and access speed (how fast the information can be retrieved). Stored information can be retrieved and, in some cases, changed. Read-only memory (ROM) means that the user cannot change any retrieved information. In the opposite case, we talk about *rewritable memory*, stored on a computer's hard drive or on portable discs. The cost of storing information is constantly and rapidly decreasing.

The key storage devices currently are flash cards, magnetic tapes and discs, and optical discs.

Flash cards

Additional memory chips – so-called *flash cards* – can be easily inserted into and removed from the body of current computers. They do not require batteries to keep information stored. The capacity of one card today is in the range of 10MB to 1GB and access is fast enough for most applications. Flash cards are widely used in digital cameras (see *Cameras* below in this chapter) and other applications. They are rapidly replacing discs (see below). Some versions of ROM cards are used in game consoles (where they are also called *cartridges*).

Magnetic tapes

Magnetic tapes, similar to those used in tape-recorders, can be used for storing digital information as well. To read or write information on a tape, a special device similar to a tape-recorder is used, called a tape drive. The drive can be external to a computer or placed inside the CPU box. The capacity of a tape can be up to 10 GB and even more. Access speed, however, is slow, which can be critical for certain applications, though this is less important for most school uses. Magnetic tapes are rewritable.

Magnetic discs

The idea of disc storage can be traced back to gramophone recordings at the beginning of the 20th century.

Information on those discs was permanently stored in the form of small mechanical (geometrical) changes in the surface of the disc. Some of today's versions of disc storage use a magnetic principle similar to tapes, and these discs are rewritable. Discs with the capacity of about 1MB are also called *diskettes*; you can insert them into a drive (disk-drive), or remove them. It may take up to a minute for a computer to read from or write to a diskette. Newer discs have a capacity of up to 1GB. The competition from flash cards (see above) is strong. Discs with even greater capacity are mounted on their own drive, and these are usually called *hard discs*. Their capacity is in the order of 10GB to 1000GB. The access time for hard discs is fast enough for most applications.

Optical discs

Information can also be stored on a disc as an optical trace. This principle is exploited in *compact discs* (CD), widely used now for storing music. The capacity of a CD-ROM is approximately 1GB. Access speed may not be fast enough for some applications involving sound or moving pictures. To address this problem, observe the different speeds marked on CD-drives: 2x, 6x,... 48x... A newer form of CD-ROM is called *digital versatile disc* or DVD, which looks similar to a CD but can store 10GB or more information. Rewritable CDs and rewritable DVDs have appeared in recent years.

Human movement as input

The most common way to input information into computers is by human hand through a variety of devices: keyboards, the mouse, graphical tablets, and touch screens.

Keyboards

The most important input device for computers currently is the keyboard, which serves mostly for text input, and, to a large extent, imitates the keyboards of typewriters. The computer has many advantages over a typewriter, even apart from its more sophisticated software and other applications. The first of these is how easy it makes it to change, delete or insert any word or phrase. The next is the ability to copy any text fragment and to move it as a solid object anywhere within a text, or to another text, usually referred to as *cut-and-paste*. Touch-typing (not looking to the keyboard and using 10 fingers) is a useful skill in the educational context today. Students can learn touch-typing faster than handwriting; they can type faster than they can write; and the results are more attractive and much easier to edit and revise.

Extensive work with the keyboard, however, sometimes causes muscular tension and requires special precautions, which students and teachers rarely take (see the section below on *Health problems associated with computers*). Newer ergonomic keyboards are becoming more prevalent, as is the use of alternative methods of writing such as script and speech recognition. Different arrangements of characters on the keyboard could make typing more effective. A radically new tool, called the *Twiddler*, is an ergonomic handheld, touch-type keypad designed for chord keying, which means that like a piano you press one or more keys at a time. Each key combination generates a unique character or command. Because of resistance to change, widespread adoption of these tools does not look probable.

Keyboards of notebooks are usually built into the *book*. Keyboards are not usually built into palm computers. Sometimes a keyboard is represented by a screen image on which you type by touching keys with the tip of a special pen. Sometimes, lightweight unfolding keyboards are used for palm text input.

Musical keyboards

Musical keyboards look like a traditional piano or modern rock-group synthesizer keyboard, only smaller. Attached to a computer, this peripheral can be used far beyond the imitation of a piano. The standardization of digitized sounds of most instruments in MIDI (Musical Instrument Digital Interface) allows students to play and even to compose musical pieces performed by different instruments or an orchestra, and immediately hear a performance of the piece by those same instruments. Notes input with a musical keyboard can then be edited with a mouse. The avenues for students' musical self-expression are in this way dramatically enlarged.

Mouse and its alternatives

To manipulate screen objects, you need to *point*, *choose*, *grab*, and *open* them. In today's computers, these operations are usually done with a special instrument, which indicates an object on the screen and moves it as a solid body. This instrument is called a *mouse*, a handheld, traditionally grey, plastic body that you move on the table-top, which is usually covered by a small mat called a *mousepad*, designed to improve the movement of the mouse. As you move the mouse, a small object (an arrow, for example), called a *cursor*, moves on the screen, mimicking the mouse's movements on the table. The mouse has buttons that help you to extract, pick up, and manipulate objects. You move the cursor to an object and click a button; the object now is attached to the cursor and can be moved. If you click another button, the object *opens up*. These actions are part of GUI or the graphical user interface.

There are other devices to transform movements on screen into information manipulation inside the computer similar to the mouse. They all act similarly, but the physical movements of a human hand working with them can be quite different:

A handheld mouse, not lying on the table, can have a small gyroscope inside, and is useful when you show something to others on a big screen.

A *trackpad* is a small panel (about 3 by 4 cm) over which you move your index finger to control the cursor.

A *trackball* is a ball about the size of an egg embedded into a panel, which you can rotate.

A *joystick* is a small lever (as in a car transmission gearshift) used mostly in computer games.

There are also very small joysticks inside some keyboards called *trackpoints*, which you can push and deflect with your finger. These are also used as the mouse part of the Twiddler mentioned above, where the trackpoint is controlled with the thumb.

Wireless mice that have no moving parts are more reliable and have become more popular. Among them there are handheld mice that you do not place on a table but move in 3D space.

Graphical tablets

Another type of input is to draw or write with a pen. The difference between a computer pen or stylus and an ordinary one is that the computer pen moves over a special surface called a *graphical tablet*, and the trace of the move can be represented on screen. The computer can also measure levels of pressure. With appropriate software, a computer can imitate almost all existing drawing techniques and create some exciting new ones. The computer is very useful for technical drawing – now, mostly part of computer-aided design or CAD.

Handwriting

The most effective way to start written communication for children (and adults) is to have them type on a computer. But handwriting is still a popular and useful skill. Consequently, handwriting recognition, which immediately transfers handwriting into block letters on the screen (and text in computer memory), is a valuable supplement to keyboarding, and sometimes a major input technique (for example, in certain kinds of environmental observations). With palm computers, you can write text that can be recognized by the computer using a special stylus. Handwriting and drawing by hand on a large whiteboard can be done with a computer also. In this case, you write or draw on the board with a special marker that is traced by an infrared or ultrasonic detector.

Touch screens

The devices discussed above are intuitive enough but nevertheless separated from the objects on a computer screen. Another promising type of device combines seeing with touching, allowing you, for example, to outline an object on the screen with your finger and then move it to a different position with the same finger. This is already achieved with touch screens. A finger cannot indicate a very small object on a screen. However, this limitation can be relaxed by using a *stylus* on the screen (a kind of pen or pencil designed for this kind of interaction). Touch screens can work well and are more intuitive for small children, but are not widely used. One reason for this is their cost, which is higher than an ordinary screen and mouse. Nevertheless, they are the most popular devices in most information kiosks and in palm computers.

Further options for human movement input are discussed below under the sub-section on major trends in ICT.

Visual input

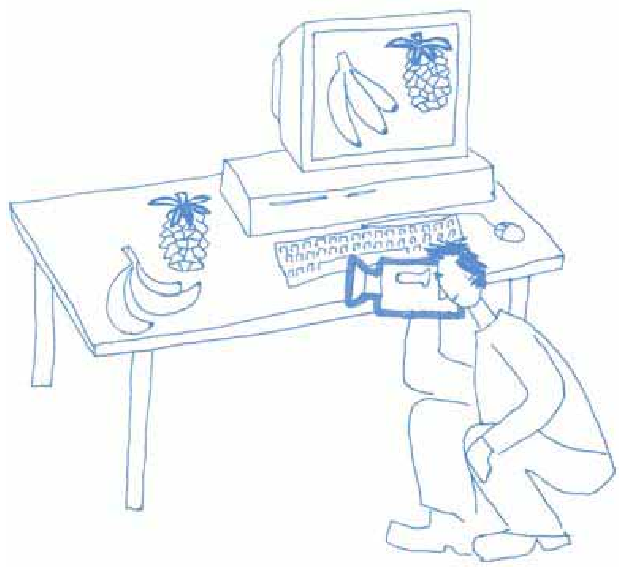
In the mid 19th century, photography was invented as a means of fixing and storing visual information in an external medium using a chemical process. In the 1930s, devices were introduced that transform visual information into electronic form for immediate transmission via electromagnetic waves: TV technology. In the 1950s, simultaneously with computer technology, methods to record and play back analogue TV and still images appeared: the videotape. At the end of the 20th century, digital photography and digital TV became an integral part of computer-based ICT.

Cameras

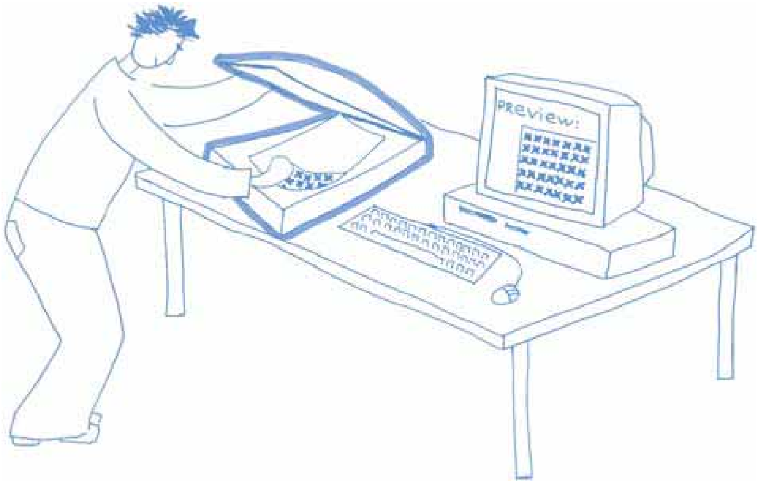
Cameras store or transmit visual images. The photographic camera stores a still image on photographic film for further chemical development. Instead of putting an image onto a film, a *digital camera* places it in the computer's memory, or in the memory of the camera for transmission to a computer for storage or direct printing afterwards. An interesting application of digital cameras is the projection of a small image (such as a bug, for instance) onto a large screen. Nowadays, digital cameras can store video images also.

Scanners

Scanners look very like copying machines, but are smaller and usually work more slowly. Instead of producing a paper copy of an image, a scanner transmits an image in digital form to a connected computer. Scanners can be used to transform information from a paper source – a text, an image from a book, a drawing, or a photograph – into a digital image. Additional devices can be used for scanning 35mm slides. There are also handheld pen-size scanners that you can move over a line of text or a bar code for input or storage inside the scanner. Special 3D (three dimensional) scanners can produce scanned images viewable from different angles.



Optical character recognition



A special situation occurs when an image is a text (or text combined with graphics) in printed or handwritten form. In this case, the image of the text can be transformed (converted) into a computer text file that can be processed as one does other texts in the computer (e.g. insert a phrase; change a shorter name to a longer one, and so on). This process of transformation from picture to text uses sophisticated software called *Optical Character Recognition* (OCR).

Aural input

As with visual information, non-electronic, that is mechanical technologies, were developed first to store sounds. Then, electronic technologies were developed to transmit sounds (telephone, radio), followed by electronic media and tools to store sounds (tape-recorders).

Microphones

Microphones transform sounds into electric signals for storage or transmission. There are different types of microphones and different ways to work with them:

- A microphone can be fixed in a stand in front of a speaker who is standing or sitting.
- Speakers can hold a microphone in their hand.
- A lightweight microphone can be attached to a speaker's clothes.

Information converted by a microphone into electrical signals can be transmitted via a wired or wireless channel to other devices.

Sound recording

Sound can be recorded with a usual tape-recorder. To process sounds with a computer, you need to convert them into digital form. A microphone can also be plugged into a computer directly. In this case, the computer serves as a recorder. Digital recorders to store sound in digital form using flash cards are becoming increasingly popular. Modern computers can easily store hours of speech. Music recordings, processed and compressed by computer (in MP3 format, for example), occupy very little memory. The spread of this process, on CDs and through the Internet, is changing the recording industry and affecting mass culture.

Speech recognition

During the last few years, software has been developed that allows a computer to transform human speech into a text file similar to the conversion of handwriting as discussed above. This transformation can be done with a level of quality that makes it adequate for educational applications, and is useful, for instance, in learning English.

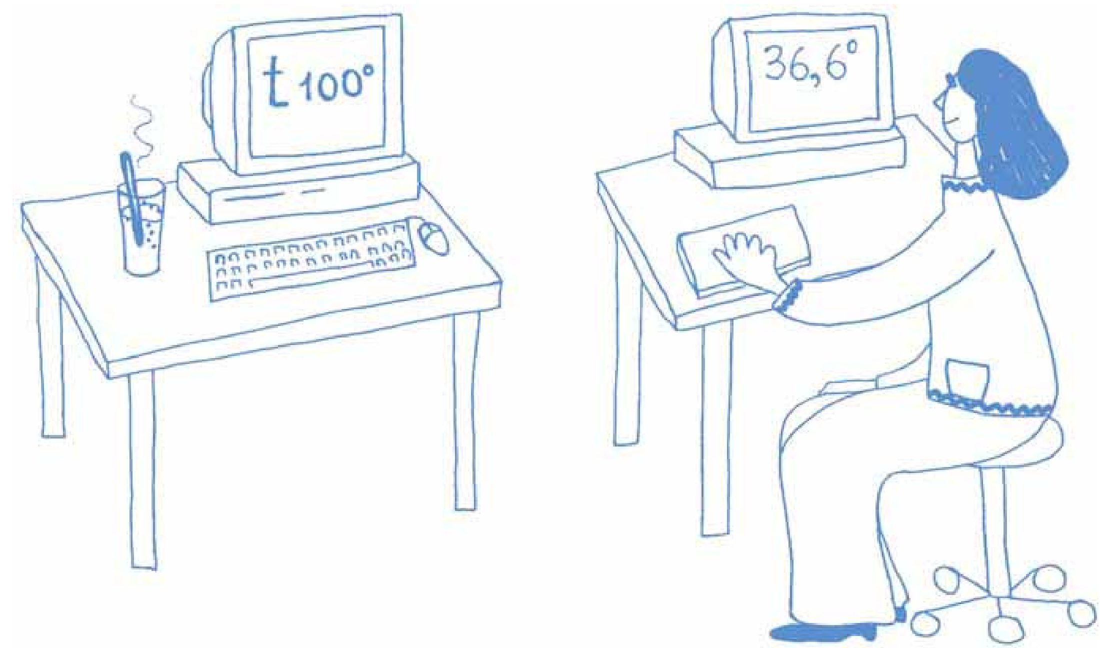
Sensors for input

Measurements of the environment like temperature, humidity, acceleration, or magnetic field, can be input to a computer-linked device called a *sensor*. A sensor generates an electrical signal that is then usually transmitted to a computer via an interface.

More sophisticated sensors can measure such parameters, store, and display them, even if a sensor is not connected to a computer. This can be done by individual sensors or by what is called a *data logger*, a special device or small box to collect and store data. The content of measurements can then be transferred to a computer. Very promising in school education is the growing number of sensors – from those that measure acid rain and heavy metal oxides ratio in potable water to the Global Positioning System (GPS), which allows anyone to find geographic coordinates and related information on the earth's surface.

Output

Output refers to information that a computer sends to a human user, or, sometimes, to other technical devices.



Visual output

The most immediate computer output is a visual image on the monitor screen.

In most computer applications, the image on the screen is discrete, and consists of millions of picture elements called *pixels*. The colour and brightness of each element appears as a combination of three colours called *RGB* for red (R), green (G), and blue (B), with varying brightness for each colour. In reality, for every particular screen, each of these three basic colours consists of the entire spectrum of light waves. The brightness (intensity) of the three basic colours is coded by a symbol from a finite range. The symbol and the range of old computers were just one byte (8 bits). Today, colours are usually presented by 3-byte coding (24-bits) representing millions of colours) or 4-byte coding (32-bits) representing billions of colours. The latest technology appears to be able to capture all possible variations in colour. In normal light conditions, the human eye can recognize differences in brightness (contrast) in the range of 1:10,000 or even more. Existing output screens can provide differences in brightness up to 1:1,000. In many cases – in most school conditions, for example – ambient light reduces the contrast radically, and so teachers need to adjust conditions of vision and the absolute brightness of screens. The optimal brightness of screens lies in the range of 50–400 Lux.

Resolution (the number of pixels in rows and columns) is usually named by acronyms such as SVGA (800x600) and XGA (1024x768). The ratio of the two factors is 4:3. The resolution is limited by characteristics of the screen, but mainly by a computer's power to *refresh* images quickly, which is needed to make visualization of the processes adequate and the computer-human interface smooth. XGA is the most widespread resolution in use today but higher resolutions called SXGA and UXGA are coming.

TV screens similar to, or the same as, computer screens used today, offer a slightly different way of presenting information – partly digital, partly analogue. Generally, today's TVs produce less detailed images than good computers, though the newest TV standards have images of the same quality as good computer images. This improved definition is called *HDTV (high definition TV)*. The move to HDTV is accompanied by a trend to change the aspect ratio (the fraction of screen width to its height) from 3:4 to 9:16, which is the ratio usually seen on cinema screens.

Theoretically, the limits of a visual image are the limits of human perception, which means that the screen can provide all the colour and brightness variations in the smallest details in the visible field (and even pay attention to two-eye stereoscopic vision). In reality, existing screen images are somewhat more limited: they have less detail than the human eye can grasp. The human retina has about 300 million cells whereas the best screens today have about 10 million pixels. Eventually, there is a natural limit to the improvement in quality that the human eye can perceive, which will occur when the computer screen is large enough to cover the prime area of clear vision and, at the same time, the smaller pixel-like details are no longer seen separately.

Of course, further improvement can help in some applications. For example, a graphic designer can look at a large screen containing a larger image, and then move in closer to look at a detail. That kind of situation can be covered by the standard zoom options of software systems.

In some countries and regions, there has been concern over monitor safety. This problem has two aspects. The first is image quality. Older monitors (especially, bad quality TV sets that are sometimes used as monitors) have a blinking, non-stable image, and can cause considerable eye tension. The second issue is the radiation (mainly, radio frequency) that the monitor emits. National and *de facto* international safety standards have been established. Presently, monitors are as safe as possible, especially in combination with other proper conditions such as attention to ambient light. One of the key parameters of image quality is refreshment rate, which by most standards, should not be less than 85 Hz. In many newer computer models, it is about 100 Hz.

The classical display technology is the cathode ray tube (CRT), used in most TVs as well as in most monitors. This device is limited by its large depth-dimension and weight. A safer and more comfortable alternative is the LCD (liquid crystal display) monitor, which takes up much less space on a desk, and is important for many classroom applications. They are more expensive than CRT monitors today, but the prices for a whole computer system are not dramatically different.

Projectors

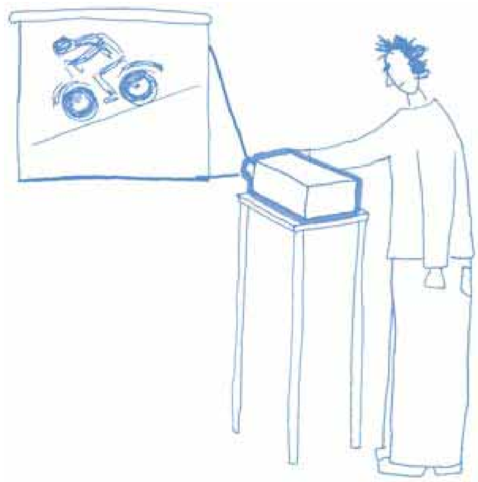
Computer images can be projected onto a screen. The beginning of projection traces back to the centuries-old *Laterna Magica* and Shadow Theatre. Projection flourished in the cinema era. Pre-electronic projectors used transparent film with an image to be projected. The 35mm film can be used in a roll as in dia-projectors (almost non-existent today), or cut into slides for use in slide projectors. Today, all slides (or screens – information objects to be projected) can be made on computer or be input to a computer and presented on computer screen. Special software used for projection of screen images, constructing, and organizing them is called *presentation software*. One of the popular software products here is Microsoft's PowerPoint.

Electronic technology has made it possible to project computer-generated images as well as images from a camera and from a VCR (video cassette recorder). The projected images, different from a computer monitor or TV screen, can be of any size. The only limitation here is that the brightness of the image is reduced proportionally to the area (or squared linear size) of the image. If the ambient light in a room is stronger than the projector's light, differences in colour and brightness of different parts of the image on the screen are not seen clearly enough or, in some cases, at all. The projection device is usually called a *multimedia projector* or *LCD-projector* (indicating, not in all cases correctly, the technology used), or beamer.

Projector technology has developed affordable solutions that are available now in many schools. A computer presentation or video image can be brought to any classroom using a portable screen (weighing less than 2 kg), a portable projector (less than 2 kg), and a computer (less than 2 kg). In fact, each of the items can weigh less than a kilogram.

One of the important trends for monitors and projectors is standardization of the digital interface between computer and the device. The *DVI (Digital Video Interface)* standard describes the digital interaction between monitor and computer.

Stereovision



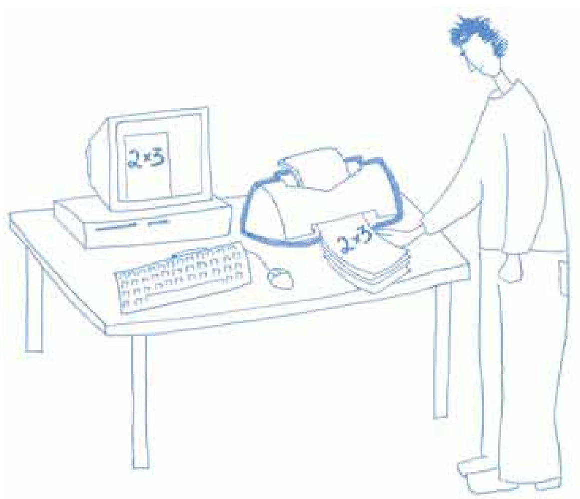
The ability to see with two eyes is important for human perception in some cases. For example, stereovision is useful to estimate distance along with other instruments like accommodation, head movements, and relative size of objects. Accordingly, it is possible to improve perception on a computer by creating a stereoscopic output. This can be done with separate screens for each eye, or by showing on the screen alternating pictures for each of the eyes. Closing screens for eyes alternately can solve the problem of showing to each eye what is needed. The closing can be implemented, for example, by glasses in which the lenses are made out of liquid crystal and become transparent and opaque alternately.

Printers and plotters

A printer transforms screen images into images on paper, so-called *hard copy*. A natural consequence of this is a need for paper and ink. The problem of cost here can be serious for schools in particular, because it is so easy to generate printouts in large quantities.

Laser printers produce black and white images and text of good quality for all school applications at an affordable price. In fact, laser printers changed the appearance of the world of written text. Once, the quality of print correlated with the respectability of the author but this is no longer so since, at first glance, all printed papers look the same. Alternatives to laser printing are *LED (light-emitting diodes)* and *ink-jet printing*. These printers are used in schools as well, but do not provide any considerable advantage. The generation of printers before laser printers were so-called *dot-matrix printers*, which used principles similar in some respects to old typewriters with printer ribbon and mechanical impact. Dot-matrix printers are useful if a school has poor quality paper or if you need to use wider paper or long rolls of paper (for banners, for instance).

It is desirable also to have *colour printers* in schools. A little while ago, the price of colour printers and supplies was too high for most schools but, in recent times, the situation has changed and colour printing has become much more affordable.



A recent invention in printers is so-called *Random Movement Printing Technology* (RMPT). Printers using this technology can be the size of a computer mouse and used in the same way: randomly moving it over a sheet of paper of any size leaves text printed on it.

A device similar to a printer in its functionality, but based on a different technology, is a *plotter* in which an image on paper appears, not as a combination of dots, but as a continuous line of ink.

Audio output

The audio channel is under-exploited in modern ICT in comparison with the visual channel. An important aspect of aural perception is locating the sound source using bi-aural (stereo-phonic) mechanisms. Two loudspeakers of mediocre quality are the most widespread audio output for consumer computers. Headphones can be used for stereo output as well. Some are better than others in quality of sound and the level of blocking of outside noise. Headphones can provide better quality than loudspeakers of the same price. In general, headphones are more useful for schools than speakers. Headphones can be coupled with a microphone.

Control

Control applications were among the most important applications of ICT before the advent of personal computers. Among specific cases are control of industrial machinery, power plants, and missiles. By contrast, personal computers mostly control output devices like printers. However, even this situation is changing, since a personal computer can, for example, be the control centre of an *intelligent house*, where the owner instructs the computer to operate all home appliances.

Communications

The real power of computers comes with linking them together, and in this section some of the key ways of doing this are described.

Communication channels

As noted above, computers are connected to other ICT devices by communication channels that can be wired or wireless.

In general, wired (cable) connection remains the more common type of connection. A cable connecting a computer to a peripheral can be used for three purposes:

1. to transfer energy (electrical current) to a peripheral;
2. to transfer control signals to and from a peripheral (for example, a printer can receive a command "start printing", and send a feedback "not-ready", or "start sending the image to print", or "out of paper"); and
3. to transfer input or output information (text to be printed to a printer, or sound to be digitized from a microphone).

It is common to transfer different electrical signals through one cable in several separate wires. (Actually, the same wire can be used for many signals simultaneously as well.) For different channels of communication, different cables are used. When we connect a cable to a computer or peripheral, we use *sockets*, sometimes called *ports* or *plugs* in the computer's box.

A crucial issue in the use of cables is standardization. Travellers, for instance, know well that about a dozen power plug standards exist internationally and perhaps a hundred telephone plug standards. Fortunately, standardization in the computer world is becoming more prevalent. At the same time, manufacturers are producing more and more new sockets. Consequently, when connecting a computer to external (peripheral) devices, one must be aware of such labels as PCMCIA, USB, IEEE 1394, and DVI.

An important characteristic of a channel is the speed of transmission it allows. For some applications, including school ones, it is also important to plug in or unplug a peripheral device while the computer is working. Old interfaces often required the computer to be turned off while you plugged in or unplugged a device. The newer USB interface does not require turning off the computer while connecting a new device.

After decades of experimenting, wireless connections have become more and more reliable and popular. Using these channels can be critically important for schools, because they provide much needed flexibility. A channel allows computers to be moved between classrooms while keeping the network still operating. In the classroom, it allows children to sit where they are most comfortable without having to struggle with cables. Wireless connections can still be used between keyboard and computer. Brand names like Bluetooth, Airport, as well as standards of Wi-Fi (wireless fidelity), or IEEE 802.11, are used to describe common wireless interfaces. Wireless communication, however, has its limitations since, for example, infrared connection works well in a direct-sight situation only.

Networking

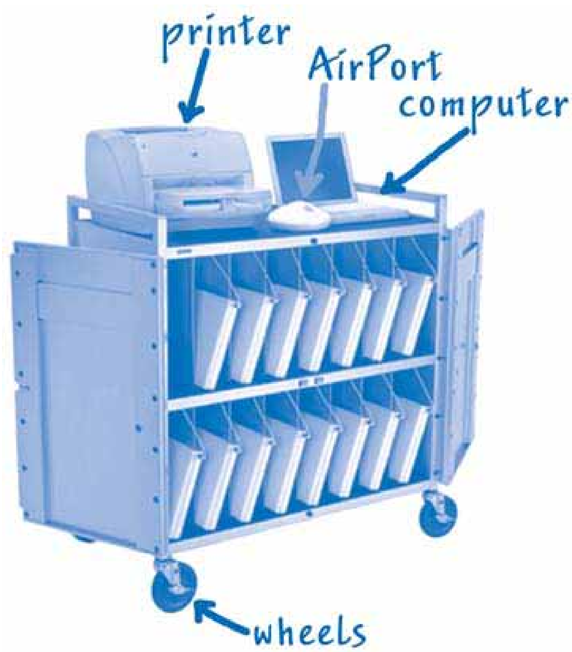
Computers linked to communicate and exchange information constitute a network. The most common standard of communication via wired local area network (LAN) is IEEE 802.3 (*Ethernet* is another name). It can be wired or wireless.

Sometimes a single computer called a *server* is dedicated to information storage and exchange for a network. Other computers are *clients*. Often, computational and storage power are concentrated in the server, and client computers are made as simple as possible. Such clients are called *thin clients*. These computers have few precise mechanical works (spinning discs) and a small and cheap display that is hard to break and easy to replace.

In the school context, relatively primitive computers can be useful when all that is needed is basic text processing. It may then be sufficient to have just a keyboard with simple electronics, small memory, 4 or 8 lines of LCD and interfaces. The *thin computer*, also called a *thick keyboard* or *smart keyboard*, consists of a keyboard extended by a minimal display device to see what you are typing, and has a limited memory, an interface to transfer your text to a server or a printer, a processor to manage all of these, and a power supply (usually an inexpensive accumulator battery).

Internet

The next natural step is to link or network separate computers. Two computers can be linked via modem but this process is expensive if the computers are really distant from each other. We may compare this computer linking with the courier mail of the past, where a messenger brings a letter from one point to another. The high cost of this form of communication was reduced by the modern postal service. Developers of the Internet (known also as the *Net* or the *Web*) thought similarly that having electronic post offices functioning automatically in many places would cut the costs of individual communications radically. As with ordinary mail, one can move bulk mail between two major post offices in two cities as well as deliver individual letters locally. In the computer world, this is called *email*, and it was the starting point of the Internet.

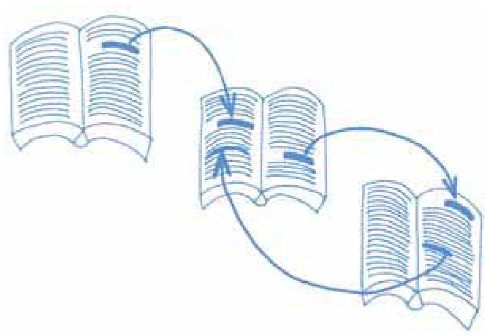


Several important features contribute to making the Internet the most democratic information medium today. Besides sending and receiving electronic mail, the Internet provides an opportunity to place an information object (however complex and possibly linked to other objects) on a computer, give it an address, and make it available to a range of users who are also connected to the Internet.

Hundreds of millions of people in every country of the world now use the Internet. A popular way to communicate over the Internet is to post information (usually text or pictures) to a personal or business *homepage*, or *website*. Another Internet feature is *user-groups* who have access to *bulletin* boards – a collection of information on a specific topic that can be read and extended by members of a specific group with access. Emails move so quickly – in seconds from any sender to any receiver – that they allow for an exchange of information *online* (staying Internet-connected, sending and receiving messages). This mode of communication is also called *chat*.

Today the Internet is the biggest ever network channel and source of human information. Over the last decade, the Internet has grown exponentially in numbers of participants and in the amount of information available. Access to the Internet is possible, not only with the average personal computer, but also with simpler equipment called a *network computer* (a kind of thin client), which has an Internet resource and connection but without computer software and storage. A TV set with a simple device like a Nintendo-SEGA game machine can be adapted to provide access to the Internet. So can an enhanced telephone set.

Videoconferencing



The idea of combining telephones and TV communications has been tried for many years. The principal problems have not been so much technical as organizational, to do with infrastructure (allocating channels), and economic (it has been extremely expensive). In the last decade, however, computer algorithms and standards of compression, as well as channels of communication, have improved greatly. A roving video camera attached to a computer can automatically focus on a person speaking. Participants have microphones mounted on their desks and when they ask a question, the camera moves in to film them, and the image is displayed on a monitor screen. A human face and figure, slides, video, Internet, whiteboard writing and drawing can all be seen on-site or transmitted via the Internet. The result is an instant multimedia presentation.

Channels for distant communication

For most educational institutions today, telephone lines and modems are the usual communications media for connecting with the Internet. The speed of information transfer via telephone lines is usually below 56 Kbps (if the fre-

quencies used are the same as for voice transmission). It is possible to transfer data and pictures and even low quality, live video signals via such channels. Telephone lines can also be used to transfer radiofrequency signals to make transmission much faster, which is the technology used in *digital subscriber lines* (DSL). An alternative is a radio channel via air (amateur short wave or another radiofrequency band, for example 2.4 GHz). An example is GPRS (General Packet Radio Service), a standard for wireless communications that runs at speeds up to 115 kilobits per second. Satellite communications in GHz bands are among the most rapidly growing new ICT media today. When the rate is fast enough to transfer an acceptable video-audio signal, it is usually described as a *broadband* channel (starting from 300 Kbps). Optical fibres with much higher frequencies provide broadband connectivity.

DIGITAL INFORMATION RESOURCES

Information objects and their screen presentations

This section deals with different types of information objects and their screen representations, including instruments to operate with them (editors), and then moves to more sophisticated tools.

Graphical user interface or GUI

Early personal computers could not display graphics well. The only information objects to be displayed then were texts, arranged in lines. A profound breakthrough in the history of computing was the invention in the 1970s and its adoption in the early 1980s of what is called *graphical user interface* or GUI (Apple's LISA, Macintosh, and, then, Microsoft's Windows). The difference in perception and understanding of an information object presented as a text, a table, a formula, or a computer program, in visual form can be dramatic. The ability to deal with an information object as something real – that is, a manipulable object – makes it even more powerful. Generally GUI allows you to use your eyes for information perception and your hands for actions over information objects.

Direct manipulation of graphical objects on the screen in a way that allows you to see what is happening is referred to by the acronym *WYSIWYG (What You See Is What You Get)*.

Desktop and window metaphor

In many computers, before dealing with any specific information object, you find the computer screen organized as a *desktop*. Several object names, called *icons*, lie on this desktop. You can move these and place them wherever you like. You can *open* an object, see its presentation (text or picture) on the screen, and work on it. Some of the objects are folders. Inside folders you find the names of other information objects – some of them are the names of other folders. Some of these are executable programs and you can start running them, usually with a graphical effect of the run seen in a *window* on the screen.

One-dimensional editing

Texts

From the birth of the personal computer, working with texts has been the major application of ICT. Soon it initiated a new culture of writing since text on screen turned out to be much more flexible and transformable than written or typed text. The technology influenced the psychology and social context of writing, which, in turn, changed technology.

Here is an example of how technology is changing the nature of text. In traditional written language, we may write, for instance, “see p. 56” or “compare Johns and Black, 1992”. In reference books structured alphabetically like encyclopedias, these references can be given also by a difference in font, as in “This work led to the teaching of *pedagogic anthropology* in the *University of Rome*." Here combinations of words in italics – *pedagogic anthropology* and *University of Rome* – refer to other sections or chapters, which can be found alphabetically, with explanations about pedagogic anthropology and University of Rome respectively. The action of looking for another page, or another volume of the same encyclopedia, or even another book at a different library, is very much simplified with computers: to find a reference or link, you simply click a button and you are immediately transferred to the desired pages, books and libraries. To create a link, you work in a text-editor in a natural and elementary way. The text containing these links is called *hypertext*. The links are sometimes called *hyperlinks*. It is more natural to call them simply *links*.

Sounds and musical tones

Recorded sound can be presented on screen and edited in the same way as any text.

A special type of sound is a musical tone. Here the sound can be composed, not only changed. The usual notes can be presented on the computer screen and used in a standard way. Notes can be represented in a more graphically intuitive way by height and length in combination with MIDI interfaces.

Video

Working with pre-recorded video-fragments, their cutting, sequencing in an arbitrary way, adding sound and special effects is now possible using ordinary personal computers. For children starting from an early age, this kind of video editing constitutes a powerful environment for their communicative development.

Timeline

A timeline of events can carry icons or pictograms, or other names linked to information objects representing events. In this way, a timeline is similar to time wall-charts. In these charts you can see the whole timeframe, with much more detail of events. The timeline can also be represented as moving in response to the cursor.

Two-dimensional editing

Images on computer screens are combinations of pixels, and so the obvious way to construct or change an image is to create it pixel-by-pixel. To make this process simpler, we can use a *magnifying glass* tool. Of course, in most cases, this method takes too much time, but it can be used in special cases to make minor changes. More often we use corresponding methods of editing images by:

- changing digitized photographic pictures, or
- making and changing different types of drawings.

Pictures

In the case of photographic images, the computer extends dramatically the set of tools and operations available: resizing, cropping, lightening, darkening, sharpening, and so on. In this way, photographs can be transformed quite professionally, and then combined in sophisticated ways.

Drawings

In computer drawing, there are two major options:

- Using a brush tool or pen tool.
- Using additional software tools similar to a ruler, compass, and templates.

In the first option, software and hardware were developed to mimic traditional techniques and introduce new ones. The second option, the computer version of technical drawing, has developed enormously, especially in the field of Computer Aided Design (CAD) – see below under *Three and four dimensional editing*.

Maps and multilayer images

One option with computer images is to have several *layers* for an image, which is helpful in an application such as editing maps.

A special kind of graphical design is the production of plans and geographical maps. Today this is done mainly in so-called *Geo-Information Systems* (GIS). Maps produced with GIS are examples of *multilayer images* that can be edited in each layer separately. Good GIS has sophisticated mechanisms to represent objects like rivers, state borders, and place names on maps in order not to overlap.

Three- and four-dimensional editing

Computer aided design

Computer Aided Design or CAD has replaced traditional drawing almost completely. CAD allows you to create a 3D object on the screen that you can then turn around in space or zoom in on to see in more detail.

Like pre-computer design, CAD systems:

- have developed in different directions, for use in architectural design, fashion design, machine construction (cars, aircraft), electronic design, and other fields; and
- use libraries of ready-made templates from particular professional fields, and multi-layer construction.

So-called *Computer Aided Manufacturing* (or CAM) is computerised design of the manufacturing process. CAD/CAM is a combination of two.

Computer animation

Sophisticated and expensive instruments as well as children's simple tool-kits can be used to create artistically impressive or scientifically precise and enlightening computer animations. More and more movie scenes are now produced in artificial settings with characters designed on a computer by means of special software.

Students' animations are usually simple and two-dimensional (flat). Adding a time dimension makes them 3D objects. Simple animations made by groups of students over several hours can be more educative for the creators and more exiting for the spectators.

Multimedia presentations

Tools are available to make and show sequences of static (still) screens of images. Screens can contain visual representations of various information objects: pictures, drawings, diagrams, tables, as well as important lines of text, visualizations of experimental data, and mathematical models. A sequence of screens constitutes a *slide show*. Such sequences can run autonomously, without a human operator, but are much more effective in association with live human speech. This is a so-called *multimedia presentation*.

Combinations of different kinds of output and different kinds of information objects are usually called *multimedia*. This term was coined in the early 1960s to denote the new synthetic genre of *avant-garde* artistic stage performances comprising action-painting, music, declamation, pantomime, slide-projections and dynamic colour lighting effects. In the 1970s, multimedia became the trade expression applied to joint enterprises in designing, producing, promoting and marketing best-selling books bundled with hit-movies of the same plot (or vice versa), accompanied by the film's music soundtrack, T-shirts emblazoned with portraits of starring actors, and other paraphernalia. The computer industry picked up this coinage in the mid-1980s and used it to describe hardware and software configurations able to run alphanumeric, graphic and sound processing sub-routines simultaneously. Of all technologies, computers are ideally suited to mixing or combining media.

Human-computer interaction and communication

Virtual reality and cyberspace

Cyberspace and *virtual reality* (VR) are perhaps the most frequently heard, and least defined, expressions of the digital era. The term *cyberspace* was coined by the Canadian science-fiction writer William Gibson, author of *Neuromancer* (1984), who fathered a genre of morbid cyberpunk novels. *Virtual reality* was concocted as a commercial brand name for a line of advanced graphic video games in the early 1990s. Both coinages stuck and became household words in media and computer science. Cyberspace connotes an informational space that is generated *inside* each functioning computer and spreads *outside* toward a final confluence with other local cyberspaces in the emerging global web of interconnected computer networks. Virtual reality refers to the patterns of ongoing events in time and space that are perceived by our senses through visual, audible and tactile interfaces. Here is how Bart Kosko defines VR in his book *Fuzzy Thinking*:

> A VR is a computer world that tricks the senses or mind. A virtual glove might give you the feel of holding your hand in water or mud or honey. A VR cyber suit might make you feel as if you swam through water or mud or honey. VR grew out of cockpit simulators used to train pilots and may shape the home and office multimedia systems of the future. The idea of advanced VR systems as future substitutes for sex and drugs and classroom training is the stock and trade of modern science fiction or 'cyberpunk' writing. (Kosko 1993)

Virtual reality has entered modern slang. Even contemporary anthropologists and philosophers use the term *virtual realities* (with no reference at all to digital technologies) to discuss dreams, myths, hallucinations and poetic fantasies, as well as a psychic fabric of scientific hypotheses, theoretical thinking, logical and mathematical reasoning, and other imaginative functions of the human mind. The shortest path to grasping the idea of computer-based virtual realities is to play a video game of car racing or, even better, war aircraft fighting, so popular among teenage boys. However, the use of simulated reality for learning purposes goes back at least to the 1960s, when professional flight simulators were introduced to train pilots and air craft controllers. They make an exemplary case, which we now consider.

Let us assume you are a novice sitting in the cockpit of a small plane that rests on the ground. Through the windshield you see a runway and adjacent airport facilities. On a panel below is the flight instrumentation: altimeter, air speed and horizon indicators, vertical velocity gauge, compass and other navigational equipment. The engine is already warmed up; your hands and feet are on a throttle lever and rudder pedals, and you are about to begin your maiden flight. By command from the digital instructor, you push the throttle to full and see the plane start rolling down the runway. Gathering speed you raise the elevator, and the plane takes off – you are airborne! Excited, you gain height, but all of a sudden heavy clouds appear with rain and a severe thunderstorm.

The plane starts banking (horizon line is tilting), and in a panic you try to damp it by turning the ailerons, but in vain. The next moment the plane dives, goes into spin, hits the ground and explodes in a ball of fire. Luckily, except for the authentic cockpit, sensual impressions, motor responses and manipulative activity of yours, everything you have seen behind the windshield or read on instruments' dials has been computer-simulated – the runway, rolling, speed gathering, take-off, height gaining, rainy clouds, thunderstorm, banking, diving and crashing. In other words, all these events belong to the domain of virtual, not genuine reality.

Nonetheless, this was a reality you could perceive and interact with as if it was authentic and genuine. More to the point, the outcome of such interaction might be quite different had you been more knowledgeable and experienced in piloting. Now this goal is within your reach. By re-starting the simulation program, you can repeat your virtual flight over and over again. Most probably, your initial attempts will end lamentably several times in a row until you manage not only to take off but also to land the plane safely. Indeed, you must try hard to avoid previous mistakes, improving your performance in operating the controls while doing climbs, glides, turns and descents, and learning how to solve various navigational problems.

It is customary to summarize the main attributes of virtual reality in three words: *Presence*, *Interaction* and *Autonomy*. These attributes are especially relevant in using the most advanced (still rare today, but tomorrow undoubtedly more frequent) VR-based educational environment.

The first attribute of virtual reality, presence, is the belief in one's authentic, or genuine, existence in the simulation. This is more easily achieved by perceiving the VR environment not on a separate screen, but inside a data-helmet with goggle-like displays, one for each eye, with sensors reading a positioning of the user's eyeballs and head. As you move your eyes and head to the left, images are rapidly updated and you feel you are actually looking at objects on the left. You may also be equipped with a pair of data-gloves (and, someday, probably, a data-suit) coupled with viewpoint control enabling you to see your hands and body in the simulation (at least their graphic or symbolic representations, say a finger, a palm, or catching glove shaped as a cursor on the screen). Presence extends the friendly, business-as-usual feeling of the iconic interface to include the actor/player/learner. The sense of presence is also enhanced if a consistent way of interacting with the microworld's objects is used. If a squeezing glove can grasp objects, the user's belief in a real, stable world naturally increases.

The second attribute of virtual reality, interaction, is the ability to change features of the simulated world in a consistent, natural, and organic fashion. This is achieved by making the data structures of the world-model mutable in natural ways (e.g., by cutting holes, lifting things, or joining them together). Properties such as conservation of volume and shape, constancy of colour and of manipulation technique, support natural interaction. The three-dimensional physical world, which in fact is logically complex, seems simple and unambiguous to people with a lifetime of experience in navigating it.

The third attribute of virtual reality, autonomy, means that the objects presented have inherent behaviours and can be trusted to exhibit them automatically when simulated. In other words, if the virtual universe plays its part, the user's mind is freed to do the creative work of designing and constructing her or his own learning projects. The task in question may consist of altering the universe's laws and testing the results.

A situation gets more complex when a student moves from a solitary activity in a closed virtual micro-world to a networked cyberspace on a global scale. For example, there are collaborative games that involve building complex worlds with hundreds and even thousands of players. It has been found in such situations that no amount of central planning on the part of teachers suffices. *Top-down* design of virtual worlds (such as is certainly necessary in packages like the flight simulator) may be counterproductive in collective games aimed at the development of creative capacities. We believe it is better to populate a pre-fabricated environment with users, to observe their needs, to provide them with tools as required, and then to let them build the world(s) they want.

Text on a computer screen is an example of virtual reality in the broadest sense. The basic human actions in this reality comprise creating a new element (typing a character), extracting (cutting), or adding part of an object (pasting). As mentioned above, this type of environment is characterized by the term WYSIWYG. Hypertexts are created in a more sophisticated manner, using a special computer language called *HTML (Hypertext Mark-up Language)* and special editors. A modern language to describe objects of all types is called *XML*. A language to create VR 3D-objects permitting VR-actions and feedbacks is called *VRML (Virtual Reality Mark-up Language)*. Three triggering mechanisms, supported by VRML, are:

1 Proximity – execution based on viewer position.

2 Viewpoint – execute when selecting viewpoint.

3 Touch – execute on viewer clicks.

A more advanced version of the language is X3D (eXtensible 3D).

Speech synthesis and analysis

Speech synthesis and analysis, as well as handwriting recognition, were touched on in the section above on hardware. We return to these topics now in the context of man-machine communication because of the importance of these channels for school.

How does one *teach* a computer to talk? How can a computer form an oral image of a sentence of text? How can we inform a user about anomalies or routine events occurring while operating a computer (technical errors, incoming electronic mail)? These situations involve *speech synthesis*.

The simplest solution is for the software maker to pronounce and record the sound beforehand. However, it is impossible to record all conceivable texts that a computer might have to pronounce, and equally impossible to dictate all possible sentences.

However, we may record separately the minimal acoustic atoms of speech, and then try to compile sonic images of words in the same manner as we compile their written images out of letters. But if we do this literally, atom by atom, we will get something unintelligible to the listener. This is especially true in difficult languages like English and Russian. As a compromise, we may record the soundings of every word in a language (quite a big job), some of the most frequent word-blocks, pairs or groups of words often pronounced in one phrase, words that sound differently when they appear in various parts of a sentence, depending on whether these are interrogative or imperative mood, and so on. Modern computers have sufficient storage capacity for such an undertaking. There is no doubt that in the near future word-by-word synthesized speech will have attained a sufficiently high quality to be marketable as a good substitute for sentence recording.

As for *analysis* of audible speech, progress in this field requires, besides an increase in storage capacity, solving what might be called the *problem of understanding*, particularly with regard to context. A computer has to be very smart indeed to understand the subtleties of human speech.

Computers for special needs

A well-known phenomenon of living organisms, including humans, is compensation – the ability to substitute some if its functions and organs for lost ones.

Computers and ICT are involved in the process of compensation in many ways. Computers can improve human senses, or substitute one for another. They can do even more, and operate different devices such as home appliances. Even for persons with the most severe challenges, the computer is a helpful tool with which to communicate and control the environment.

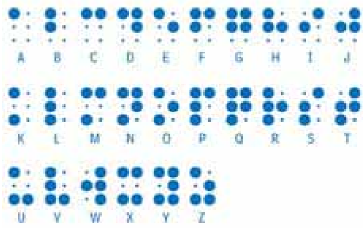
Visual disabilities can be compensated for with tactile or aural perception. Braille coding was invented long before computers, but Braille is a good example of discrete (in fact, binary) coding. It encodes any letter as a combination of dots in given positions, and so tactile reading and writing in Braille have been the form of written communication for blind people for years.

Modern ICT have improved on Braille in straightforward and important ways. There is software to translate letters, digits, punctuation marks and other symbols into Braille codes; a special printer using special paper then can print these codes and other graphical images in relief form for a blind person. It is also possible to provide online reading: on a computer extension, pins corresponding to Braille dots pop up on a template line to form Braille letters. Alternative keyboards are also available for blind people, including ones especially designed for Braille (9-keys). They include a Braille line on which the typed text is *displayed*. Keys of ordinary keyboards can be marked with Braille dot-letters as well.

Another channel of perception for blind people is aural. Besides simple recording, computers can help to transform text into audible speech (see above, *Speech synthesis and analysis*). In the simplest case, a computer reads aloud a sequential text, word-by-word. More advanced *screen readers* exploit structures beyond linear text, including hypertext. There are structures of text in programming languages and other professional environments that screen readers can navigate a blind person through.

For the non-blind, an aural channel can be used for input as well. In fact, full communication between user and computer can be based on verbal processes. A possible consequence of this is a decline in Braille literacy among the blind population, as there has been in other skills such as knowledge of multiplication tables since the advent of the calculator.

The hearing-impaired can also be considerably supported by ICT in two major ways. The first is the well-known amplification of incoming sonic signals. Unlike the old fashioned analogue hearing aid, digital devices can provide immensely wider customized choice and fine tuning of frequency equalization versus loudness levels to help compensate for an individual's aural deficiencies.



The second aid is a speech visualizer for persons with more serious hearing losses. Invented in the early 1940s and named *Visible Speech*, this device analyzed sound energy distribution of different speech formats, and displayed them as patterns of white, grey, and black patches on a monitor. The observer had the burden of guessing, interpreting, and deciding whether or not these images represented particular articulated syllables. Today, the digital automated system converts spoken words into a typed text shown on the screen. In this way, even totally deaf people can converse through the telephone or in other situations where they cannot hear a speaker's words. For blind-deaf persons, the output signals of such systems may be fed into a digital Braille display to provide the same opportunity.

In other areas, kinaesthetically (motor) impaired people can control their environment with the help of a computer and additional hardware. Text entry can be a major method of general communication for children (and adults) who have various types of problems including severe physical disabilities. Children with cerebral palsy, for example, are able to communicate more easily by using bigger trackballs. There is a whole spectrum of new and emerging input devices, including some controlled by human breath only. At the same time, human adaptation can be high. For example, some people can type quite effectively on a standard keyboard with only one hand.

To quote Nicholas Negroponte, chief of MediaLab at The Massachusetts Institute of Technology: "We may be a society with far fewer learning-disabled children and far more teaching-disabled environments than currently perceived. The computer changes this by making us more able to reach children with different learning and cognitive styles." (Negroponte 1995)

Software tools

Software, the name given to the coded instructions that tell computers what to do, comes in many different forms. Here we focus on software tools that are useful for schools.

Operating systems

The software foundation of a computer system is called its operating system (OS). It is the environment with and through which other software communicates. OS with Graphical User Interface was developed by Apple and used in Macintosh computers. The most popular operating systems today are versions of the Windows system developed by Microsoft. In the 1980s, an operating system for larger computers called UNIX was created. A version of UNIX that is popular and available for no cost today, even for less powerful personal computers, is Linux.

Personal productivity tools

The most popular application of computers today is text writing and editing, which extends to producing hypertexts and presenting Internet pages, spreadsheets, and sending and receiving emails. These tools are often called *office applications* because they are widely used and effective in offices. The dominant product integrating various office applications is Microsoft Office: a simpler but free competitor to it is called Openoffice.org.

Work with information objects assumes the ability to find any object you need. This search in a collection of objects can be based on looking for objects with specific attributes. Thus, you can look for a book with a specific author, title, or publisher. A software system that supports these kinds of activities is a *database*. One can use a database to:

- search for a particular object;
- add a new object (new entry);
- change the system of fields (for example, delete the field "publisher" and add the field "most relevant school subject"), and format of screen presentation and print-out; and
- construct a new database that makes connections with existing ones and transfer information between them.

Professional tools

In most fields of human endeavour, specific applications have been developed with specific software tools. These collections of tools are called *virtual workshops*. In fact, you can call a collection of these instruments an editor of virtual reality. They can also be referred to as *automated instruments*, or *electronic assistants* of a human editor. Thus, in certain professional fields, we have specialized mathematical text editors, sound editors, database editors, and so on.

CAD-systems, noted above, are used in different areas of design, including machine construction (for example, automotive and aircraft production), architectural design, book design, and microchip design. Naturally, specialized hardware can be required for CAD such as a more powerful CPU, monitors with higher resolution, graphical tablets, and plotters. Geo-Information Systems, also noted above, are specific tools for the design of maps and plans.

A special kind of design activity is the design of processes. Among these are:

- computer-aided manufacturing (CAM), usually based on CAD design;
- design of human activity in project planning and implementation; and
- software design (also known as computer programming), one of the most sophisticated areas of human activity today.

Numerical data processing and visualization

Under *Hardware* above, we discuss data collected by peripheral sensors such as the parameters of a physical system, biological experiment, or chemical manufacturing. Other data collected might be the results of polls and elections, which can be input manually or by using a scanner for written documents, or directly, as in the case of voting, through a computer terminal, or counting people with a photo-sensor. All these kinds of data can be organized in tables or databases, and then processed to make them *smoother*, to find, for example, median values.

Simulation

If we have a mathematical description (that is, a mathematical model) of a real-life system or process, we can simulate it with a computer. *Simulations* can be time-consuming: it might take a week, for example, to develop a really good simulation of the next day's weather. In some cases, however, we can shorten the process of simulation by using more sophisticated mathematical methods and algorithms.. A system for simulating complex systems behaviour based on differential equations and graphical diagrams is called *system dynamics* and can be implemented with the help of a software environment (virtual lab) called *Stella*.

In many cases, we may have a small piece of text (for example, the name of an information object) associated with two other pieces of text. It happens that the first and the second elements of the pair are taken from given lists, and are usually presented as a table or spreadsheet like the following:

	John	Xenia	Zulfia	Tang
Geography	A	A	B	B
Mathematics	C	A	A	A

Here we have school subjects as one list, students' names as a second list, and marks associated with them as table entries.

The situation becomes more interesting when you introduce dependences between the cells of a table. For example, you can require that the number in a cell should be the sum of numbers of two other given cells, or even the total sum of a full column. This leads to what are called *electronic* (or, better, dynamic) *spreadsheets* – a tool of visualization and simulation used by bookkeepers, economists, and others.

Control

Control is one of the most important real-life applications of ICT. Some of the processes of control are invisible, automatic, and do not assume ongoing human involvement. Others are interactive and assume the permanent participation of a human being in the system. In both cases, visualization is important.

Information sources and hypermedia

As we have seen, a great deal of information can be stored in a computer. A server, for example, with the capacity of a terabyte and costing a few thousand dollars can store the text of a million books, or about one thousand hours of video. Practically all the texts ever written could be stored in computers in one modest size building. Before long, one will be able to do the same with all art galleries, photo collections, and scanned archives of important documents, major speeches, music, and popular or artistically created movies. Nor is it necessary to have all this information in one place. The sources of information can be distributed all over the world and accessible via the Internet.

Major efforts in these directions are being made in the form of electronic libraries, digital archives, libraries, and museums, and individual attempts. Some of these depositories are proprietary and closed for outsiders or require a subscription fee; but many are free to enter, open for the public, and can be used freely for educational purposes.

In this context, two major problems arise: the *quality of information* and the *accessibility of information*. Neither problem is new. The first problem exists in the form of some tabloid newspapers or amateur writers. To some extent, control over quality has previously been based on moral and legal boundaries, but even more on economical and technological mechanisms. Distributing information widely was expensive: it pays generally, for it to be accurate.

The second problem is clearly seen in lost scientific and technological inventions, forgotten addresses and telephone numbers, and lost birth records. To deal with this problem, people invented libraries and archives, sophisticated forms of indexation and catalogues, review journals, citation indices, telephone directories, and all types of reference books, with their associated footnotes and references.

With the dawn of the Internet Age, these problems became more severe. The Internet is full of poor information and hard-to-access or wasted information. To find needed information, you can spend hours and still not find what you want. For this reason, some say the Internet is useless, even destructive and dangerous. In overcoming these difficulties, the world ICT community has invented many mechanisms.

Hyperlinks. The encyclopedia mechanism of reference has been extended enormously. A major opportunity provided by modern ICT is the ability to gather in a single computer information contained in millions of volumes contained in other computers. By using the mouse to click on a word on the computer screen, you can immediately *call up* (possibly, in a different window) a piece of information referred to by the author of the initial text who provided the link or reference. Catalogues and reference libraries of Internet resources have been developed and placed on the Internet by institutions and individuals.

Descriptions. Books and museum collections are searchable because items there have been described and the descriptions are stored in catalogues. ICT are ideal for making catalogues but descriptions need to be added. In the past few years, major attempts have been made in this direction by establishing standards of so-called metadata.

Standards. Another dimension is standards for storing data like texts and images. There was a time when you bought a new computer and a new text editor only to find that you could not read your old files. Therefore, a strong trend is to have a system of standards that are free, open, written in understandable form, and which describe how data are stored and displayed on screen.

Reusability. Many information objects are present as parts of other objects. An immediate example is a painting in a museum collection. For obvious reasons, especially in education, we would like the opportunity to access such an individual object independently. Technically it is easy, but serious organizational and copyright problems await solution.

Search engines. Major attempts are being made to keep track of all Internet information resources. This tracking can be based on an analysis of word content. Thus, you can ask a search engine to show all references to a word, or word-phrase, over the entire Internet. More sophisticated searches can be done using more complex inquiries, for instance, containing a certain combination of words, together with a particular word, but perhaps not containing some other word.

Portals. Search engines are approximate search methods, and they do not evaluate the quality of any information found. Another approach, combined with the search engine approach, consists of evaluating and describing Internet resources by particular organizations or professional associations to ensure quality of the resources as well as quality of the search, and to gather all this information in a single location, called a *portal*.

Safety systems. The mechanisms noted above do not limit access to the Internet by any computer. At the same time, there is increasing concern among parents and teachers over the dangerous influence of the Internet on the younger generation. Pornography, hate, violence, and narcotics are often targeted specifically at young people. Concerned citizens are therefore seeking to form a barrier against this influence – an Internet safety infrastructure. Parents or a school can subscribe to a safety service, and all access to the Internet will go through this infrastructure, which does not permit the user to go to proscribed websites.

Health problems associated with computers

Today, the computer is the major component of the working environment for millions of people. While working with computers can be more or less effective, it can also be damaging to one's health. The major human organs involved here are eyes and hands. Problems with eyes are caused by concentration on screen images, which are aggravated by unclear or flickering images, by glare, and from bright reflections on the screen. The problem with hand muscles is described as *Repetitive Strain Injuries* (RSI). In these cases, proper posture, exercises, and relaxation during work are helpful. For students, these considerations are even more important.

Other negative factors are excessive heat and noise. As previously noted, modern computers need increasingly more processor power for software applications. Fans installed alongside the CPU dissipate the resulting heat, but these produce noise. Another source of noise is the disc drive. High temperature can also cause emission of gases from different components of computers like plastic. There is debate about possible health problems associated with electromagnetic radiation of different frequencies emitted by computer monitors. While there is no evidence of damage caused by the electro-magnetic fields of modern monitors, nevertheless, caution is advisable because students are increasingly using computers in schools.

Repetitive strain injuries are not new. Prior to office machines, accounting clerks used to suffer severe cramp in their hands, which often led to permanent disfigurement. Pianists and other musicians suffer similar ailments from hours of practising, and sometimes promising students are so afflicted that their professional careers are disrupted. Similarly, students with an aptitude for computers may never get to reach their potential because of hours of damaging keyboarding. Video games are doing their share of damage. It is important that potential sufferers are aware that the prevention of RSI may simply require finding a comfortable and efficient posture, and maintaining a balance of movements while working.

Children are generally enthusiastic and become easily infatuated with ICT. They often keep performing an enjoyable task with great concentration until near exhaustion (e.g. making and playing their own animated cartoons for hours with few, if any, breaks). Prolonged activity without regular breaks can cause eye focusing problems (accommodation) and eye irritation.

When a student's focusing system is locked in to a particular target and viewing distance, the eyes may be unable to focus smoothly and easily on a particular object, even long after the original work is completed.

Eye irritation may occur because of poor tear flow over the eye due to reduced blinking. Blinking is often inhibited by concentration and staring at a computer screen. Desktop monitors are usually located higher in the field of view than paperwork, resulting in the upper eyelids being retracted to a greater extent. Therefore, the eye tends to experience more than the normal amount of tear evaporation, causing dryness and irritation.

Younger students are not the same size as adults. Most computer workstations are arranged for adult use and, since children are smaller, computers do not fit them well. Therefore, students using a computer on a typical office desk must often crane their necks upward further than an adult. Because the most efficient viewing angle is slightly downward about 15 degrees, problems using the eyes together can occur. In addition, students may have difficulty reaching the keyboard or placing their feet on the floor, causing arm, neck, or back discomfort.

Students viewing a computer screen with a large amount of glare often do not think about changing the computer arrangement or the surroundings to achieve more comfortable viewing, and this can result in excessive eye-strain.

Inadequate lighting can lead to visual headaches that often occur toward the front of the head, and toward the middle or end of the day. Other symptoms – eyestrain, tired eyes, double vision, and red or dry eyes – are more general. The lighting level for the proper use of a computer is about half as bright as that normally found in a classroom. Increased light levels can contribute to excessive glare and problems associated with adjusting the eyes to different levels of light.

Here are some recommendations for parents and teachers:

- Have students' vision checked to ensure they can see clearly and comfortably, and to detect any hidden conditions that may contribute to eyestrain.
- Limit the amount of time that students can continuously use computers. A 10-minute break every hour will minimize the development of focusing problems and eye irritation caused by improper blinking. Also consider having shorter, more frequent breaks.
- Check the height and arrangement of monitors. A student's size should determine how the monitor and keyboard are positioned. In many situations, the computer monitor will be too high in the student's field of view, the chair too low, or the desk too high. A good solution to many of these problems is an adjustable chair that can be raised for student

comfort, since it is usually difficult to lower the computer monitor. A footstool may be necessary to support the feet. Monitors should be placed as low as possible in front of students, and notebook computers are preferable to the desktop type.

- Check the lighting for glare on the computer screen. Windows or other light sources should not be directly visible when sitting in front of monitors. When this occurs, the desk or computer should be turned to prevent glare on the screen. Draw curtains or blinds to reduce window lighting.
- Reduce the amount of lighting in the room to match the computer screen. A smaller light can be substituted for a bright overhead light, or a dimmer-switch can be installed to give flexible control of room lighting. In other cases, a three-way bulb can be turned to its lowest setting.

Different safety and ergonomic requirements for interacting with computers and other equipment like printers have been developed in different countries. One internationally respected set of requirements has been developed by TCO, the Swedish labour association (see TCO 2004).

MAJOR TRENDS IN ICT

In the final section of this chapter, we look at major trends in ICT that might determine one's choice of computer, and what is likely to lie ahead in ICT.

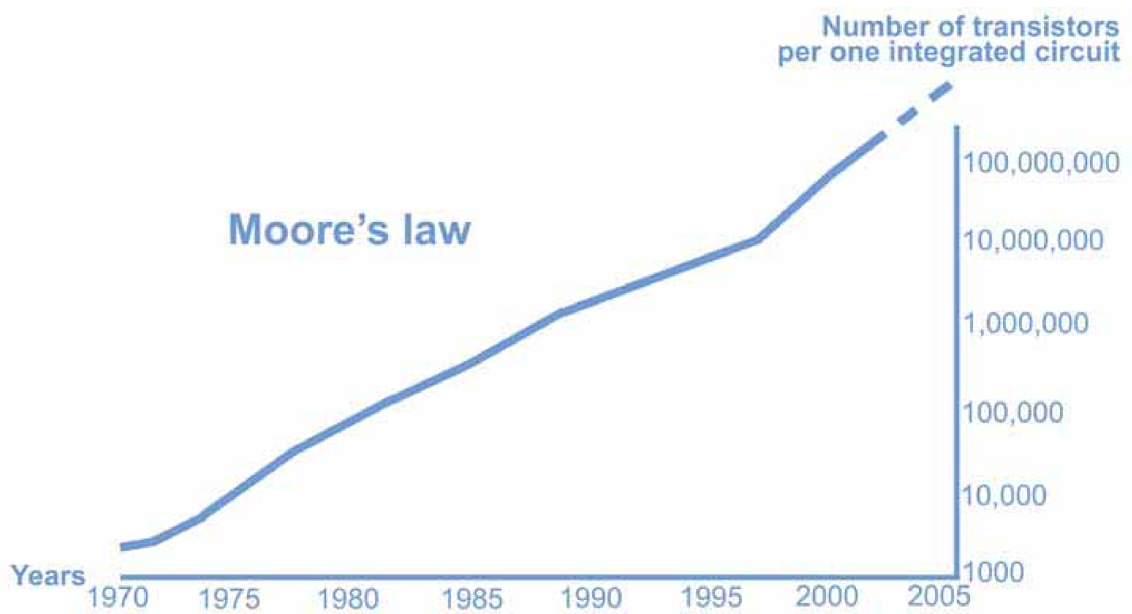
What kind of computers do we need?

Sometimes we hear from decision-makers in the field that young students need less powerful computers, and that when we want to teach programming to high school students, we need powerful ones. In fact, we believe the opposite is true. Young students need big, bright, intuitive, interactive computers.

It is more important to have modern and advanced computers in primary schools than at other levels of education because they can help provide students with opportunities to create and display according to their rich inner world, enabling them to express themselves more adequately, and opening up more opportunities for learning. Friendly interfaces, high quality graphics, and sound can dramatically extend the range of ICT applications in primary school. To achieve this, all the resources of present and future personal computers are needed. Otherwise, we risk missing that sensitive period in a student's growth when both body and mind are receptive to the acquisition of perceptual traits and symbol-manipulating skills that are essential for further intellectual and creative development. This view cannot be overstated. Unfortunately, many policy-makers in education remain unaware of these facts and are still recommending obsolete computers for kindergartens.

What changes lie ahead?

One impressive but, of course, overly simplified way to describe and predict developments in technology was formulated by Gordon Moore in 1965 in an article for the magazine, *Electronics*, on the future development of the semiconductor industry. Moore described an exponential curve of quantitative changes of computer power measured in terms of the density of microelectronic components in one integrated circuit of CPU or memory. For the last few decades we have seen this parameter double about every 18 months in line with his predictions. This exponent affects growth in computer speed and memory size. Recently, Moore (1997) announced an update to his law, but whether growth will slow remains to be seen.



What has been happening to computer cost over this time? The answer is not quite so optimistic. New technology is generally expensive; the price of a new computer model stays high for several months, then falls for a couple of years and begins to stabilize after major consumers and producers have moved to newer technology Before ending the line, liquidation prices can appear. Then old models are replaced by new ones of almost the same (inflation-adjusted or not adjusted) price, as the previous model was two years earlier, after it had fallen from its peak. In absolute figures and not taking inflation into account, we can say that the prices of the most popular personal computers are 4-6 times lower today than they were 20 years ago.

The price of ICT is determined to a great extent by the size of the market. If a tool is in demand and easy to use, the price falls. The prices of the most popular computers are slowly going down. The specialized tools of ICT will eventually be as affordable as home appliances such as TVs or stereo systems. There are good reasons to buy recently stabilized equipment. However, it is short-sighted to buy obsolete computers for schools. Accepting donations of used computers can initially be exciting; it can also lead to complete disillusionment in the technology. Even more than in other cases, we need schools to invest their additional resources in good technology, so that teachers' time can be spent on teaching and not with time-wasting obsolete equipment.

The increasing power of computers has allowed qualitative changes in human work with computers. The first computers using Graphical User Interface were a thousand times less powerful than computers of today in memory size and processor speed. We now consider the major dimensions of changes in ICT.

Consumer society and ICT

Investment in the development of more powerful computers is demand-driven. How is the demand generated? Of course, people are always interested in storing more information, and faster retrieval. At the same time, software companies are releasing new versions of their popular software that use the full power of the latest processors from hardware manufacturers. Software producers then help drive demand.

One of the results for this escalation is that powerful computers running memory-hungry applications are at the limits of their power. An unexpected consequence is that most computers have become noisier: more powerful processors emanate more heat, and to dissipate this heat more powerful and noisier fans are needed.

Ease and comfort of use

People without extensive training are frequent users of computers today. They have some skills in the special applications for their work and a vague general understanding of how a computer works. One reason for this development is the user-friendliness of computers, which means they allow you to do simple things simply. The easy-to-use Graphical User Interface (GUI), for example, permits users to rely on their intuition to operate in three-dimensional space. Like other interfaces, GUI allows mistakes (for example, in text-writing) to be easily rectified.

These improvements have allowed computers to be used by professionals from different fields. The next step is to bring some ICT to non-professionals. Today's computers are still more difficult to operate than a TV or microwave; and desktop computers are still not comfortable enough to be part of everyday life because of the space they occupy, together with heat and noise. Notebook computers do not really approach the easy use of a book. Think about how much easier it is to open a book (seconds, as opposed to minutes for a notebook computer). New options are expected.

Nevertheless, searching for information on the Internet utilizing the screen of a home TV is now possible, simple and cheap. The growing information culture and new literacy is likely to bring simpler modes of operating widespread ICT appliances, greater clarity of user manuals, and better understanding of these by lay people.

Further visualization

Visualization has been called the *second computer revolution*. The number of pixels on a computer screen and the speed with which an image changes, as discussed above, determine the quality of the computer image. Recently (on the computer technology time-scale), computers have become capable of TV/video applications. We can now store hundred of hours of TV-quality video, show it as *seen on TV*, or without advertising, and edit it as needed in a way similar to text-editing. Of course, image quality depends also on having high quality peripheral devices: for output, computer monitors and projectors, and, for input, cameras and scanners. Here, too, we can see how computer power drives demand.

Quality of sound

Improvement in quality of sound follows a similar path as quality of visual images. On the one hand, sound requires less memory and computational power to work with. On the other hand, manufacturers and consumers usually underestimate the value of computer sound. Sound quality is important from psychological, emotional, and ergonomic points of view. We expect higher standards of computational power to improve sound quality and to herald more applications of sound, as well as in speech synthesis and speech recognition, language and early learning.

Human movement and other types of communication

Currently, a person interacts with a computer mainly in two-dimensions. The keyboard and the mouse are operated as discrete objects. The computer screen is a *desktop*. Is it possible to move to another dimension, one that allows objects to be grasped, touched, moved, and smelled? Numerous research projects are underway, some of which promise to become part of mainstream reality in the next decade. Intensive research is going on, for example, in the fields of kinaesthetic input and output. A computer will *feel* human movements visually or via special sensors. It will also provide feedback through gloves with motors in them. Smell input (and output) is also in the experimental stage.

Computer reaction to movements – for example, changing visual images in response to a head turn or other non-verbal cues – can be achieved with the use of trackers mounted on head or fingers, or seeing human movements. A haptic device involves physical contact between the computer and the user, through technology such as a joystick or data gloves that sense the body's movements. With a haptic device, the user can feed information to the computer and receive information in the form of sensations on parts of the body. For example, in a virtual reality environment, a user could pick up a virtual tennis ball using a data glove. The computer would sense the movement and move the virtual ball on the display. At the same time, the user feels the tennis ball in his hand through tactile sensations that the computer sends through the data glove, mimicking the feel of the tennis ball in the user's hand.

That type of interaction can be implemented with an *exoskeleton* – a system of artificial bones and muscles (electric motor-based) tied to the human body to imitate reaction of the environment. In particular, force feedback (FFB) simulates weight or resistance in a virtual world. Force feedback requires a device that produces pressure on the body equivalent or scaled to that of a real object. It allows a person in cyberspace to feel the weight of virtual objects, or the resistance to motion that they create. Tactile feedback (TFB) produces sensations on the skin, typically in response to contact or other actions in a virtual world. Tactile feedback can be used to produce a symbol, as in Braille, or simply a sensation that indicates some condition such as heat. Touch and hold are not the only physical relations in the real and virtual worlds. The proximity of an object can be manifested by a sound, for example. Sound can also represent execution of a procedure like opening a door or giving a greeting.

To summarize, we see among existing and emerging extensions of the usual computer interfaces the following:

- Larger screens, including touch-screens.
- Stereoscopic images (different for different eyes).
- More use of trackers.
- More proximity.
- More sound feedback including proximity.
- Computer-generated odour.
- More accurate and sophisticated force feedback.
- Tactile feedback, specifically aspects of touch not covered by force feedback.
- Accurate simulation of the behaviours and other characteristics of soft tissues.
- Integration of data from several sources.
- Integration of the real world with virtual worlds or switching between real and virtual worlds.
- Video and audio input via head-mounted devices simulating human perception.

Computers to go

The real limitations of computer size, weight and portability do not follow from its computational or memory power, but from the ability of humans to receive information (via video-monitor) and to send information (via keyboard). Therefore, the following general options exist:

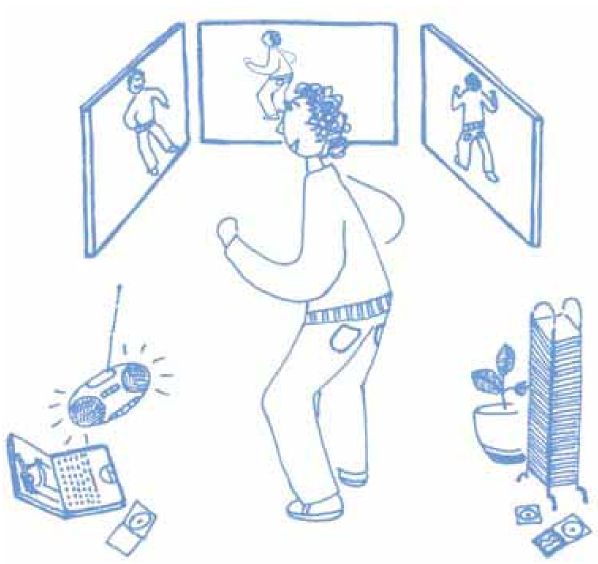
Notebook computers are complete computers with full functionality and with all major devices of the desktop computer. A popular current version does not contain any drive for removable discs (floppy, CD or DVD), but has USB ports to which you can plug in a flash card or external drive. Notebooks can communicate with all peripheral devices via RF and IR channels, and with the outside world via radio-channels as well.

To make it even smaller and cheaper, there are also **sub-notebooks** that have a less convenient keyboard, smaller and weaker display, and less functionality, in particular, usually having a less powerful OS than desktop and notebook computers.

For greater savings, you can get **smart keyboards** with a very simple (for example, 8 lines of text) display, with the major function to store text input. The price can be 3-4 times less than the price of a regular computer, and so this is a popular option for schools.

Palm computers or palms have the functionality of sub-notebooks, but are even smaller with just a screen of palm-size. The screen is used also as an input device for handwriting, pointing and moving objects. Palms are really good for taking notes on the move, and for collecting data from different sources (like measurements from sensors).

Wearable computers



The changes discussed immediately above lead next to the concept of wearable *computers*. The key devices of wearable computers are *glasses* through which computer images are displayed (in particular, these can be images of real reality). A pair of stereo glasses can be fitted with a pair of stereo speakers, and a microphone in a VR-helmet.

A further idea is *to wear* a computer that has no input-output devices in it, and is connected to the world through wireless channels only. Such a computer might receive your email, for example, but to read it you need to come to a screen with a wireless interface compatible with the computer.

A wearable computer would *recognize* context – that is, it would *know* not only “what time is it now”, but also “where you are” and “what is happening around you” and “how you feel”.

Local information space

A VR-helmet is a very *local* presentation of the information space to a human. There are other means for providing comfortable access to information and instruments to work with at home, at work and study places. These include:

- Screens and speakers for output (including touch screens, for output and input).
- Wireless keyboards, mice, hand-held scanners, and speech recognition devices for input.
- Common information space for all points of access organized for sharing by many users.

For example, in a school-and-home integrated network, students could come to any computer with their keyboards, or even mobile phones, and enter their own information space incorporated into the school information space and global information space.

The human element

Physically, access to information is limited by a computer’s communication speed, which is limited by bandwidth, and this, in turn, is limited by frequency range. However, the human factor is more critical here. Everybody seems to agree that Internet surfing can be even more harmful for children than TV-viewing. Sophisticated search engines and agents can help but most of the work to make information available and to ensure its quality must come from humans. Therefore, the Internet community and infrastructure of support of many other people are needed.

Merging of mass media and the Internet

As previously indicated, computers are now integrated with television. Cellular telephones give you a keyboard, a TV-screen, and an Internet connection. Increasingly, content, media, and devices are integrated in a digital format.

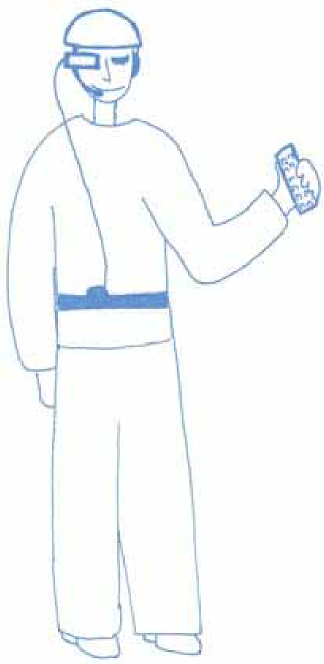
Computers also serve for information searching, storing, and processing (for example, to find a TV transmission via an Internet TV-portal, or to cut out commercials and store a show along with adequate text description).

More models of reality

Even an autonomous, non-Internet-connected computer is a powerful device for constructing your own information objects – indeed your own models of reality. Constructing static objects, books, and graphical art can require considerable computational power. Even more power is needed for computer simulation and visualization of the results of the simulation. Progress in this direction is based on increasing computational power and, even more, on developing more sophisticated tools that are comfortable for human use.

More understanding from computers

From the beginning of the computer era, the idea existed to delegate to the computer the most sophisticated functions of the human brain. Progress in this area has been slower than expected. Eventually, however, some of the hoped-for developments have occurred, for instance:



- Computers now play chess better than humans.
- Computers recognize oral speech and handwritten words.
- Computers recognize objects in environments and act accordingly.

From these activities and achievements, we see now that the critical issue in further progress is building up more computer models of physical and psychical reality (that is, more understanding of the world).

Economy of ICT

Unlike matter or energy, an information object can be consumed many times with no additional cost for its reconstruction or refuelling.

Digitization prices have dropped, so that it is becoming affordable for libraries to make their unique collections digitally available. Huge libraries can be stored on a single desktop server. CDs and DVDs have become easier to copy in the technical sense. It is not hard for pirates to break copyrights. More and more music is available on the Internet, and music albums of a favourite composer can be stored on one DVD. Information tends to be free.

From this perspective, there is a growing interest in the UNIX operating system. Originally developed as an advanced, heavy-weight, and hardware-demanding operational environment, but more robust, reliable and safer than Windows or Mac OS, UNIX, and especially its modern lighter version Linux, can run on smaller computers than today's versions of Windows. And Linux is free of charge, as are many applications developed for it. Other applications, like OS Lindows and applications for it are much less expensive than most commercial software.

In fact, there is a lot of free information on the Internet. Several countries have launched free electronic archives, and digitized their cultural heritage.

The idea of open and free information space is at once popular but also disturbing, not only among educators, but among software developers as well. Many software products in schools are open and allow:

- teachers and students to use data and images for their personal use;
- students to create experiments in virtual labs, and teachers to create tests; and
- students to store their work for a period of study in a unified information space open to other students and teachers, parents and other schools.

The major question is how will the creators of original information work be paid for their work. A possible answer is that information will be free, but that human service provided on demand will be compensated adequately. Questions of further development of free information resources are under consideration currently by an important international association called The World Wide Web Consortium (W3C).

3

SCHOOLS IN TRANSITION

TEACHERS AND LEARNERS

Before focusing on ICT in classrooms, which we do in Chapter 4, this chapter provides some background in pedagogy, and examines what is involved in teaching and learning, as well as the institutions – schools – that we have developed for teaching and learning.

Educational events

An educational event occurs between someone who is willing to educate, namely the teacher, and another, willing to be educated, the learner. A synergy of wills is a prerequisite. Otherwise, there is no place for proper education, and we should talk about conditioning, drilling, training, moulding, pressing, or whatever else might happen between those officially labelled as *Teacher* and *Student*.

The teacher is always in search of a learner, and vice versa. When there is no learner in sight, teachers will try to awake, or invoke the will to learn in anyone they happen to meet. The teacher does this by challenging the other person's curiosity, ambition, inquisitiveness, or just playfulness with any means at hand. Anything that works is good for this purpose.

A learner is also always in search of a teacher. Where there is no teacher available, learners will recruit anyone they meet as a possible teacher. If there is no one at all, they will figure out a kind of virtual substitute teacher inside their own soul.

We discern three facets of any educational event: encounter, communication and interaction.

1 Encounters are face-to-face meetings; situations when you find yourself faced by other individuals and feel prompted to relate somehow to their presence.

2 Communication is an exchange of messages, sent and received by at least two people, expressing their feelings, thoughts and intentions to each other in the hope for reciprocity.

3 Interactions are processes where two, or more *actors* (in our case – teacher and learner) influence and affect each other's actions and behaviour while striving to reach their goals, doing some common work, or performing a joint task.

Any interaction, by definition, generates information. Not all information generated by an interaction needs to be communicated; some parts of this information may be intentionally concealed. One actor may purposely search for, uncover (at times compel), and collect the information that another actor tries to conceal.

At times it is difficult to draw a strict line between communication and interaction. For example, if during language classes (especially on rhetoric), a teacher uses verbal means to enact modes of argumentation for students, communication and interaction become one and the same. A number of authors, analyzing patterns of communication in European cultural (especially educational) traditions, have pointed out such recurrent themes as surveillance, interrogation, and the threat of punishment.

Basic activities in learning

Let us recollect some well-known facts about human information activities and other actions in the process of learning that will later be transferred into ICT contexts.

Communicating by different ways and means

For centuries, communication between human beings has been carried out in oral and written form. Oral communication goes through the aural channel of information, more often than not supported by the visual channel (a speaker's movements and everything else that constitutes theatrical aspects of communication).

Oral communication used to be immediate until recent centuries when it became possible to have it recorded. It was an interesting moment in human history, when the recording of dynamic images of communication (as well as images of the world) was invented and developed, before the recording of dynamic sound was possible. This was the era of the Great Mute (as they used to call the cinematograph until it was coupled with recorded sound), where moving pictures on the screen were accompanied by subtitles (and live music) only.

Communication can go in one direction as in radio and TV broadcasting, or in two directions as in oral discussions or telephone conversation.

Written communication goes through a visual channel, where text is supported by pictorial illustrations.

All these models and modes are presented in learning and teaching, and all have been, and are being, radically changed by ICT.

Object making

Learning can involve also doing something in the physical world, particularly, making objects. This includes making messages, which, in this respect, intersects with the communication process, though the accent in the doing is made on constructing the message, not delivering it. Therefore, cases of doing in learning are represented by constructing:

- an information object (an actual or potential message),
- an information process (composing and editing),
- a mental, inner object (reasoning and imagining), and
- a material object or process.

These activities, while being in many aspects interrelated, can be efficiently supported by different uses of ICT.

Observation, reflection, imitation

Observation is another process involved in learning. The learner is an active participant in the game here. A further important element in the formation of a thinking human being is reflection – the process and the ability to observe yourself and your activity *from the outside*. An ancient and powerful tool for reflection is a mirror. Observing another human in order to copy, imitate, and do the same, is another important model of learning. The modern type of mirror that keeps track of disappearing images is a video-recorder.

Information searches and questioning

Searching for information was not a popular activity in traditional schooling but has become more and more important in modern life. Previously, if any searching was done, it was primarily in a person's memory. People were considered intelligent, knowledgeable, and wise if they could *output* quickly the needed information from memory. Even then, books (of wisdom) were occasionally used to answer a question, but the books were not considered as an everyday source of information with the exception, perhaps, of medical doctors and lawyers. Today the search and retrieval of needed information is becoming a core activity in work and learning. Asking an expert is a special case of information search.

The faculty to question was recognized long ago as a mark of the genuine philosopher and scientist; but it was also reflected in ironic sayings like "One fool can ask so many questions that a thousand wise men will never answer". As with information searches, questioning is becoming more and more important in the information age.

Receiving aural and visual information in studying a school subject is a prerequisite, but it is just the first step to assimilating its content. True learning occurs only in an intensive conversation between teacher and student, as well as between students, as all good pedagogues since the days of Socrates have known. What a pity that this principle was forgotten, or neglected by those teachers in many 20th century-era schools who thought they were there to teach, not to converse.

CONTRADICTIONS OF SCHOOLING

Contemporary education is replete with contradictory demands. Here we touch on some of these.

Creativity versus discipline

Perhaps the most tormenting question of contemporary education is how to reconcile two contradictory demands:

1. fostering inquisitive and creative minds eager to explore the unknown and solve unprecedented problems; and
2. training the same creative minds to become skilful, adroit and highly disciplined performers of particular, subject-specific, manual and mental tasks.

To a large extent, the lamentable rift between verbal and practical, hands-on learning, so deeply rooted in the established system of schooling, aggravates this contradiction. The contradiction is compounded when you consider the further problem of motivation, which has been moved to the forefront by all modern pedagogical theories.

Compulsory versus voluntary

Can you force a small child to play? Obviously, not. Children start to play only when they feel like playing. Equally, no teacher can force a student to learn actively and wholeheartedly unless they have a deliberate desire to do so.

Of course, we can, and often *do*, teach appointed subject(s) to students and make them learn quite successfully, judging by standard achievement tests, without any strong need and desire on their part. So, what is wrong with that?

The trouble with *compulsory* (that is, passive) learning is that while students appropriate a given piece of curricular content quite firmly, they all too often remain incapable of *applying* it to anything else besides right answers and getting high examination scores. As it happens, a student often cannot relate a newly acquired fragment of knowledge to other pieces learned previously, especially in other subject areas. Unable to connect recent acquisitions to what is already known, and to perceive the outcome as coherent whole, they can hardly be expected to transfer a powerful mathematical concept into a field of science in order to grasp the laws of physics and chemistry, or use the latter for better understanding of a living cell. It goes without saying that these disjointed chunks are even harder for students to apply to real-life issues outside school.

Schooling can bring forth truly substantial results only when coupled with inner motivation and self-propelled learning – in other words, when particular skill development is driven either by genuine curiosity, or by some pragmatic consideration as, for example, when seeking to find a clue to some intriguing riddle, or to solve a problem one has stumbled upon in a game.

We are back at our starting point. Is it possible for teachers not to compel and coerce, but to provoke, entice, or tempt students to embark on truly *active*, all-absorbing and penetrative learning? And, if so, then how?

There is strong reason to believe that ICT can help bridge the yawning gaps just described. First, however, it is worth recollecting that students generally *want* to comprehend a particular subject or master a methodological cornerstone of so-called classical schooling and, second, summarize the criticisms of this schooling, and review proposed alternatives.

Classical hierarchy of learning and personal responsibility

In medieval times, knowledge was a set of divine commandments transmitted from a teacher to a student, who was obliged to take them reverently and obediently. Later, Nature and its laws displaced the Deity, and the teacher's duty was to provide students with the knowledge of those natural laws, discovered by scientists, that would lead the human race further along the path of progress.

Three fundamental educational assumptions that date back to Socrates and later Descartes have until recently been taken as unquestionable:

1. Simple skills requiring little understanding are the easiest to learn and therefore easiest to teach the youngest or the mentally less capable.
2. There is a hierarchy of skills from simple to complex, and a hierarchy of performance from that requiring little understanding to that requiring abstract knowledge. To move up this ladder, the preceding rung must be mastered. In other words, Lesson One must be mastered before the student can successfully move on to Lesson Two.

3 There is a progression towards maturity that must be followed: the very young or the retarded cannot learn via abstract understandings and therefore must be taught by the route of simple skills and bits of information, which they eventually combine into large units.

Under this system of education, a team of workers or mental *agents* must manage learning activities, each performing a single, elementary function. This hierarchical organization is something like a tree in which the agent on each branch is exclusively responsible for the agents on the twigs that branch from it. It is easy to construct and understand such an organization because each agent has only one job to do: it needs only to *look up* for instructions from its supervisor, then *look down* to get help from its subordinates. Metaphorically speaking, these agents constitute something like a *machine* built purposefully to manufacture these particular, strictly specified products.

We do not doubt that there is room for teaching and learning certain disconnected, step-by-step accruing skills, required by many occupations, by this method.

But the great realization of the 21st century is this: no scientist, political leader or preacher knows for certain how to decide on this or that issue of global scale, nor what advice to give any of us on our daily cares, living in a world that is changing in all its facets at an ever accelerating pace.

The destiny of mankind depends, rather, on decisions made (or not made) by each conscious and responsible person. It has become crystal clear that the long-established and respected ways of teaching in schools are not good enough. We must be concerned, not with adapting to a given world out there, but with making this world different.

The educational system of the 21st century must be oriented toward creating conditions that allow school students to act and learn freely in productive collaboration with their teachers, and also with their parents and other members of their community, local and global. In this, the application of ICT appears to be a necessity, as well as a pledge of success.

OLD SCHOOL AS ORGANIZATION

In the previous two sections, we describe basic relations and activities of learning, and expose certain basic contradictions of schooling. As we see next, existing schools fail to exploit most of these relations and activities and do not contribute much to the resolution of the various contradictions. After investigating the limitations of what we call *old schools*, we outline the psychological background of possible changes that are occurring, and then proceed to the changes themselves.

Activities to sustain

It is assumed that readers are familiar with how the *mass*, *standard*, *traditional* school works today. Let us call this the *old school.* To redesign such schools with the help of ICT, we need to take a fresh look at them as though we have never seen such enterprises before. We need to consider them anew and decide what to take into the future.

School-related activities can be broadly divided into two categories – internal and external – that the school as an organization is called upon to sustain.

Internal activities are carried out within the school's scheduled hours and inside the school walls. These core, central, obligatory and strictly formalized activities – one is tempted to say almost *sacred* activities – are the school's classes or lessons, comprising teaching and learning. Activities during intermissions are *profane*, and activities after scheduled hours are a mixture of the two. There are also internal activities of administration and supervision, and teachers' meetings, which are conducted without the involvement of students. All these activities imply an exchange of information, carried out through a number of channels, some established, officially approved, and highly formalized; the others, informal, weakly delineated, not always approved, often rebuked and prohibited, and thus covert, and even kept in strict secrecy.

External learning activities, besides sports and clubs, are mainly homework. Students do their homework in an isolated, individual manner. The relation to internal activity is often through short assignment notes. Consultations with teachers, discussions with peers are occasional and irregular, as is cooperative work. External activities of school administrators are working meetings and consulting with superiors and colleagues from other schools, seminars, training sessions, and conferences.

The learned context of learning

Neither organizational aspect of schooling should be neglected in relation to the use of ICT. As Penelope Eckert puts it:

> One of the greatest errors in education is to assume that the larger social context of the school is irrelevant or even secondary to learning. ...The social structure of the school is not simply the context of learning; it is part of what is learned. What a student learns in the classroom is indeed a very small other part... What the Burnouts learn in school is how to be marginalized... High school, therefore, is not simply a bad experience for these students – it teaches them lessons that threaten to limit them for the rest of their lives. (Eckert 1989)

Writing about business organizations, rather than schools, managerial scientists often refer to *learning organizations*. Here is what one writer, Ronny Lessem, says in a paper titled *Linking artisan and scribe:*

> Since at the present rate of technological change the problems to be solved differ from one day to the next, it follows that everybody in the organization, from those who frame the policies to those who manipulate the ultimate details of technique, must be endowed to the possible extent with the *means of learning* [our italics]. (Cited in Rhodes 1991)

One must ask here whether the school can evolve and change its structure and functions in response to the new challenges. Is the present school an organization that learns, or it is just a system, a machine, functioning according to predetermined and inherently closed programs?

School as a social institution

Lewis Mumford, an outstanding historian-philosopher of technology, described the new kind of religious, socio-political, industrial and military organization, invented during the Bronze Age under the aegis of the priest-kings, as a *megamachine*. Being essentially coercive, undemocratic and hierarchical, such an organization paved the way to, and was inherited by, succeeding civilizations. Only recently was it questioned and challenged by a new vision of human progress based on other principles. (Mumford 1966)

Through this millennial old legacy, the school appears to be the social organization most resistant to change. In fact, it mostly strives to keep its basic structures and functions unchanged, including its information circuits, channels, and routes. Below, we examine typical approaches to channelling information, which, in turn, were determined by the traditional concept of so-called compulsory mass education. To make things clearer, however, we must trace the latter's origins back to three or four centuries ago.

There was no serious lack of quality as long as education remained a heavily guarded treasure or luxury, accessible only to a chosen few. Formal schooling was reserved exclusively for the high priesthood and aristocratic families, and denied to anyone outside the cloisters and castle walls.

School as an invention of industrial era

The *classical school*, as we know it today, was invented at the dawn of industrial, mass-production-of-everything era. General education was claimed as the property of the people at the verge of the 17th and 18th centuries in Europe. Just and democratic at its inception, this path led in time to quite a different state of affairs. Historians and theoreticians usually say the school was first modeled after a printing-house – as Comenius announced in his 1657 book, *A Living Printery, or An Art of How Swiftly, Yet Informatively and Lightly to Stamp the Wisdom Not On Paper, But Upon the Minds*. It was not just a coincidence that schools were associated with the most advanced information technology of the time – the printing press with movable characters. The minds of pre-schoolers were considered a plain tablet or a blank sheet of paper upon which teachers could write anything they, or some higher authority, would think appropriate. In a short while, the thinking about what was appropriate to teach children was taken away from teachers and concentrated in the hands of those in political and economic power.

No less significant technologically and educationally was Gutenberg's concept of setting up a line of type by using separate letters cast in a uniform pattern in a mould: the origin of the standardized, replaceable part of ever increasingly automated machinery. It was only logical to apply the same principles to schooling, and since the mid-19th century, this approach has prevailed in most Western countries. A system was established where children and young people could learn different subjects from different teachers who, in their turn, could rely safely on a standard, ready-made curriculum and procedures designed by other specialists.

Information routes and flows in the classical old school

At the top of the said system, we see centralized pedagogical research institutions that design the curricula, instructional methods, textbooks and other materials, which, after having a stamp of approval from ministries of education, are distributed to schools and teachers. A teacher's duty is to read and follow closely the body of these materials in order to deliver it piecemeal to students, who are expected to memorize the content one chunk after another, and checking in to see if they succeed. The basic, though rarely announced, assumption is that teachers need not add a word to what has been given from higher authorities.

A principal and a supervisor receive from the higher educational authorities an approved bundle of curriculum-and-procedure materials and distribute these different packages among the teachers of particular disciplines. Each teacher subdivides the received package in accordance with the age grouping of students, the quotas of curriculum content to be assimilated daily, and the school timetable. Teacher-to-student communication is predominantly oral. Visual aids are usually illustrations taken from books. There is little hands-on activity with physical materials and tools on workbenches. The teacher is a lecturer, not a master of a craft (menial or mental). Little communication exists between teachers of different subjects on how to collaborate in making the educational process truly involving and exiting.

What teachers and learners do during classes

Here is a brief list of what teachers and learners do in the traditional classroom of the old school:

- Teachers speak, learners listen.
- Teachers talk to learners, who listen to and supposedly perceive, understand and memorize what is said. Often, this is all that teachers do on a strictly formal, *technical-operational* plane.
- Teachers write letters, numbers, words and phrases on the chalkboard to help students hold facts in their short- and long-term memories.
- Teachers paste (clip) to the chalkboard, or hang on the wall, posters with pre-written (printed) letters, words and numbers, and then point to them with their finger or a pointer while giving explications, explanations and instructions.

- Teachers draw or use ready-made diagrams or images of certain objects or scenes related in some way to what they are saying.
- Teachers bring three-dimensional objects to illustrate lessons.
- Teachers manipulate these 3-D objects (other than to point to them or take them in their hands to show them to the class) in a transformative way, for example by using them in applied functions they are meant to illustrate. To show such manipulations and transformations of 3-D objects, teachers use workbenches.
- Teachers conduct spectacular experiments that excite students and which they remember all their lives.

In short, notwithstanding the content, the main tool and carrier of the teacher's message is the word, or, more precisely, the oral and, to a lesser degree, written speech. At the same time, we know that the additional activities are listed in ascending order of their supposed educational efficiency (and labour intensity).

In such classrooms, learners are not required or expected to:

- *do* anything besides follow a teacher's presentations and instructions expressed in oral and written words (texts) until they can assimilate and reproduce verbally the knowledge and skills required;
- *draw* in language or mathematics workbooks except perhaps for geometry, or drawing primitive diagrams for science (in most cases, learners are not taught to acquire drawing skills);
- *manipulate* or transform three-dimensional objects, other than, perhaps, paper, scissors, glue and pencils.
- *discover*, invent, design, and construct during classes anything of their own in relation to the curricular content; or
- *converse* with classmates on the content being taught.

This picture may be over-simplified, but it broadly reflects the features of the traditional school that are deeply embedded into organizational structures in many countries.

Rigid timing

In a scheduled class period, the teacher delivers (orally, in blackboard writing, and by showing pictures) the assigned chunk of information simultaneously to all students in a monologue *broadcast* type of lecture. While taking in information coming from the teacher, students are obliged to remain silent and motionless until the teacher stops the delivery and asks them if everybody has clearly understood what was said. Then those who may not have understood can raise their hands and, after being granted the right to speak, say what escaped their comprehension. Teachers repeat an explanation twice or even three times, but often there is no time to clarify all problems, and there are always one or more students who dare not express their difficulties. Common sense prompts one to think that those who are in need might seek and find some help from their nearest neighbours in the classroom. Sadly, more often than not, such a common sense approach does not happen in *classical schooling*.

As everybody knows, communication between students during classes is usually frowned upon because it threatens to disrupt the very foundation of *classical teaching* (luckily, there are many good teachers brave enough to transgress this rule).

Monologue lecturing

Information is constantly filtered downwards through the hierarchical system and no horizontal roots are stipulated. When a teacher gives a class an assignment demanding writing, calculating, or reasoning, each student is supposed to do the task individually and by themselves. No consultation with classmates is allowed, and any breaking of this rule is often punished. Consequently, nothing even remotely resembling collaboration, productive discussion and teamwork is practised; neither are the corresponding skills being developed. As a result (and this becomes evident after some testing questions made by the teacher), not all students receive the full amount of curriculum information supposedly transmitted to them during class periods.

Students do not have the channels, and nor are they encouraged, to exchange views and opinions about the curriculum. It is not surprising then that very few of them are motivated enough to discuss such things out of classes except to complain about it. Anyway, such behaviour is not anticipated or wanted in traditional curricula and procedures.

In such circumstances, one might conclude that most traditional school authorities would readily reject the idea of adopting ICT that would enable students to sustain autonomous information exchanges during classes.

Institution for teaching only

Because of society's evolving expectations of equal educational opportunity for all and the current emphasis on relevant and quality opportunity for all, the school system has developed into an increasingly complex organizational structure. This structure requires extensive and comprehensive administration and has enough problems sustaining stable and malleable conditions to put aside the problems of its transformative development. That is, to sustain the conditions that give teachers and administrators intellectual and emotional comfort, they naturally tend to see schools as exclusively teaching institutions. They have little time to think about schools as learning institutions and do not consider it a pressing priority. What are the consequences? Howard Gardner puts it this way:

> We run the risk of investing incalculable resources in institutions that do not operate very well and that may never approach the effectiveness that their supporters – and for that matter their detractors – would desire. Moreover, ...until now, we have not fully appreciated just how difficult it is for schools to succeed in their chosen (or appointed) task ...We have not been cognizant of ways in which basic inclinations of human learning turn out to be ill-matched to the agenda of the modern secular school. (Gardner 1991)

The curriculum: a sum of disparate subjects

The sum of what must be taught and learned, despite the charge to have it integrated and holistic, remains a collection of disjointed, isolated and unrelated subjects, struggling for allocated hours in the school timetable. No evident connection exists between corresponding activities or between actors *(functional agents)*; no channels through which they can communicate and talk to each other; and no space for their mutual encounter and subsequent interaction.

Quite naturally, there is little information exchange between them precisely because subject matter in the classical school curriculum is impersonal, faceless and soulless. Neither teachers nor students can feel and see in such classrooms other living, willing, and acting personalities – those bearers of creative forces that had once brought into being all these areas of knowledge, mastery and expertise. No wonder they have little motivation to explore and develop the hidden inner potential of their own.

The origins of detechnicalized learning

The mechanical-industrial syndrome is still felt in many areas of education, especially among the administrative staff. The vision of a smoothly run manufacturing plant with its driving belts and assembly lines does often eclipse the fact that school is (or at least, is said to be) a living entity, a society in miniature, a learning community of people, comprising some adults but mostly children drawn and bound together by extreme variegated needs, expectations, obligations, and responsibilities. To quote Seymour Papert who probably, more than anyone else, has helped us to understand the vast educational potential of computers:

> The institution of School, with its daily lesson plans, fixed curriculum, standardized tests ... tends constantly to reduce learning to a series of technical acts and the teacher to the role of technician. Of course, it never fully succeeds, for teachers resist the role of technician and bring warm, natural human relationships into their classrooms. But what is important for thinking about the potential for megachange is that this situation places the teacher in a state of tension between two poles: School tries to make the teacher into a technician: in most cases the sense of self resists, though in many the teacher will have internalized School's concept of teaching. Each teacher is therefore along the continuum between technician and which I dare call a true teacher.
>
> The central issue of change in education is the tension between technicalizing and not technicalizing, and here the teacher occupies the fulcrum position.
>
> Not since the printing press has there been so great a surge in the potential to boost technicalized learning. But there is also another side: Paradoxically, the same technology has the potential to detechnicalize learning. Were this to happen, I would count it as a larger change than the appearance on every desk of a computer programmed to lead the student through the paces of the same old curriculum. But it is not necessary to quibble about which change is more far-reaching. What is necessary is to recognize that the great issue in the future of education is whether technology will strengthen or undermine the technicalities of what has become the theoretical model, and to a large extent the reality. (Papert 1993)

In fact, institutionalized, compulsory education was turned into a machine (a mechanical production system), imparting its *products* with an inner program to proliferate the same pattern in all walks of life. Hence, the school became the model for the mechanization of society. Increasingly fragmented division of labour and specialization were, and still are, the key words. In fact, it was a cycle (or vicious circle) of mutual reinforcement that reached a climax in the mid-20th century.

At the beginning of the new millennium, this cycle came to a dead-end. To become alive again, we believe the school must transform itself from a machine for teaching into a *learning organization* more focused on creative experiments than on prefabricated detailed plans and checklists.

THE BASE FOR NEW PEDAGOGICAL POSSIBILITIES

Proposals for a radical reformation of traditional schooling are numerous. To explicate them all here would be a large task. However, we shall try to give instead a composite picture of the leading ideas that we deem the most promising, substantiated, and convincing. We start with basic notions, describing child personality and development, and with the question of how to measure them.

Intelligence and intelligence quotient

Dictionaries define intelligence as the power of seeing, learning, understanding and knowing. It is a mental ability. For example, we say, “He shows little intelligence” when we mean that boy is slow in understanding.

For a long time in the West, *intelligence* has been equated with the ability to think *rationally* and *objectively*, and to express one’s thoughts and judgments in *scientifically based*, *quantitatively measurable*, *logically provable* propositions and assertions. Individuals were called intelligent if they were astute, shrewd, eloquent and quick in using words and numbers, especially in written form. In the Orient, by contrast, a man or woman who was well behaved and obedient to the supreme forces, respectful to the elders, deferential to traditions, or endowed with clairvoyance, was often referred to in terms that have been translated as *intelligent*.

Consequently, teaching and learning in Western schools were more concerned with transmitting and getting *detachable* and *distant* knowledge coded symbolically in oral and written speech, rather than with immediate interaction and participatory hands-on activities, experience and wisdom.

It was quite natural to establish a system of checking and testing both interim results and the quality of the end-products of this almost industrial-like manufacturing process.

At the turn of the 20th century, the French psychologists Binet and Simon were commissioned to research the possibility for *measuring intelligence*. From the start, the goal was to measure the sub-skills necessary for classroom success. Binet actually sat in a classroom, taking notes of students' answers to teachers' questions, and tried to construct rules for predicting who would fulfill the demands of the teacher best.

Sampling school children's abilities to utter correct answers in many schools across France, Binet created the first intelligence test, later developed and corroborated by other researchers. With these tests, it became possible to estimate an individual's *intelligence* by processing the data of one's performance on a deliberately heterogeneous set of items, ranging from sensory discrimination of colours to vocabulary knowledge, and to calculate a so-called Intelligence Quotient or IQ.

What a magnificent epitome of the era of mass-produced education: now you could quantify how bright and stupid everyone is!

In pre-industrial epochs, people perceived each other as much more complex entities. Someone could be clever enough with words while incompetent in numbers; shrewd in business but poor in writing; incapable in abstract reasoning but masterful in crafts or apt in sports. It was only after the development of intelligence tests and what the statistician Spearman did with them that the construct of intelligence nested so firmly in the consciousness of educators and heads of Human Resource departments.

Spearman found that all IQ tests that appeared after Binet and Simon's correlated highly with each other. He reasoned that they must have been measuring the same thing. Further, this cross-correlation could be explained by a construct he called *g*, for *general intelligence*. Some eminent critics disagreed, maintaining that human beings had multiple abilities, or factors of intelligence, but they were forced to admit that even these multiple factors had a high cross-correlation. Hence IQ tests became highly useful in the hands of busy school administrators eager to predict student scores and channel students according to their abilities. After all, that was how the administrators' own abilities would be measured and rewarded (or punished).

Eventually, all these tests, rather than measuring potential for achievement *became* the measure of achievement. More to the point, the tests that had been designed to sample education now came to determine what was taught. Large publishing houses began selling textbooks and other consumables to elementary schools with drill units that carried a remarkable resemblance to IQ subtests. Thus began a self-feeding, circular relationship.

There is, however, a more promising alternative view of intelligence.

Multiple intelligences

For a while, there were voices arguing that intelligence was better conceived as a set of possibly independent factors. Later findings from AI (Artificial Intelligence) research, developmental psychology, and neurology, prompted investigators to put forth the view that the mind consists of several independent modules or *intelligences*. In the 1980s, Howard Gardner formulated his theory of multiple intelligences (1983; 1993), in which he stated that people use one or more of at least seven (more recently eight and even nine) relatively autonomous, intellectual capacities to approach problems and create products. In many aspects, Gardner's views run against entrenched notions of pedagogical psychology. Gardner's seven intelligencies are:

1 Linguistic intelligence (as in a poet);

2 Logical-mathematical intelligence (as in a scientist);

3 Musical intelligence (as in a composer);

4 Spatial intelligence (as in a sculptor or flight pilot);

5 Bodily kinaesthetic intelligence (as in an athlete or dancer);

6 Interpersonal intelligence (as in a salesman or teacher);

7 Intrapersonal intelligence (exhibited by individuals with accurate views of themselves).

What is important to the present discussion is Gardner's stress on the fact that a particular intelligence cannot be conceptualized independently of the particular context in which an individual happens to live, work and play, and the opportunities and values provided by that milieu. For example, Bobby Fisher might have had the potential to be a great chess player, but if he had lived in a culture without chess, that potential would never have been manifested, let alone actualized.

The time has come for schools to incorporate a wider array of mental processes and activities into the learning process. Whereas traditional classes have been dominated by the spoken and printed word, the new classroom should practise a multisensory enhanced learning. Indeed, as long ago as 1920, Vygotsky's work (see Vygotsky, 1978) showed that a child's cognition and thinking, to a great extent, relied upon the manipulation of material objects used as tools as well as societal surrounding.

Intelligence is always an interaction between biological proclivities and opportunities for learning in a particular cultural context. Vygotsky and Papert would agree wholeheartedly with Gardner; and Papert would especially emphasize the role of immediate surroundings, allowing and prompting the child to investigate and consciously transforming purposely its material, energetic and informational aspects and components.

Unfortunately, as Gardner and Papert never miss the chance to point out, the school system, which largely reflects yesterday's Western culture, teaches, tests, reinforces, and rewards primarily only two intelligences: verbal and logical-mathematical. These two intelligences are, of course, essential for effective functioning in a knowledge society, but so are all the other intelligences. Not only have the other kinds of intelligence been highly developed by gifted graphic artists, dancers, musicians and writers, they may also be pathways to learning for many poorly achieving students who do not learn in *legitimate* ways. For everyone, developing these multiple intelligences increases creativity, flexibility of thinking, and the broad cultural and humanitarian background that enriches living.

The resources for this enrichment are typically thought of as material artifacts like books, textbooks, and computer files. However, other individuals are part of one's distributed intelligence also. Most workers do not depend exclusively on their own skills and understanding; rather, they assume the presence of others in their work environments. This view is brought home vividly when one considers an office or a classroom that is being computerized and has access to the WWW.

Testing abilities

Another approach to the nature, structure and functions of intelligence(s) has been proposed by Robert Sternberg, who suggests three kinds of intelligence:

1 componential, which is assessed by many traditional tests used today;

2 contextual, which is the source of creative insight, and

3 experiential, which is the *street smarts* of intelligence. (Sternberg 1985; 1988)

Sternberg's latter two intelligences do not often show up on traditional tests, and are not always highly valued in the classroom, since curious and creative students and those who learn by doing tend to take up more of a teacher's time and attention. Such students are later valued in the adult world, however, as creative thinkers and process-oriented employees who often affect the bottom line in productive ways.

Sternberg feels that some people's major intelligence is in the traditionally tested/graded area of *critical thinking* (generating new innovative thought and connection), and that people who are able to make things really work for them out there in real life are *contextual thinkers*. Sternberg's theory is too complex to be elaborated here in full detail. One of its outcomes is the Sternberg Triarchic

Abilities Test (STAT), which is divided into nine multiple levels for different ages, and described as suitable for kindergarten through college, as well as for adults.

In contrast to conventional tests, STAT yields separate scores for componential information processing (analytical ability), coping with novelty (synthetic ability), and (as a separate score) automatization and practical-intellectual skills. Equally important, the test puts more emphasis on the ability to learn than on what has been learned, and verbal skill is measured by learning from context, not by vocabulary. The test also measures skills for coping with novelty, whereby the examinee must imagine a hypothetical state of the world (such as cats being magnetic) and then reason as though this state of the world were true. In yet another example, STAT measures practical abilities such as reasoning about advertisements and political slogans, not just decontextualized words or geometric forms.

In fact, as Sternberg himself admits, STAT is not immune to prior learning, and nor is it *culture-free*. It is hardly thinkable to design a test that would satisfy all the considered demands. Intelligence is always used in some particular, usually rather restricted context, though it is highly desirable to have this context as wide as possible.

Sternberg's theory differs from Gardner's. However, the two theories are also highly complementary. Sternberg makes us strongly believe that intelligence needs to be seen as a broader and more complex construct than both authors declare, and the field is open to any experienced, thoughtful, and enterprising teacher eager to make her or his own contribution to the common educational cauldron.

Multiple ways and conditions of learning

We must exploit universal features of the child's (and the adult's) personality to a greater extent. Children have a natural interest and curiosity about the internal and external world, and an eagerness to communicate and to play, making collections and ordering items, creating unexpected and aesthetically significant objects. The basis for human development – habits and skills for lifelong learning – should be established early in primary schools.

Appealing to both sensory and symbolic smarts

It is widely accepted today that it is not enough for students to understand and learn fragmented information. It is equally important for students to understand the context, meaning, and gestalt of topics as well. The objective, sterile environment in many schools actually inhibits learning. Learning is also unlikely to occur when students harbour negative feelings about an instructor, peers, class work, or have difficult personal issues. The traditional classroom must be replaced by rich, stimulating, accepting, warm, and responsive surroundings. Sylvia Farnham-Diggory agrees:

> Both children and adults acquire knowledge from active participation in holistic, complex, meaningful environments organized around long-term goals. Fractionated instruction maximizes forgetting, inattention, and passivity. Today's school programs could hardly have been better designed to prevent a child's natural learning system from operating. (Farnham-Diggory 1990)

As most teachers know, students labeled *weak* or *slow* often turn out to be bright and skilful when confronted with something that is personally appealing or challenging outside the classroom. Though these students have difficulty learning in school, they often excel at making, fixing and operating tangible things: gadgets, bicycles, motors, electrical circuits, complex mechanical devices, arcade games, VCRs, various kinds of contraptions and even imaginary objects. These children are usually identified as having trouble with the *symbolic smarts* that form the core of schooling.

It is not surprising that the traditional school focuses on what *weak* students cannot do, and does not see them as possessing virtuoso *sensory smarts* in some fields. Instead, it sees them as failing to perform, or not meeting the requirements. An ideal teacher will appeal equally to symbolic and sensory smart students with a view to bringing these two kinds of knowledge into active and fruitful collaboration.

For example, a computer with a Logo environment and LEGO extensions allows students to build working systems out of tangible blocks, using their hands as well as their *theoretical* mind, in the form of symbolic expressions on the monitor screen. When students are encouraged by teachers to reflect on and confront the differences and similarities that emerge as they move across materials, sensory modalities, and kinds of descriptions, it helps them to create mental bridges between *action knowledge* and *symbolic knowledge*. Previously hidden aspects of hands-on constructions are revealed. Children who build both real world and virtual world structures begin to see the resemblance among working systems. In making the resemblance explicit, they liberate and make easily understandable the basic principles that the working systems share. (Resnick 1997)

Visual cognition and creative thinking

Visualization of inner mental imagery and the outer graphic presentation of reality in pictures, drawings, diagrams, lists, and charts is a fundamental part of creativity, discovery, invention, and problem solving. The vital importance of visualization is affirmed by the fact that a surprisingly large proportion of the human cortex is devoted to vision and visual analysis, and that the bandwidth of the visual channel is greater than that of any other sense. In many instances, the eye, and those parts of the brain that process visual information, lay the foundation for enhancing conscious thinking, which in turn, grows from our preconscious mental activity.

To take full advantage of the capabilities of the eye, the goal of visualization should be objectification. This means that a phenomenon, inherently visual or not, should be represented as having form, colour, texture, motion and other qualities of objects.

Inductive thinking relies to a great extent upon the human ability to visualize on this preconscious level. Major portions of the visual system including the retina, the structures ascending to the visual cortex, and parts of the visual cortex itself fall into the preconscious category. More powerful than a supercomputer, these functional entities relentlessly perform information-processing miracles, creating a three-dimensional, coloured visual environment that our conscious self exploits in a logical way to serve definite practical purposes. Our conceptual images are constantly being analyzed at a preconscious level, and produce useful data for establishing spatial relations, making conscious representations and building plans. In other words, the outcomes of these subliminal mental activities become the elements, tools, and procedures of rational thinking.

This is where computers make an enormous difference. When we visualize with the help of computers, video camcorders, and big-screen high-resolution projection, we restructure a problem situation so that more of it can be processed by the preconscious part of our brain – the visual system that is our silent partner. In this way, consciousness can be devoted to higher levels of critical analysis and synthesis. Especially interesting, are virtual worlds that model nothing but themselves, as do many games, chess among them. Nevertheless, by representing spatially the system of abstract relations between chessmen on a chessboard, a professional chess player can think in images. Similarly, it is also possible to visualize on a computer screen the spatial interrelations of elementary predicates and, consequently, to represent complex formulas of predicate logic (Bederson and Shneiderman 2003; Card, MacKinlay, and Shneiderman 1990; Friedhoff and Benzon 1989; Rieber 1995).

As a kind of modelling, visualization has many aspects. One is aesthetic-emotional. For example, nobody will deny that visualized mathematical objects and functions can be aesthetically beautiful. *Fractal* animated cartoons, captivatingly spectacular and shown on TV all over the world, have already inspired works of fine art (even if not eternal masterpieces). Beyond any doubt, it is precisely because of their aesthetic components that such themes as chaos, fractals, and the like, have become so popular in academic mathematical courses.

Another aspect of visualization-as-modelling is, as in the classical art of painting, selecting and making visible essential traits of the object or phenomenon depicted. By forcing us to pay attention only to what can be seen and perceived by the eye, visualizing helps to impart a meaning to a problem and makes it easier to find its solution. In the simplest case of a virtual constructor used to build interactive models of physical phenomena, we may get a picture of an ideal experiment, which is mathematically correct within a set degree of accuracy.

Using a similar learning environment under a teacher's guidance, the student can trace all levels of abstractions in modelling. For instance, there could be genuine physical objects and processes (say, a carousel on which children have a ride), material (LEGO-like) models, videotapes, computer simulations (virtual realities), graphical representations of processes' characteristics by co-ordinates and velocities within a set referential system, and symbolic modelling by algebraic and differential equations.

Heterarchy and changing pedagogy

New pedagogy is based on the opposite of the traditional classical hierarchy – that is, a *heterarchy*, a term that depicts a system in which each working element or agent is equally ruled by all others. This means that, while learning, these agents communicate or talk to each other, exchanging messages filled with related information. In this system, there are no simple linear chains of cause and effect, but more and more cross-connected rings and loops.

Behind the dazzling variety of new theories, methodologies, and working approaches to learning, one can detect several underlying patterns, or fundamental principles and practices that seem perennial. Re-christened in modern idioms, these principles are referred to as poly-sensory, experiential, project-oriented, constructivist, and connectionist.

Constructivism

Constructivism, a term introduced by Jean Piaget, asserts that the knowledge acquired by students should not be supplied by the teacher as a ready-made product. Children do best by creating for themselves the specific knowledge they need, rather than being instructed in what they must know. Seymour Papert later found that such things would happen especially felicitously when learners are engaged in constructing something external or at least shareable: a sand castle, a book, a machine, a computer program (Papert 1980). These kinds of activities lead to a model of learning that involves a cycle of internalization of what is outside, then externalization of what is inside, and so on.

Connectivism

This mode of collaboration paves the way to *connectivism*, or *connectionism* or *connectivity of knowledge*, which Seymour Papert professed after many years clinging to logical step-by-step constructivism. According to his later views:

> The deliberate part of learning consists of making connections between mental entities that already exist; new mental entities seem to come into existence in more subtle ways that escape conscious (i.e. step-by-step) control ... This offers a strategy to facilitate learning by improving the connectivity in the learning environment, by actions on cultures rather than on individuals. (Papert 1993)

Papert asserts that conceptual connections between a given notion or phenomenon and a wide array of other notions and phenomena are often helpful in gaining a more substantial understanding of a subject under study. Rather than passively receiving ready-made facts, notions and opinions, students acquire advanced skills and knowledge by solving problems in their immediate surroundings that they consider personally meaningful and emotionally exciting.

In the days of sweeping global changes, training for a particular skill or job must endow the trainee with an ability to be re-trained and self-retrained. It follows that we believe the concept of mass training to be short-sighted. Constructivist education must take command even in vocational and elementary schools, and a trainee must become a true learner. The priority is not the transmission of particular knowledge and skills from teacher to taught, but the development of the ability to acquire these by students on their own. All this, of course, is facilitated by new technologies of education.

For many decades, the polemics surrounding educational reform have vacillated between two points of view: those who favour a progressive, child-centred form of education, and those who prefer a return to a more structured, teacher-directed curriculum that emphasizes basic knowledge and skills. Today, however, a growing number of educators adhere to an alternative trend, intended to reconcile these opposing stances. This latter view is the theory of a collaborative community of teacher and students, focused on a dialogue and co-construction of knowledge. Such an approach helps resolve the conflict between traditional *instructive* teaching and *constructive-connectivist* autonomous learning. In this, too, ICT are playing a key role.

Project method: learning by designing

Among many proposals for revitalizing general education, the *learning projects* advocated and corroborated in the last century by John Dewey, Jean Piaget, Jerome Bruner, and Seymour Papert are among the most promising. The trouble is that such learning projects cannot be introduced in a form that the traditional school recognizes: as a ready-made set of precisely defined tasks or particular objectives, operations and procedures given in advance. Instead, these projects have to be found, discovered, invented, or designed in the course of a class.

To benefit from this project method, both teacher and student must acquire some generic skills rarely taught in an ordinary school. Different authors call these skills the *design mode* of thinking and looking at things, the *designer's approach* to problem solving, and *designerly ways of knowing*. Mastering and exercising those skills would eventually lead to the formation of *The Design* (or Third) *Culture*, mediating the much-lamented rift between the two cultures of C. P. Snow – the Techno-Scientific and Humanistic-Artistic.

We invite readers to take part in detecting, unearthing, and cultivating the elements and principles of design in learning. This involves conceptualizing its problem situations, generating options, making choices, conducting mental experiments, finding acceptable solutions, and evaluating probable outcomes before actually implementing them. From this standpoint, design can be seen as an innovative intellectual technology waiting to be converted into a powerful technology of education.

For a start, let us consider what makes, or might make, school learning really interesting, attractive, and successful for students and teachers alike.

True teachers do something more than just transfer information. In receiving any source-material, teachers make it a part of themselves by re-exploring, re-interpreting, and re-constructing its form and content in a personal way. Examining the phenomenon of inner speech, Vygotsky (1986) pointed out that a child, assimilating a certain notion, re-works it, and during the process of re-working, expresses the peculiar features of his own thought. V. S. Bibler, a contemporary Russian philosopher and educator, adds that in inner speech, an individual transforms the socialized and relatively static images of culture into a culture of thought, dynamic and personal. (Bibler 1996) Especially interesting is Bibler's remark that in such cases an inner speech becomes future oriented and serves as "the mould for *creating new, non-existent yet, but just possible* images of culture". We could say that true teachers act as designers of both the «images of subject-matter» to be presented in the classroom, and the tools to be used by students in order to transform given images into a personal culture of thought. In this way, they enable students to develop their own abilities to learn.

By initiating communication and interaction regarding the design of the learning process, a true teacher learns no less than the students, who, in fact, are teaching themselves and one another. These and other aforementioned theoretical concepts of modern reform-minded pedagogy can be summarized in the practical recommendations in the final sections of this chapter.

TEACHING STUDENTS TO BE LEARNERS

If you are a devoted schoolteacher in the 21st century, what should be your essential mission, main professional calling, and foremost pursuit?

The answer is in the wind: to teach students to become good learners.

What does this mean, functionally, as well as structurally? We would argue that a good learner is someone who is always alert, attentive, perceptive, responsive, and ready to be pro-active in grasping, digesting or assimilating a knowledge, skill or competence. This is true from kindergarten, elementary, middle school and high school, through years in college or university, and in all walks of adult life. If you really devote yourself to raising and tutoring such characters on a daily basis, let us consider some necessary theoretical cornerstones, technical requirements, and organizational prerequisites.

To make a good learner out of every student in your class, you may pick up and try tentatively alternate trails, tools, and methods. However, we have good reason to believe that it is wiser to adopt the strategy of what might be called *the way of new schooling*. Here it is in a nutshell:

1 Find at least two or three (better five to seven) colleagues at your own or other schools, who share your strivings and are willing to collaborate either close by or far off (e.g. via email exchange) to develop a project.

Teachers who wish to pursue such a mission must intermittently transmute themselves into part-time researchers, designers and constructors of the new educational technologies. The argument for collaboration is simple: there is no one who can instruct contemporary teachers authoritatively and unilaterally on what to do in all particular, unprecedented and unique circumstances. Therefore, teachers must think and act on their own while trying to weave a web of interconnectedness and mutual assistance with as many concerned and knowledgeable people as possible.

2 Show students a variety of optional activities from which each is asked to choose a few that are challenging, alluring, and suitable to them personally.

3 Provide a friendly environment, materials, and tools with which students can tinker freely, if only by imitating by example.

4 Encourage students by means of informal conversation and discussion to exercise playfully their explorative curiosity, adroitness, and inventiveness, coupled with developing an awareness of what they are doing in the broader cultural-educational context.

At this preliminary stage, both students and adults learn that a teacher can be not only a mentor, tutor, or instructor, but also an older, experienced, skilful, and responsible playmate with whom it is easy to communicate and interact.

5 Introduce some simple and attractive structured games with strict, explicitly defined rules relevant to the topic under study, and invite the students to play to win.

Now students learn that the teacher can initiate them into new kinds of competitive play and games that enable students to demonstrate their wit and mental adroitness.

6 Make students aware that their success in playing these goal-oriented games depends upon their willingness, and acquired ability to observe – not break! – conventional rules they have accepted by mutual agreement.

In this way, students learn how to turn the limitations and restrictions imposed by these rules into a springboard for reaching higher levels of resourcefulness and ingenuity. They come to treat the teacher as a respected game-leader, whose mastery they are hoping to equal some day.

7 Devise a series of more complicated, project-oriented games that are related to the consequent themes, topics, and tasks in various subject matters and implying a collaborative rather than competitive approach to problem solving.

At this stage, the game has been imperceptibly transformed. In fact, it will no longer be clear to anyone whether it is still a game or a cognitive, productive activity of a serious kind. Students, in their turn, will become more and more involved in mutually supporting, intellectually and emotionally rewarding teamwork for exploration, research, designing, testing and implementing their discoveries, inventions, and solutions, while seeing the teacher as a partner in real business and a competent master of the craft.

TEACHERS AS MASTER-LEARNERS

Schoolteachers must revise their positions, leaving behind the status of the omniscient one who has all the answers. Instead, genuine teachers will become advisers and learning facilitators. Influence and credibility will accrue to those who not only *instruct* but also *construct* and *connect* in front of the class, that is, by skillfully doing something they may really be interested in, prompting students to learn how to do it by their own minds and hands.

Possible learning projects are as diverse as assembling and operating model cars and toy trains, building and decorating puppet homes, writing and printing prose and poetry via a word processor and desktop publishing, turning out pop tunes with a synthesizer, drawing simple animated cartoons, or cracking the codes of mediocre computer games in order to make them more challenging.

The main goal of this construction and connection should be, of course, the acquisition of knowledge and skills required by the curriculum, plus the experience of being in control of one's own process of collaborative teaching and learning.

As a matter of fact, the authority of teachers can be re-established on the basis that they possesses three interconnected kinds of mastery:

1 Mastery of Doing – one can do a lot, but not everything, and can do more in cooperation with others.

2 Mastery of Learning – one is not the only source of information but can teach how to find alternative sources.

3 Mastery of Collaboration – one can multiply results by joint work with students and other teachers.

It is worth noting parenthetically that the word *mastery* has the double connotation of power to control one's surroundings, and wisdom to use it appropriately. Teachers of the 21st century are called to restore the dual meaning of mastery in its completeness.

EMERGING NEW SCHOOLS

Is it conceivable to embody the new pedagogical theories, methods, and recommendations espoused in this chapter within the established framework of general education? If so, why have all these brilliant ideas not been introduced everywhere? The reason (besides the inertia of educational system) is this: these ideas are technically unrealizable where the textbook, blackboard, pencil and paper are still the only external tools for instruction and learning. ICT give schools a chance to vanquish these seemingly insurmountable obstacles.

We look in the next chapter at typical schools of today equipped with affordable ICT equipment, and see what kind of positive changes can be made in the learning environment.

4

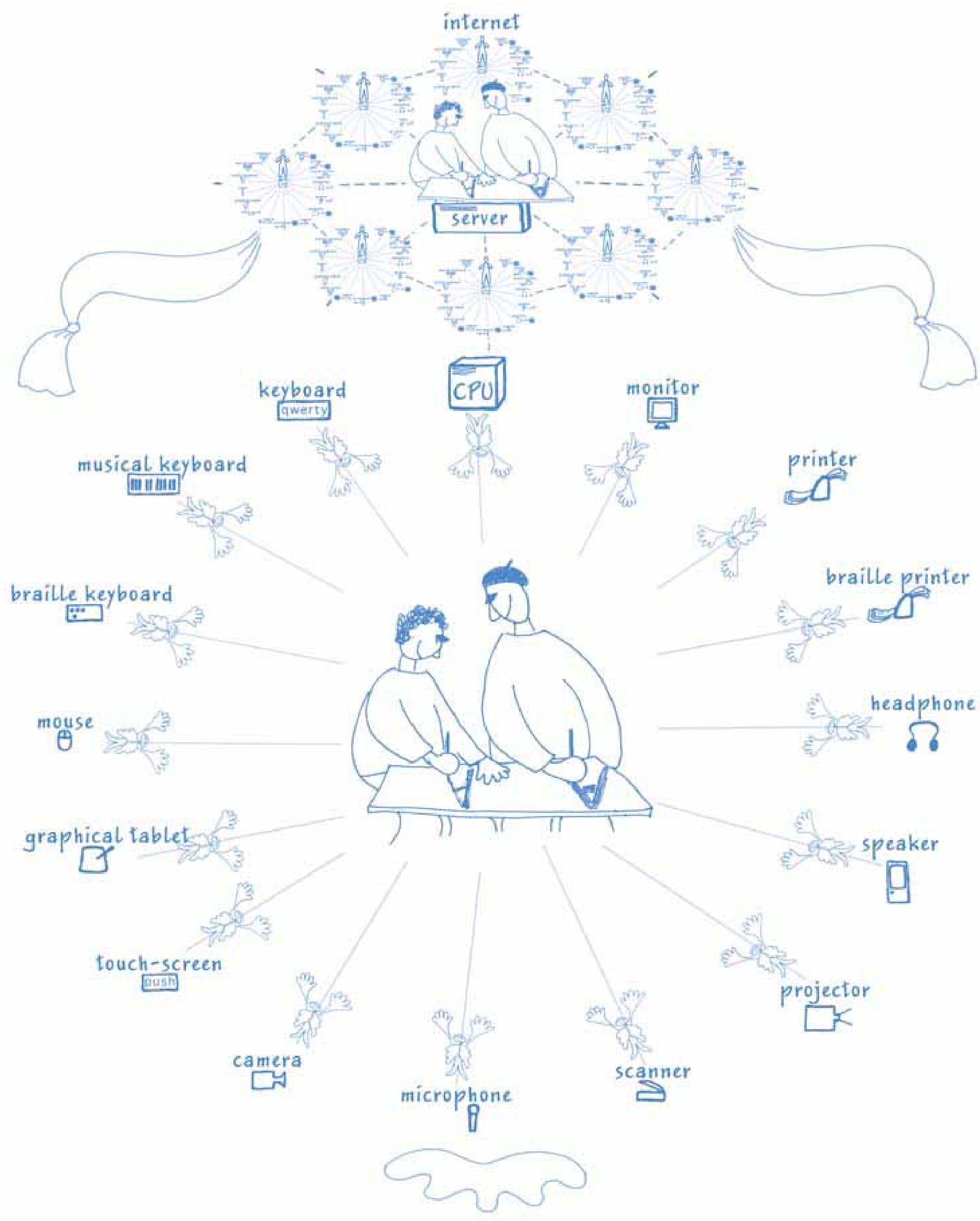
ICT IN LEARNING AND TEACHING

The latest ICT allow radically new opportunities for human activities. How will education meet these challenges? Today, in the wider society, most people who need to add up a bill use a calculator. Most texts are written and read on a computer. However, such activities are not paralleled in our schools. Even in developed countries, most children use a calculator or a computer at school only occasionally (and calculators are used more often in science classes, than in mathematics lessons). We observe a digital divide, therefore, between the world at large and the schools teaching children to enter it. Of course, we do not underestimate a further digital divide between countries and between communities within a country. In the near future, it will be possible to turn to a mobile handset to answer most problems and questions on school tests, and to receive oral or written help or advice automatically (without even using a qualified expert) in a few seconds. What does all this mean for the future of education? What does it mean for the school finding itself in such circumstances?

NEW POSSIBILITIES

Do what we are not already doing

The fundamental error that many educators commit when they consider using ICT is to view them through the lens of their current practice. They ask, "How can I use these technological capabilities to streamline or improve what I'm really doing?" instead of asking, "How can I use ICT to do things that we are not


internet
server
CPU
keyboard
qwerty
monitor
musical keyboard
printer
braille keyboard
braille printer
mouse
headphone
graphical tablet
speaker
touch-screen
push
projector
camera
microphone
scanner

already doing?" By their very nature, ICT call for innovation. It is about exploiting the full capabilities of technology to open new perspectives for both teachers and students.

At the same time, it is unwise to ignore traditional styles and models of learning as well as ideas from the past that were not implemented in the mass school but were precious exceptions.

Therefore, we need to start with things that we are already doing, but consider them anew.

Schools of tomorrow seen through schools of today

One way to introduce ICT into school education is to observe schools without computers and see what opportunities arise to facilitate various educational activities by using ICT. Starting from that point, we can recognize that schools without computers are different, and that different applications of ICT are possible. We discover that some teaching and learning activities can be advanced much more than others. Then we can reconsider how desirable different activities are from the point of view of educational goals for individuals and society. Eventually, we can discover, or imagine, certain new forms of learning beyond the reality, experience, and vision of past centuries.

Of course, it is an absolute requirement to begin in small steps experimentally and to have a program tested by broad practice before recommending it for others. Nor is it necessary for a school to have acquired all high-end ICT in order to feel the benefits and impact of ICT on practice. Every improvement in technology almost immediately finds its application in the practical work of some teachers in schools and broadens educational horizons (as we emphasize, not in just a technological sense, but in the sense of enrichment of human activities).

ATOMS OF LEARNING

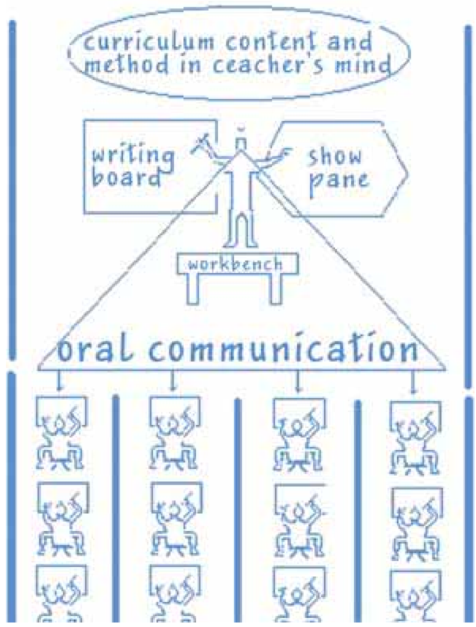
In this section, we overview the simplest elements of learning and teaching and describe how the ICT, detailed in Chapter 2, can contribute, and why this contribution can make teaching and learning more effective. We analyze well-known situations and indicate all sorts of changes made possible by ICT.

Immediate oral communication

Lecture

Let us start with an important general example of a traditional mode of teaching-learning – a lecture. In the classical model, the teacher speaks and students listen. As in other cases of oral communication, the teacher relies heavily on such extra-verbal components as the tempo of speech, voice dynamics, facial expression, gesticulation, and body movements. These *tools* of rhetoric are used to express something, to transfer information (including emotional and aesthetic), to hold the attention of students, to impress and to engage them.

Teachers control the situation by looking directly at students, tracking signs of interest or absence and other emotions, and using this (mostly non-verbal) feedback to tune up their part of the communication. Feedback from students can be oral or written (in the form of notes handed up to teachers). Depending on the teacher's rules, students have a chance to speak during a lecture or at the end of the lecture only. This communication is usually limited in time and form; students mostly ask short questions. Teachers can also pose questions to the students, sometimes expecting a non-verbal clearly visible response from all of them such as "Raise your hands, please, if you know who Newton is".



What makes the lecture an important and useful mode of learning and teaching are the following:

- One teacher addresses many students and this is economical for providing modern schooling to the whole population, not a selected elite only.
- Teachers can react to students' behaviour in a limited way by adjusting their talk, and individually in a more limited way, by addressing a short message to a specific person and giving other kinds of feedback.

- Within limits, students can solve problems of misunderstanding and unsuccessful communication by asking questions.

The disadvantages of the lecture model are that it:

- encourages passive learning;
- affords limited individualization; and
- allows limited extra-verbal communication with a limited use of the senses and channels of human perception.

What technologies are involved in the traditional lecture? And what extensions of these do we have, or can we expect in the future?

The major information channel for the lecture is the aural one. Of course there is human voice technology – you can be trained to project your voice to an audience of 100-200 people, or more. A special design of the auditorium can contribute to a lecture. Microphones, amplifiers, and other equipment can improve loudness and even acoustic quality of human speech. Students can also use microphones while asking questions. Installing audio equipment for a lecture in a large room or hall can be a sophisticated task that requires a professional. One of the important issues here is to place loudspeakers (the sources of sound) in a way that students get the impression the sound is coming from the lecturer – to amplify mutually two different channels of information, not to confuse them.

Using a microphone requires proper positioning – not too far so you cannot be heard, and not so close that your voice is distorted. Surprisingly few people today manage to use a microphone properly, and so good sound in lectures is not so common.

Radio microphones are useful when it is desirable to move around in a room or to pass the microphone between discussion participants. An option of using small and light wearable microphones simplifies the problem of proper positioning but also requires simple technical knowledge.

The loudspeaker is not the only option for amplification. We can supply every student (and the teacher, if needed) with headphones. Signals to headphones can come via wires or a wireless network. A popular application of headphones is in simultaneous translation, which is not widely used in schools, although often encountered at international meetings of researchers and others, and could be imitated in schools.

Visual component of oral communication

The visual component of lectures is as important as in other cases of oral communication. At the same time, new ICT technologies are changing face-to-face lecturing. For example, in the case of bigger audiences, the speaker's face and figure can be captured by a video camera, magnified, and projected onto a screen.

In some subjects, an important component of the lecture content is given by visual images other than that of the speaker. Most lecturers traditionally use a blackboard or an overhead projector. In some subjects like mathematics, this appears inevitable. A broader list of typical visual components includes:

- key points of a talk indicated in a written form on a chalk- or whiteboard;
- the derivation of mathematical formulas, as well as mathematical formulas accompanying discussion of physical, biological, or economic issues;
- chemical formulas and other, less important formalisms;
- drawings and conceptual diagrams;
- all kinds of ready-made images (artistic paintings, photographs, book pages, technical drawings, maps) as illustrations; and
- real objects and processes (like experiments), if they are big enough to be seen by an audience.

ICT extensions of this communication are based on projection technology. As noted in Chapter 2, a projector can greatly increase the size of an image if the ambient light is not too bright.

Now, a combined computer and projector open new possibilities and generate a new culture of oral communication accompanied by screen images.

In comparison with pre-computer lectures, this new technology allows the following:

- The speaker can combine pre-recorded images (including text) with images made during a lecture. Pre-recorded video fragments can be included accompanied by sounds if needed.
- Images of real objects obtained via cameras can be downloaded to a computer or connected directly to the projector.

This technology allows for clearer visualization, and saves time the lecturer needs to spend on writing. However, lecturers need to be aware of the following:

- Text on the screen should be economical.
- *Sans serif* fonts (like this) are easier to read on screen.
- Do not read the text from the screen; screen text is a tag to what you are saying.
- Leave a little time for an audience to absorb each slide.

It is often helpful to give listeners a printed copy of all slides from a presentation to take away with them (for example, these can be printed six slides per page).

The natural screen image of a lecture usually calls for two screens: one to enlarge the figure and face of the speaker, and the other for the visual-textual part of the speech.

Of course, digital video images can accompany transmitted and recorded lectures, placing the lecturer's face or figure on part of the screen, and surrounding it with other material, or simply using the lecturer as a background voice.

Communication between teacher and student

Today, teacher-student communication – whether face-to-face, live, synchronous, or online – is carried out within strict temporal and spatial boundaries. These boundaries are largely imposed by the school timetable with its:

- sub-division of the class period into a lecture or demonstration (sort of one-way broadcasting) and consecutive conversations with individual students that may or may not involve attention and participation from the rest of the class; and
- sharp divide between in-school and out-of-school time, where no direct communication is supposed.

Assuming the school's information space is digitized, these boundaries might be easily crossed, or broken down technically. However, to get there, we first must face two new problems. The first is how to weave a reliably functioning network, or a web of mutual interconnections between all persons involved. The other is to allow enough time for each network user to communicate adequately with other network users.

Communication initiated by students

A good teacher needs time and space to respond to students' questions, statements, raised hands, looking through the window, smiling, and other types of verbal and non-verbal behaviour, as well as to encourage their participation in group activities. This vital human component is not thrown out by the use of ICT. Indeed, we should think about elements of the teacher's role as being supported or automated by ICT. At the same time, ICT make possible new forms of teacher-student communication. As we know, email has revitalized letter writing, while voice mail and answering machine sometimes help when wanting to say something that is hard to do face-to-face.

Students' speech

Microphones and screen presentations can help students even more than teachers. There are many cases where a student who is considered weak in oral communication develops eloquence, and even confidence, by using screen presentation support.

Answering teachers' questions

One of the drawbacks of teachers' questioning in the traditional school is that usually only one or two students are allowed time to answer during each class period. Computers, however, can record written and even oral answers by all students on the timeline.

Electronic digital lectures

Let us consider now the opportunities provided by modern ICT for broadcasting lectures with synchronous participation of learners. Synchronicity supports the organizational discipline mentioned above. A new opportunity provided by computer technology today is bi-lateral interactivity. Students can answer the questions teachers ask, and ask them questions, too, all in a written form, from wherever they live. Naturally, a CD and regular textbooks can accompany the course of such lectures.

In such situations, the major advantage of a digitized lecture is the breadth of the audience it can reach. The physical limitation here is the time zone. Of course, the number of actively participating students cannot be too big, but they do not all need to be in the same place.

For the teacher, the digitized lecture has other advantages. First of all, the lecture can be transmitted online (synchronously with the real event) to many places at once. Feedback is possible in the form of written notes sent by students. The teacher can show on screen the face of a student who has asked a relevant question. Other students asking questions that might be anticipated can receive standard answers generated by assistants or automatically.

The second option is to distribute a recorded lecture in canned form, recorded on DVD or videotape, or via the Internet. The advantages of these media are:

- mass distribution, multiplied audience;
- better quality text accompanied by pictures, and additional readings; and
- availability anytime, anywhere, at a learner's convenience.

ICT (printing and recording) make a considerable difference in delivering lectures. Nevertheless, certain advantages of new technologies can also be considered disadvantages. For example, the requirement to meet face-to-face at lectures at a given time is a discipline that organizes the process of learning. Sometimes, it is a welcome discipline for a professor! On the part of students, the obligation to make written notes provides additional support for concentration and memorizing through kinaesthetic activity and provokes online re-thinking of the content.

In some regions and communities, many people already receive general education by means of radio or magnetic recordings. Sometimes even a combination of radio transmission or playing a record and simultaneous face-to-face tutoring is used to good effect in general education. Many people learn foreign languages while driving and listening to audiotapes. The next step is TV and videotapes. These add something to the traditional lecture: you can see lecturers at their best time of the day, the voice is clear, the face is close, and so on. Eventually, we arrive at the HDTV and DVD era, with its picture-in-picture format.

Is it possible to learn using combinations of the abovementioned media? The answer is *yes*. Is it helpful to add to lecture text materials and video-audio records? Again, *yes*. In other words, the traditional lecture is not dying. It is in danger of becoming more interesting.

Reading

The lecture is not the only way to channel curriculum information to students. Students read textbooks and go to the library on the teacher's advice. They visit museums and art galleries, and take excursions to see natural scenic attractions, great architecture, and other monuments of historical and cultural interest. Each visit may bring them an enormous amount of information that helps them to assimilate, enrich, and enhance the knowledge they get from the formal curriculum.

ICT can be of great help in providing multimedia information on objects and sites of such kinds, especially those that are located too far away to be observed directly, or inaccessible for other reasons. At the same time, we should remember that understanding implies active participation on the students' part: the transformative inner reworking of content delivered. As Jean Piaget loved to say, to understand is to invent.

Reading is an important activity of the traditional school. Books contain not only written text, but also visual information. Good reading in the traditional sense implies, of course, good formal memorizing though this is becoming less important. It also means active reading – making notes, writing out quotations, and looking for and into other works referred to. Reading is part of the whole business of constructing a personal information space by the student. A process-intensive way of acquiring a particular piece of learning content can even help a student memorize it by heart.

Electronic digital textbooks

Let us consider the best possible canned (recorded) course of lectures. They have good video-audio quality, and may be accompanied by a printed text since the substitute of text-on-screen is not completely satisfactory today. Typically, lectures and accompanying textbooks can contain educational material of an advanced level or some optional information. In a lecture, this material can be relatively short and marked by a special introductory statement. In a textbook, it can be printed in smaller letters or placed in an appendix. In both cases, the options are limited, because of limits of material time and paper. In the case of electronic media, these limitations do not exist.

Modern electronic digital media such as DVD can accommodate hundreds of thousands of text pages. The digital lecture-textbook can thus be organized to display different levels of material, both in the sense of depth and breadth of subject matter and in the sense of how it is presented to the student. It can contain references or links to other related material whereas the lecturer has to point to the blackboard or show a slide again. The digital video textbook can also provide links to another part of the course, or to another course, or indeed to any piece of information available in the school library and beyond on the Internet.

Broadening the range of materials used in classrooms

ICT are making it increasingly easy for teachers and students to have access to a broader range of materials than they can use in the classroom. The simplest example is the copying machine, which allows teachers to make copies of articles, charts, or printed instructional materials from outside sources and to distribute these among students. Supplementary computer tools such as scanners or digital cameras allow teachers to bring in outside sources, enter them into a computer, and customize assignments. For example, teachers can bring a timely article from the morning newspaper into class, scan it in minutes, and have their students work on rewriting, editing, or adding other research material to the story on the same day. Encyclopedias, art collections, atlases, and other reference books in a less expensive, and less space-consuming electronic format will be of everyday use in classrooms.

Already, in many schools, students can browse interactively or conduct electronic searches in CD-ROM databases, encyclopedias, or other reference work. Thus, the new technologies allow access to a broader range of instructional resources. They also offer students the opportunity to learn how to use electronic tools to access information and develop research skills in solving problems.

Web learning

Learning on the Web is one of the most promising and rapidly developing areas of ICT in education. At the same time, it is one of the most complex psychologically and socially controversial fields. There may be problems for some students with sensitive topics like sex education, narcotics, and political or religious extremism. Some voices are calling for compulsory technical restrictions imposed on accessing objectionable sources of information.

There are also hybrid situations where content can be pre-loaded onto a learner's computer and integrated with other dynamic environments on the Web. Automated and human responses can be mixed.

Writing

Speed of writing

Most people, and especially children, can type faster than they write, and they can learn to type faster than learning to write. For smaller children, writing in clear calligraphy is a major problem. ICT allow students to learn communicative skills independently of the kinaesthetic ability to write. Writing in a clear script is important, but this can be trained separately, while students get on with the excitement of communicating.

Writing as designing and constructing

Two Russian proverbs reflect the irreversible character of some oral and written communication:

> *A word is not a sparrow – you can't catch it after it has fled.*
> Nearest English equivalent: *A word spoken is past recalling*.
>
> and
>
> *What is written with a pen cannot be cut out with an axe.*
> Nearest English equivalent: *What is writ is writ*.

In oral communication, this reality will probably never change. However, one of the beauties, and the banes, of the modern computer is that you can change whatever you want at any time. Moreover, changes are reversible. You can keep all versions of a paper or manuscript, and changes are traceable. In other words, the written object is close to the ideal in its flexibility. Indeed, perhaps for the first time in history, it takes less time to make a change than to think of it.

In education, this means that students are free of the horror of fatal errors. They are in a more adult position: if you, the Teacher, do not like it, I, the Student, can change it. As a result, the whole culture of writing in school is changing.

In the traditional school, the student writes an essay and the teacher offers corrections and advice. The student often pays little attention to these corrections and even less to the advice. In a very few cases, the student may argue with the teacher but there the story ends. In this new model, students with a little effort have a chance to improve the text, rewriting part or parts of it, and resubmitting it to the teacher for comments, and then taking these into account. The resulting evaluation of their work will take into account the efforts to improve it. A student's work can be reviewed, and undergo formal and informal evaluation, by peers and also by different teachers like the science teacher, the language arts teacher, or the ICT-coordinator, all at the same time.

The process of producing written work can be sub-divided into three main phases: *prewriting*, *writing*, and *postwriting*:

1. Prewriting includes deciding on a topic to write about, brainstorming one or more topics, reminiscing and selecting the most significant aspects, and gathering and organizing thoughts about how the writing is to be structured.
2. Writing is the creation and the online reading and editing of an emerging text.
3. Postwriting comprises rewriting, stimulated by immediate editorial feedback from the teacher (and classmates), then meticulously checking for spelling and grammar, correcting the syntax, revisiting and changing word sequences. It also may include any other editorial and publishing work down to physical manufacturing the book with stitching, sizing and binding. Students write better when they have a real audience for their written work and when the teacher offers them convenient channels and mechanisms for reaching a wider reading public via, for instance, the Internet or school newsletter.

The writing process described above is not confined to fiction or non-fiction literature. It is archetypal for all kinds of activities related to design and implementation of any project – be it erecting a skyscraper, establishing a bank, or writing and debugging a computer program. Above all, this circular procedure is a powerful conceptual tool for truly efficient perception, thinking, cognition, and learning. By its very essence, it implies discovering, inventing and creating meaning, which can be expressed, presented and embodied in fleeting spoken words, in corporal movements, gestures, and postures, in graphic symbols, in hand-made articles, or in heavy-duty mechanical devices.

In general, writing in schools today is becoming closer to other types of design and construction activity, including top-down planning using outliners, using pieces of old work, and different stages of finishing.

Spelling

Another feature of ICT that is changing radically the art of essay writing is spelling. What once took considerable effort has become a trivial task with automatic spelling checkers. The immediate adoption of spelling checkers would be too radical perhaps for the school system in certain countries. However, to ignore them means adding one more item not of direct use to academic knowledge to be acquired. Therefore, we should rethink the goals and values of education, and place more critical thinking, perhaps more language construction, and more teaching about computer tools into the writing process.

Hypertext

What distinguishes inner speech from outer speech in oral or written form is its non-linearity. Thinkable objects are not linear, but a network of associations. This is reflected in the hyper-structure of texts, which with printed-paper, can be represented in the form of footnotes, endnotes, and bibliographic references. To teach children hyper-writing is not difficult because for them it is more natural than it is for adults who have learned how to linearize and discipline speech.

Multimedia

The multimedia information object is a much more natural thing in a child's inner world than a text. ICT provide tools for making these objects visible on paper and on screen, on the Internet, or for a classroom performance. After students make multimedia objects, by writing texts, collecting information from the Internet and encyclopedias, inserting drawings and photographs made by themselves, adding speech and sound, it becomes natural to share it with other students and the teacher. This hybrid activity can be important for mastering cognitive skills.

Cooperation and sharing

Students sitting together in the same classroom, or communicating over a long-distance network, can do cooperative writing. This is important, first, as practice for joint work and, secondly, for life, but is generally neglected and sometimes even suppressed in the traditional 20th century school.

The ability to copy and email information objects like essays, pictures, and presentations gives students the opportunity to share information easily with, and receive comments from, others outside the classroom. These other audiences could be teachers of different subjects, other students and friends, parents and relatives, local community, a pen pal, or (by posting it on a website) others in the world.

Essay writing and citation

There is a downside when it comes to the influence of ICT on essay writing, as many teachers have discovered. Essay writing on different subjects and topics became more and more popular as a reaction to standardized tests in the 1990s just as the Internet was becoming easier to use. Within a few years, teachers found they were reading more and more identical essays submitted by students. Students had discovered a new, easier way to *write* an essay – find it on the Internet.

This kind of cheating led to a whole system and even a commercial business of counter-measures to provide teachers with tools to detect copying. Are these countermeasures good or bad? There is no question that copying without acknowledgment is bad, but the solution is not to police minute phrases that might be parallel. There is an opportunity here to introduce students to appropriate ways of citing the work of others, which after all is the basis of scholarship. What teachers should look for is independence and originality of thought. The reaction to a discovered case of copying without citation should not be that this is a deadly sin but rather “Good for finding some relevant information. Now tell me what YOU think about this topic and include a correct reference link, please”. A disagreement over the printed word is rewarded and becomes a basis for critical thinking and evaluation.

Transforming oral speech into written form

The classical work of taking dictation can be radically transformed as well by ICT. A teacher may ask students to use their computers to make a sound recording of their oral text, recited as normal speech, and then to transcribe it. Each student may play the recording back while listening through individual headphones as many times as they need to write down every word. The advantages of such dictation are obvious:

- All students work at a pace that suits them best.
- A teacher can trace the progress of each student in detail by simply connecting to the screens of students' computers.
- When teachers see a student finish a task, they can provide more oral text, either as live dictation through a microphone, or as a pre-recorded sound file. In this mode, every student in a classroom can move along at their personal pace, not interfering or competing with other students for the teacher's attention and time.

The next stage would be to give the class an assignment to make an abstract, or synopsis, of the teacher's oral text. The major difference here is that students themselves choose the object of transcription. It can be a TV discussion or a movie segment, a political leader's speech or, in the best case, something recorded by students themselves – a teacher's introduction, a street interview on the environment in the school area, or Grandma's story of her childhood. Digital technology provides a comfortable environment for this activity: to slow down the tempo, segment and mark the texts, see the speaker, and so on.

Group discussion

In the new paradigm, there is much more space for class discussion with many students participating. Such discussions can start with a text or a hypermedia piece presented by teachers or students. The major points expressed by the participants can be recorded and presented on screen. Thus, the evolving discussion is visualized. Moreover, short video-clips of speeches can be made and presented on screen in the form of icons. The teacher can participate as moderator. The discussion is not limited in space and time: it can go on the Internet as live chat or be delayed. Prerecorded and recorded discussions can be sent as an immediate-to-all or delayed message. At the same time, screen-written images help to make discussion more systemic, effective and disciplined.

Teachers' notes

Notes can help teachers say what they intend to say. Teachers can even prepare the whole text of a lecture in written form, though this is usually less effective than a lecture without notes or with a limited use of them because it narrows the channel of communication (including eye contact) and misses out on feedback. At the same time, short notes in the form of key points or key words presented to the audience beforehand can make a lecture easier to follow.

Students' notes

Notes made by students can help them remember information provided in lectures. What can ICT add to this situation?

- Notes can be taken by students on computer unless it is too noisy to type during lectures.
- Notes can be made before the lecture by teachers and distributed to students with extra space to add hand-written notes, or notes in electronic form.

Autonomous automatic recording

Finally, an entire lecture may be recorded on camera.

Working with a recorded lecture, students can produce written text with the needed level of detail and additional links, screens of the presentation placed properly, a still image of teacher's face, or audio-video fragments at the most dramatic points.

With ICT, no teaching and learning activity need be left without audiovisual, graphic, and alphanumeric documentation, including students' work, comments, drawings, and written reports. Instant access to these records allows prospective students to discover that they can master these new conceptual tools and to control and improve their own work performance. The earlier they begin, the better.

Overview

From an educational point of view, writing priorities have changed in all aspects, including calligraphy, spell-checking, and oral input.

- Writing is not textual: it is now multimedia composing.
- The products of writing can be made accessible to a large audience, including, by means of the Internet, anyone in the world who might be interested.
- The process of writing can be collective, involving the author's classmates, students from other schools, editors, and many others.
- Text is not static, but in constant development.
- Computers can help in speed and quality of writing.

While acquiring basic writing, reading, and communication skills, students become accustomed to various ways and means of acquiring, transmitting and using information and knowledge needed to achieve concrete goals. Presenting one's thoughts and collected information to other people can be the final stage, for instance, of a history or science project, or the major part of a journalistic activity, or an initial part of a fund-raising campaign.

Science experiments and observations

Certain fundamental concepts of mathematics and science are given to visual realization (modelling) that ICT are well suited to reproduce. In such cases, students can freely manipulate objects representing these concepts on a computer, experiencing in different ways the dynamic relations between their actions and the visible behaviour of the model.

For example, by connecting to a distant sensor, a computer can display a graph showing the measured distance from the sensor to a moving body (for instance, the body of a student walking back and forth along a wall in the room). In this case, the walking student can see the correlation between their moves and the graph. They can follow a given graph pattern or explain in words what was happening at this or that moment previously recorded and seen on the screen. Or they can tell what one should do to produce some particular pattern on the screen. Then, they can command or advise another student or the teacher how to walk with eyes closed.

For another example, the concept of thermo-conductivity can be demonstrated and explored using a temperature sensor and thermal perception of the human skin.

In the world beyond school, computers automatically collect data and control real three-dimensional material objects and processes. Similar applications can be exciting and educational in school contexts as well. Children's construction kits can include interfaces, input sensors, and output devices such as motors and lights. A computer program can control a model constructed by a child. Even more importantly, students can write the computer program. Furthermore, there is a *programmable brick*, which has input connectors to which sensors can be attached. This piece of integrated hardware and software also has output connectors to which motors, bulbs, and sound signals can be attached.

One can input a program into the brick memory. The program is written on a regular computer and then transmitted to the brick by wire or infrared ray. The student can design a robot, for example, and plan its behaviour in a chosen environment. Then the robot is made out of LEGO blocks and the description of the robot's behaviour, in the form of a computer program, is put into the brick's memory. Modern bricks can interact with each other and also with computers via infrared connection.

Of course, this needs software support to provide interfaces between input-output devices and the computer, as well as between computers and human beings. This software can include algorithms for data processing and visualization. The computerized science lab combines many types of sensors with software to collect, store, analyze, and graphically present data. The sensors can be wired to computers or transmit data wirelessly; data can also be accumulated on a small device called a data logger for later transfer to a computer.

School use of general and professional applications

As the experience of schools tells us, many students are ready to use conventional application packages. With them, students can tackle tasks similar to those facing adults; they can write, draw, edit, make a database, and create a spreadsheet or screen presentation.

We note several special types of software that have clear and productive use in schools (even elementary schools):

- CAD (Computer Aided Design or Drawing).
- GIS (Geographic Information Systems).
- Data analysis packages.
- Project planning software.

Needless to say, professional applications of CAD are too complicated for beginners. Moreover, since they offer a broad spectrum of ready-made tools and instruments, they make it impossible for the student to create a tool for a particular task – an activity that is immensely rich and valuable from an educational point of view. However, there are school versions of these applications that have special features that allow for more simplicity and openness of use.

GIS allow a student to use existing maps and to put more information on them in the form of a word, picture, or hyperlink. The teacher can use the map, without accompanying text, to check students' memorization of geographic names. There are software products, called *timeliners*, that can be used in learning history in much the same way that digital maps help in learning geography.

The computer as an instrument for data collecting, analyzing and presenting in visual form is an important tool to balance technicalities of paperwork upon data (e. g. environmental or social) and understanding their meaning.

Project planning software is another way to visualize, in this case the process of design and implementation of a student or team activity, including a learning activity.

Virtual laboratory

In a computer-run virtual laboratory, we can stage experiments that imitate real ones. A student or teacher can construct shapes, choosing, pointing, moving, indicating numerical parameters by sliding an indicator, or by direct input. They can also change settings easily. The student or teacher then simply pushes the START button and the experiment begins. The parameters' values can be organized in tables, and their data can be presented on graphs. For example, we can see colliding molecules and create a graph of the distribution of their speeds. It is important that students conduct many experiments and get their numerical results quickly, so they can produce their own hypotheses and verify them.

In solving algebraic equations, students can use graphs to verify their calculations and transformations of the formula. In models of atomic and molecular structures that simulate individual particles' interaction, students can track emerging phenomena such as temperature, pressure, states of matter, phase change, absorption, latent heats, osmosis, diffusion, heat flow, crystals, inclusions, and annealing; chemical phenomena such as exchange energy with bonds, chemical equilibrium, heat gain and loss in reactions, explosions, stoichiometry, colour, spectra, florescence, and chemiluminescence, plasma, surface tension, solutions, hydrophilic and hydrophobic molecules, conformation, binding specificity, and self-assembly.

Working with microworlds can help a student to construct knowledge of real world subjects (physics, geometry, economics, environmental studies) as well as of abstract mathematics. The applications in secondary schools have been very successful, especially in geometry and physics. *Geometer's Sketchpad*, for instance, is a computer environment in which students do their own mathematical research, set up experiments, state hypotheses, and prove or refute them. This software has radically changed the perspective of how to treat a school subject that has remained fundamentally unchanged for 2000 years. A similar product for teaching physics is called *Interactive Physics*. There are algebraic manipulation packages of a similar kind. Aimed at learning geometry and physics in middle school, these programs are successfully used for preparatory purposes in primary education as well.

New software allows children to construct any combination of simple machines, which helps in the development of reasoning skills, including spatial, causal and design thinking. Another important class of microworlds is tutoring environments for typing, spelling and foreign languages.

Mathematics teaching today is in a paradoxical situation in that every mathematical problem can be solved by a personal computer. Therefore, as in other subjects, we are forced to rethink how and why we teach the subject. At the same time, ICT are a boost to experimental mathematics, allowing students to draw graphs of functions, and check relations in geometrical configurations in which parameters as a point position can be changed by dragging a mouse.

Organization of the learning process

Guided learning

A software program can incorporate a teaching strategy, which gives pieces of information and tasks to students and interacts with them. The simplest versions of this approach are referred to as drill and practice. In some cases, this works quite well – for example, typing tutors. In other cases, a large investment is required to produce a quality product (as in foreign language teaching). Nor are all products equally effective or appealing to students' imagination. One extreme case is the *electronic textbook*, which is still generally a paper textbook brought to the computer screen.

Tests and examinations

Traditionally, testing (assessment) gives teachers and students feedback and serves as a basis for certification of learning and teaching as well as a gateway to further education or a job. There are obvious reasons why testing procedures should be simple in a technical sense (so as not to require much time from the person who conducts it) and objective (in order not to depend on the test-giver's attitudes, views and conditions). This has led to so-called multiple-choice tests, which can be extended in new ways by ICT.

What are the advantages of such tests? Clearly the procedure is quick and objective; results are stored automatically in the computer and are available via a network. Problems can be chosen from item banks, and even generated randomly as specific cases of a generic parametric problem. The problems themselves can be presented in a multimedia form. Extensions of multiple-choice tests are possible, for example, including blind-maps, grammar exercises in the form of filling in blanks, and written dictations. Computers now recognize oral speech, so they can check the answer to a foreign language exercise, for example.

What more can an automated testing program do? A computer can certainly record all interactions with students. To make it economical, we can limit this recording to all text inputs and some oral (through microphones) and kinaesthetic (with a mouse) inputs. The problem, then, is how to evaluate these moves and how to react to them.

There is a big temptation to automate the process of interaction. This is a model of so-called *programmed learning*, developed long before computers came into existence, and then revitalized in the form of *Computer Aided Instruction* (CAI). In some cases like touch-typing, this works perfectly. It can work also in the process of learning technicalities of certain ICT environments such as text editors, CAD packages, or search engines. Open inquiry technicalities can be learned in the same way by, for instance, varying structural parameters of a system under experimental investigation and registering the changes in its functional behaviour.

Can the inquiry itself be monitored and controlled along similar lines? This is the Philosophers' Stone, sought for years by researchers and prophets of ICT in education. A definitive answer has yet to be found.

Nevertheless, it is clear that automation of much of a teacher's work is possible. We can outline some features of a system that supports interaction between student, teacher, and information environment:

- Scripts of interaction are available, understandable, changeable and able to be constructed by educational researchers, textbook writers, willing teachers, and students (the most controversial and the most exciting opportunity). Records of interaction are also available in an understandable and structured format.
- The system of script writing and use can be integrated into general school information space, and into specialized learning environments used by a student or teacher. The system can monitor and control a student's use of tools, resources, search and observation instruments. Students can thus be restricted in using calculators, spell checkers, equation solvers, historical databases, Internet space, looking inside living organisms and chemical molecules. Strictly enforced, this can make learning in a rich ICT environment similar to the 20th century school.
- The system provides tools for organizing usual and complementary educational activities, including classwork and homework, essay writing and submitting, word-problem solving in mathematics and physics, conducting virtual experiments in the setting provided by a textbook or a teacher, or constructed by a student.

Elements of this complex information system are already in use in schools worldwide. While they are not the final solution for everyone, they may be useful in almost any school. For example, any school can use a computer to record test scores, to place individual assignments on a school website , or to collect students' works via email.

Diaries and portfolios

A prerequisite for success and progress in learning is keeping diaries of the learning process, as well as portfolios of texts, drawings and other artifacts produced in the class or workshop. Teachers and students should make their diaries and portfolios as encompassing and detailed as practicable.

Furthermore, because innovative pedagogical proposals are always restrained by a lack of time, diaries and portfolios save a great amount of time that would be spent gathering information, or on labour-consuming routine operations. In general, as we have seen in other areas, ICT allow teachers and students to achieve their particular educational objectives within the standard school time periods, or even faster.

Information resources for education

We can summarize the categories of components and activities that are integrated in the school information space. These are:

- Information sources
- Information instruments
- Control tools

Individual pictures, texts, sound recordings, maps and other information objects, and their collections constitute *information sources.* They can be properly described and open for use by all students, teachers, and textbook authors. They are numerous – currently millions of items are organized for education.

Information instruments are much less numerous. There are dozens, not hundreds of them. Most are produced in the long process of labour-consuming programming, debugging, testing, and revising; some were developed in the form of code open for further improvement by anyone interested.

Control tools for the learning process implement specific content and didactics in school practice. Many of them are made with the help of certain generic instruments.

MORE COMPLEX EDUCATIONAL EVENTS

In this section, we consider more complex educational events and how ICT can be used as successful learning tools for these.

Approaching the new literacy

Literacy is the ability to vocalize a written text, or, conversely, transcribe an oral text. This skill is overvalued in the same manner as mechanical numeracy – the ability to do calculations mentally or with a pen and paper – because often we measure overall learning success of students by the speed of their oral reading or mental calculations. ICT can do these operations much more quickly and with better quality anyway. At the same time, higher-level competences are becoming more and more important. Priorities are changing. The new literacy – the system of basic linguistic, logico-computational, and communicative skills and competencies, needed to deal with internal and external technology – is a latchkey that opens the doors of subsequent stages of organized teaching and learning. An introduction of ICT in schools gives students an impetus to learn, unlocking many doors of perception and cognition.

We now discuss the roads by which young learners can approach the new literacy and the role of ICT.

Oral language learning

The first, and in many cases the best, teacher is a child's mother and other family members. Different processes are involved in learning the mother tongue, like imitating, asking questions and claiming help. A child also learns a lot just by moving, seeing, listening, smelling, and falling. An adult's presence and interaction is not always critical. Interaction with the physical world, observing and imitating an adult's behaviour, can sometimes be enough. Usually a computer cannot add much to, or substitute for, the development of this process of understanding physical reality. However, it can provide a considerable part of what an adult does in connection with a child's learning activity. Every object on a screen, for example, can pronounce its own name when touched. If an action or an event is occurring on the screen, the participants can explain what they are doing. Today's computers can even ask questions, hear and correct answers.

Student universe

The simplest and most convincing application of ICT in school occurs on the very first day, when students tell a computer (with the teacher's help) their names. Now it happens in written form by typing: in the near future, it will be done aurally, in combination with keyboarding. The computer will memorize the names and even print out corresponding name badges. The badges are given to students (teachers and other adults at school have the same kind of badges), who can now read their teacher's and each other's names. Reading becomes practically important!

In the next step, the computer asks for more information about each student. The computer then prints out a series of pages. If you cut and bind these together, you will have your first address book containing the names, addresses, and telephone numbers of all your schoolmates.

At some point, you start to collect your family memoirs – photographs, stories, letters, and combine these with additional findings in electronic archives. This kind of project may be extended indefinitely.

Written language learning

Learning how to write a language is a combination of learning to:

- produce letters and their combinations – words on paper with brush, or crayon;
- write words in the correct spelling;
- write down oral speech; and
- generate a text based on your understanding of what you are going to say.

Traditionally, children learn these activities sequentially. In fact, the last step usually comes too late and the natural urge of the child to communicate freely is thwarted (mostly by grammar exercises). Eventually this delay reduces students' interest in oral communication as well.

Many-faceted texts. Evidence shows that young children do not think of texts or writing strictly in print-linguistic terms. Given their first notebooks in school and let loose to do their own thing, they draw pictures and invent symbols; some write letters, some make their names, words, even phrases. Almost all declare they can "write and read already".

At the same time, modern children are bombarded visually by many other *written texts* that actually have many facets not reducible to just words. Among these are labels, trade marks, colour codes and graphic instructions on cereal boxes and candies, table games and hi-tech toys; traffic signs, comic strips, TV-station and car logos, mailed advertisements, and many other impressive things of similar kind, which children can perceive, bring with them into a classroom, and reproduce here and there on paper without much hesitation. All these are part of a child's communicative world and cannot be cast aside and ignored as anomalies of no interest to educators.

Small children are especially inventive and productive when given a computer with a multimedia (text/graphic/sonic) editor. Very often they produce dynamic pictorial presentations and even animated stories with a soundtrack of an oral enactment, with photos or drawings of the main characters, and with commentaries on their action and behaviour. More often than not, picture drawing precedes writing, and the accompanying oral commentaries are usually more complete and elaborate than a fragmentary and abruptly written text.

However, once all this is done, a teacher can ask students to transcribe their spoken words using the keyboard, or just picking up needed letters from the alphabet shown on the screen. Even if the first attempts do not produce real outcomes, students can always try again, and in time make small, noticeable improvements.

Nomination. An important part of learning a mother tongue and the world is students' creations of their own language. In a more scientific way, we can say that giving names corresponds to the elementary act of cognition through discovery, as well as gaining control over what has been named. While teaching names of objects, letters should not necessarily be written in calligraphy; they can as well be handled as pre-fabricated units and posted beside, above, or underneath the drawn images. Students can be encouraged to *read* their texts in both a sequential and non-linear *omni-directional manner*.

As soon as students start writing in this way, it ceases to be something non-situational and isolated, taught compulsorily and out of context (the plague of so many elementary grammar classes). It becomes storytelling, re-enacting of the plot of a play, a thought made visible, and a communication of created meaning to others – activities already familiar and pleasant for all children. The itch to read aloud what has been written amid this enthusiastic exchange occurs immediately, providing powerful motivation to continue this joyful and collaborative learning-by-doing.

Virtual reality of words and meanings

Let us reminisce for a moment about how the ABC is typically taught in an ordinary school or kindergarten. The teacher typically demonstrates a set of different large-sized characters, usually paired with pictures of objects designated by the words that start with the same letters. Then, the teacher writes them on the blackboard, or parades three-dimensional plastic or wooden items taken from a bag and places them upon a desktop. The student composes them into a scrabble-like series of two- and three-letter words (*on*, *at*, *or*, *dad*, *mum*, *boy*, *sun*, *sky*), and reads each word aloud. After the demonstration, each student is given assorted cardboard printed or wooden block characters with an assignment to build and, hopefully, write the same words on the paper. As any teacher knows, this is by no means a simple enterprise, if only because of the physical obstacles involved.

The teacher's immediate objective is to keep 25 or 30 students' attention. In practice, only the children sitting close to the teacher's desk perceive the intended message in its entirety. Those in the back rows inevitably miss relevant points, shades, and nuances. They also are more susceptible to distractions and deviations, ambient sights and sounds, the temptation to whisper with one another, or just falling into a daydream. Now and then, a boy or a girl may start to scream desperately and appeals for help because something went wrong. In coping with these encumbrances, teachers strain their voices and exaggerate their gestures, and periodically call by name the students who need to be woken up. And teachers barely have time to look over their shoulders at what students are scribbling in their workbooks, and they have even less chance to consult with or instruct the more confused and perplexed ones.

When it comes to evaluate their progress, teachers can hardly summon each student to the blackboard before the class is over. The rest are inevitably relegated to the daily homework of copying letters – an assignment requiring mechanical repetition and devoid of any cognitive effort or emotional reward.

Now assume you are giving the same lesson in an ICT-networked classroom. Each student's desktop is supplemented with an enveloping VR-helmet, gloves and other paraphernalia, which these pre-literate children have already mastered technically by playing computer games. This time you invite them to put on the gear for an adventure in *The First Grader's Grammar Cyberspace*. In a moment, students see and hear via their private high-resolution multimedia displays the image of a teacher sitting or standing in equally close proximity to each student. There is a *live*, synchronous, or online digital closed-loop translation of what you actually do on the black or white (magnetic) board, or upon your desktop with three dimensional characters as you compose words and read them aloud during the aforementioned letters and words demonstration.

If students do not comprehend or miss something, they can raise their hand and ask the teacher to explain or repeat it once more. All the other students can hear and see the question and the teacher's response. After the introductory stage, the teacher can decide whether or not to continue the explanation individually.

When the demonstration is complete and an assignment is understood, all the students see and hear the teacher offering a set of characters to compose and copy the exemplars. This time you switch from *live* online communication to a prefabricated program. Now the children have the visual, aural and tactile impressions of dealing with genuine material objects, which are in fact only interactive virtual realities. Each student starts to work independently offline and soon discovers that the characters encountered have some intriguing features. When touched, perhaps they spell their own names; when two or three are joined together, they pronounce the word (if rightly composed), or emit a protesting sound (if the combination is wrong). When students place two, three, or more words in a row, they hear them pronouncing the whole sentence. The students do not need to ask a teacher whether a word or sentence is right or wrong, the program makes this clear, and students can move on to the next part of the assignment – practising writing the words they have formed by manipulating tangible characters. The students see a virtual sheet of paper and a pen or pencil-like stylus, which they grasp, and start to write, seeing scribbles appearing instead of expected letters.

Everything written on VR-paper with a VR-stylus is instantly erasable (though it is actually being saved as backups for later evaluation). Thus a student can have any number of tries until a more or less satisfying result is reached. Students can address a teacher orally or have an online conversation to share their doubts, troubles, feelings, and thoughts concerning the task, without disturbing classmates. The teacher, meanwhile, can watch on a multi-screen display what is happening on each student desktop simultaneously. If you want to focus on Mary's or John's desktop, you can enlarge their particular screen. You can whisper in their ear something encouraging, soothing, reproaching, or enlivening, as well as giving them a helpful hint while remaining unheard by anyone else. You can also point with your finger to this or that character or word, even grasp it with your hand to change its position.

If you think it desirable, you can address the whole class and draw everybody's attention to a typical or rare and interesting problem under consideration, and then let them return to their individual work. At the end of a class period, the teacher has the full records of every student's activity, and thus will be able to track and evaluate what they have accomplished.

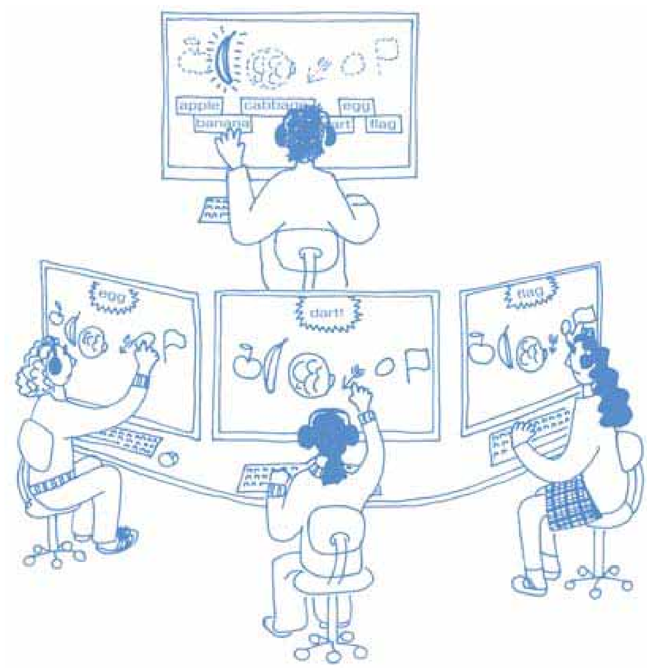
Learning oral speech by the deaf

The visual and tactile representation of speech patterns can be instrumental in teaching deaf-mute children to speak. Students are given a visible or tangible sample pattern of a particular vowel, consonant, syllable or word. They are asked to articulate corresponding sounds while watching on the display what is being actually produced by their vocal apparatus. Next they are requested to compare and evaluate achieved results against a sample. If considerable discrepancies are detected, students are asked to repeat the procedure in order to improve their articulation until it is as close an imitation as possible of the sample.

Foreign language learning

As is well known, the most effective method of learning a foreign language is to live in the country concerned. This is the basis for a natural approach to learning languages even when one cannot be physically there.

A pre-ICT version of this approach was called *immersion* and consisted of a series of role-play games controlled by a qualified teacher. CD-ROM versions provide similar simulated interactive environments with sounds and images. The ability to have written, and, sometime in the future, oral interaction is the principal element of this concept.



The Internet can provide different levels of presence, starting from email communication to virtual museums and videoconferencing to (in the future) online virtual reality where a large number of students will be able to collaborate on global educational projects, where foreign language learning will be combined and supported by on-screen automated translation.

Design and construction in learning

Here are the main stages of a designing-constructing cycle:

- defining needs, goals, requirements and limitations of a design;
- building up teams, defining working plans;
- writing down specifications and drawing first sketches and blueprints;
- making models and prototypes;
- checking and verification of specifications; and
- making the final model.

In a school setting, ICT are a base for a simplified CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) system, in which a technical drawing on a computer screen can eventually be transformed to a real object made of material that is simple to process, but we extend the design concept well beyond this and so we continue with some other representative examples.

Microworlds

Agents to be taught by students

As we have emphasized, the computer is a universal information-processing machine. In particular, a computer with adequate software can simulate and present on screen different real or imagined settings and environments. These are sometimes called *microworlds*. Microworlds are helpful in different applications.

First of all, microworlds are effective and popular tools for learning fundamental aspects of computer programming, especially structural programming. Ideally, they establish a direct connection between a student's semi-formal planning of activity in the microworld and its implementation. The link between the two is called a special *Agent* or sometimes *Executor*.

An Agent is capable of performing a set of commands given by a child – for example, to move across the screen, make turns, and leave a trace of its movements. In a sense, the child is *training* the Agent to perform quite complex tasks.

A specific example is the *Robot-in-Maze* microworld. The maze is a labyrinth usually within the boundaries of a rectangular grid. An Agent called Robot has a limited set of elementary sensors such as the ability to *see* or *feel* a wall in front of it and a repertory of predetermined actions like, for instance, *head North*. A large set of tasks can be given to the student. The first tasks begin simply with, for example, the maze as an empty rectangle. Further tasks can bring a student to sophisticated issues of structural algorithm design. Students can immediately see the execution of their plan on the computer screen.

Another well-known example is the *Turtle* microworld. An Agent called, and looking very much like a, Turtle can move forward any specified distance, turn to any specified angle, draw geometric figures, and change shape and colour. The most important example of a Turtle microworld is the Logo family. In fact, some of the Logo languages combine the idea of microworlds with general applications components (text, graphics and sound editors) and general office applications.

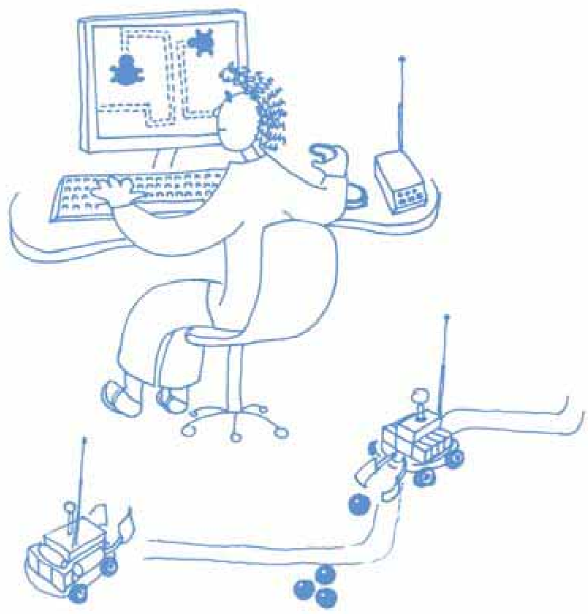
Let us describe the main educational advantages of microworlds, which are evident even in the most basic forms.

Being in command motivates learning activity

A teacher begins by showing students how an Agent can be made to move by typing commands at a keyboard or by clicking pictorial icons and setting sliders, determining kinds, directions and parameters of the Agent's movements. For example, typing FORWARD 100 makes an Agent move in a straight line a distance of 100 Agent *steps* of one millimetre each. Typing RIGHT 90 causes the Agent to pivot in place through 90 degrees. Typing PENDOWN causes the Agent to lower a pen in order to leave a visible trace of its path while PENUP instructs it to raise the pen and leave no trace. Students need to explore a great deal before gaining mastery of these steps but the task is engaging enough to carry most children through this stage of learning.

Since learning to control the Agent is like learning a language, this activity mobilizes the student's expertise and pleasure in speaking. Since it puts the student in charge, it also mobilizes the student's expertise and pleasure in commanding. To make an Agent trace a square, you walk in a square yourself and describe what you are doing in the language of programming. And so working with the Agent mobilizes as well the student's expertise and pleasure in motion. It draws on students' well-established *body-geometry* as a starting point for the development of bridges to formal geometry.

Students' first goal in this microworld is not to learn formal rules but to develop insights into the way objects move in space. These insights are described in the Agent's *language* and thereby become *programs* and *procedures* for the Agent. For example, suppose a child wants to *teach* the Agent to draw a house. First of all, it is necessary to make an Agent draw a square, then a triangle on top of it. A teacher may provide helpful hints on how to write a proper command. A more complicated problem arises when it comes to making an Agent that can move only along straight lines draw a circle. A teacher does not provide answers, but rather introduces students to a method for solving, not only this problem, but a large class of others as well. This method is simply to *play the Agent* – that is, for students to move their body as the Agent would move on the screen in order to draw a desired pattern: when you walk in a circle, you take a little step forward and you turn a little, and you keep doing this until the full circle is completed.



It is worth noting than such geometry is not insignificant. Thus, students are led imperceptibly to an intuitive grasp of physics, calculus and mathematical modelling that is used in many other areas of contemporary science, technology, and humanities alike.

Building learning aids

No less important, by *teaching* the microworld's Agents, students learn to design and construct their own software tools and aids to be used in learning the *hard* items of the standard mathematics curriculum and other subjects. The first project of this kind was successfully implemented in the mid-1970s, and the corresponding methodology has been used ever since. The story is described by Seymour Papert in his book, *Mindstorms* (1980), and goes something like this.

A class of fourth-graders had just started to study fractions and, as often happens, many appeared to be rather slow in grasping the issue. Traditionally, in such cases, the backward ones would have been given additional instruction and tuition. Now, instead, they were equipped with Logo microworlds (already familiar to them) and invited to find and develop some means for explaining and teaching fractions to themselves and others who needed help. They were also provided with seed ideas on how to think of themselves as collaborators in the project and its data collection, processing and reporting.

Each day, before going to the computer, the students spent 5 to 7 minutes writing their plans and drawing their designs for making, comparing and analyzing fractions, presented as graphic objects in their personal designer's notebooks. Then they worked at computers for 40 to 55 minutes individually or in groups, having full freedom to choose which concepts they wanted to teach, what the sequence of their lesson should be, and what instructional games, quizzes and tests to include. The amount of time spent at the computer was limited in order to fit the project into the schedule of the class and of the school.

Over the course of four months, the class had developed several programs on teaching fractions that were diversified conceptually and quite useful in classroom practice. Judging by pre- and post- tests, students' ability to work with fractions, as well as with the microworld proper, had increased considerably. They had not only discovered that *fractions are everywhere* and can be easily explained in their *becoming*, but also acquired fluent ability to do other problems by manipulating fractions. The very integrating of mathematical concepts, drawing, constructing and writing made these disciplines mutually supportive.

The possibilities of microworlds in education are limitless. Supplemented with specialized tools, they enable students to create environments for the entire range of learning activities, from producing animated cartoons on central themes of literature and history to conducting scientific exploration and constructing advanced industrial machinery. Above all, they enhance students' general competence and confidence in active learning.

Artificial life experiments

Students can make working models of living organisms using blocks from construction sets that have motors, gears, wheels and sensors. After connecting their artificial creatures to a computer, they can write computer programs to control the behaviour of their animals. As mentioned above, the programmable brick – a special microprocessor included in the construction set – allows the model to function and move independently of the desktop or notebook on which the controlling program was written.

Such systems allow the images on the computer screen to be realized in three-dimensional, tangible form. Through these activities, primary school children can explore and discuss some of the central themes of Artificial Life research. This is not merely a scientific and technological topic, but a set of extremely powerful ideas that include emergence, bottom-up design, and system-oriented thinking. Giving children access to the forefront of modern science is, in general, an effective learning strategy. When children sense that they are involved in a new and dynamic adult enterprise, they eagerly invest themselves in the process.

This project on artificial life can proceed in three-dimensional physical modelling and computer-screen versions. The students start with simple, easily understood rules or units, and study how complexity emerges from interactions among elements. Moving from simple to complex, from concrete to abstract, is just how children learn in everyday playful surroundings. Furthermore, they learn best when they are building and inventing things that they believe in and care about (which is why living things are useful at this stage).

For example, a youngster might program an animal like the screen turtle to move toward a light, but change direction if it bumps into any obstacles. Children can explore how artificial organisms behave in different *habitats*, and how they interact with other creatures. In addition to changing an animal's program, students can change its habitat. For example, a student might try adding more lights, or making the lights flash, and then wonder whether the animal will behave differently in the new environment. Which light will it seek out? Why? Children can also change the hardware or software of the animal and see the difference in its behavioural pattern. In many cases, such experiments pose a question of basic similarities, as well as distinctions, between organic and mechanical organization.

By the same token, students are not restricted to artificial animals: they can also build and program various machines, from vehicles to robots. This system-oriented approach influences the way children think about systems of all kinds: physical, political, and economic. But the most important thing is how this process influences the way students think about themselves as human beings who create systems, not the other way round.

Basic music composition

Let us consider an example of a design and construction activity in music. Traditionally, music classes in elementary school concentrate on performing and not on composing. On the other hand, children aged 7 and up, with no knowledge of formal musical notation, can learn how to create simple melodies in one or two years by operating a computer with an audio synthesizing and editing microworld used as a medium and tool for structuring and shaping the *material* of sound. A microworld of this kind provides a choice of musical notes in the range of seven octaves and commands that set a desired pitch, volume, and duration to consecutive strings of sounds (and pauses). Further, the sound can be given the coloration of any particular instrument and be made to simulate the sound of an ensemble of several instrumental voices.

The student's musical work with the computer is divided into three stages with well-defined features: a musical scrawl, musical sketch, and musical project.

The first stage is indiscriminate exploration: each student produces various sounds for the sheer pleasure of it and without paying much attention to their quality. After a while, they limit themselves to playing with low or high sounds, with an emphasis on the duration of the sound. Then students can start to build small melodies that lack formal structure since they are chosen at random. At this point, they are usually more concerned with the duration of the melody than with the actual sounds. At the end of the first stage, students select the sounds they like most, name them, and create melodies based on these sounds. In this way, they learn to program the sounds and melodies in a natural way, because they have a need to do so. They start to exercise auditory perception and to pay more attention to pitch than to duration.

In the second stage, students usually discover short sounds by chance and they start to glimpse the effects of sounds' parameters (pitch and duration). Thus begins a period of discriminate exploration of the musical microworld as they reflect on each sound's qualities. The sounds are not chosen at random anymore. Duration is the most prominent sound quality at this stage. The development of sound appreciation is apparent in the expanding selection of meaningful words that students use to name, not only sounds, but their created melodies as well. Once students begin to play with short sounds, they then tend to regulate the quantities of sound. For example, they discriminate between long and short sounds, while associating them with numbers; they combine closed notes, or make repetitions of two or three sounds, which results in sketches of a more formal organization where, for example, the first and last sounds are the same.

The third stage brings mastery of this particular music microworld. Here, students match the commands of sound qualities with desired pitch and duration. They become capable of anticipating a sound in their minds and generating it with the computer to produce more elaborate combinations leading to more complex musical patterns.

From this point on, students are aware of what they can do with this programmable instrument by setting a goal and carrying it out. There is an evident tendency toward perfecting the musical sentences and making them more expressive. The students are trying successfully to compose music they can dance to or sing, and to depict aurally some simple scenic actions and characters. The structure of the computer programs they create shows the development of musical intelligence and the ability of even quite young students to appropriate important concepts in their own way (Gargarian 1990; Bonta 1990).

Scientific research

Students at all grade levels and in every domain of science should have the opportunity to use and develop the ability to think and act in the ways associated with empirical inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. The general model of scientific research and the qualities required of a researcher have many things in common with the models and qualities described above as important for most social roles, far beyond the purely intellectual one.

Stages and types of research activity in school education are:

- formulating goals and research hypotheses;
- finding basic information, known experiments and results from the Internet and other sources;

- contacting experts, group discussions, carried on during face-to-face meetings and via telecommunication;
- overall planning of a project, correcting plans in progress;
- designing and constructing the investigation setting;
- running experiments in hands-on, automatic, and distant mode;
- observing results, measuring, and collecting data;
- analyzing and presenting data using mathematical models and means of visualization;
- discovering patterns, finding connections, making explanations and conclusions, verifying hypotheses and producing new ones; and
- conducting group discussions of results in classrooms and producing reports, presenting and publishing results via the Internet, screen, and text formats.

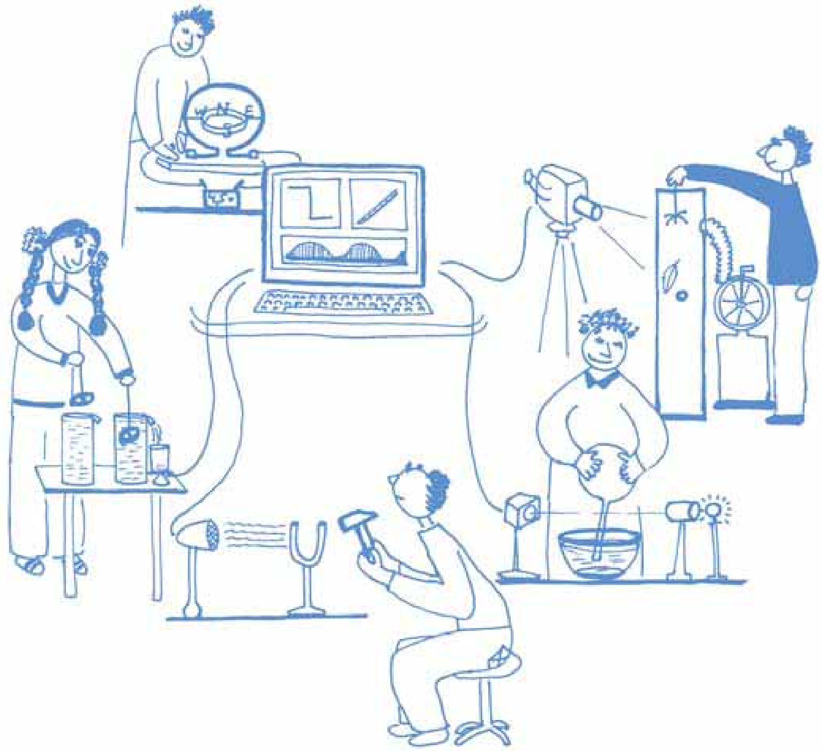
Based on the previous discussion, we can compile a list of hardware and software instruments to support these activities. Of course, special types of research may require special tools. These tools include:

- general office applications with text and graphics editing;
- lab equipment including computer-based testing and measuring devices; and
- tools for numerical and algebraic computations, spreadsheets, graphing, and statistical analysis.

Research in social sciences and humanities

Research in the social sciences and humanities has much in common with research in the natural sciences, as well as with artistic projects. Moreover, interesting educational results can be achieved in combination with different activities by, for instance, interviewing people for their opinion on a specific scientific fact or on the environmental consequences of an industrial process, or making pictures or drawings of local streets.

In this field, a research scenario might call for students to collect personally relevant information on their neighbourhoods, starting from their own files. It is conceivable that students start with the history of their family and expand it to a nation, and then to all humankind.



Organizing and presenting information, the creative and artistic recording of human impressions and transcribing interviews are some core elements of artistic and social science projects. In many cases, a project does not necessarily include every stage. For example, a design project need not actually be built, even in a physical model form, for the preparatory work to be rich and motivating for students. Sometimes the final result is a model on the computer screen; sometimes the important step is a discussion that leads to a new element in the project's future shape.

Providing support to the school and community

It is well known that among middle and high school students you can find high-class experts in ICT. The challenge is to cultivate the ever-expanding circle of such gurus and to use them productively for themselves, the school, and the local community.

A much more serious challenge is to prepare the school, the parent body, and the community for students' new roles. For example, in many cases it is worthwhile to exploit ICT belonging to the school after hours, when all formal lessons and informal school activities are over. A question then is whether we can trust students to keep order in the computer lab and support local citizens coming to use the computers.

All these decisions and changes should therefore include a strong organizational, social, and psychological component. For example, a special course for students on how to help *computer-reluctant* teachers and to empower and encourage them to use computers in the classroom can be an important component in transforming school practice.

Main advantages of ICT

In creating this new teaching and learning environment, ICT offer numerous advantages and provide opportunities for:

- facilitating learning for children who have different learning styles and abilities, including slow learners, the socially disadvantaged, the mentally and physically handicapped, the talented, and those living in remote rural areas;
- making learning more effective, involving more senses in a multimedia context and more connections in a hypermedia context; and
- providing a broader international context for approaching problems as well as being more sensitive response to local needs.

In summary, we believe that ICT enable teachers and students to construct rich multisensory, interactive environments with almost unlimited teaching and learning potential.

From the learning-teaching perspective, ICT should support:

- access to online resources that use a powerful combination of video, text and graphics, prepared by specialists in a centralized facility and delivered to individuals or groups by technology;
- provision for the teacher to teach a whole class or part of a class, assisted by technology as appropriate;
- provision for all students to learn the same way or to choose ways that suit their individual learning styles, assisted by technology as appropriate;

- access to individualized curriculum pathways, managed by technology;
- access to individualized diagnostic testing and assessment of progress, managed by technology;
- allowing students to move independently between learning areas as necessary, managed by technology;
- large screen video display (projector);
- individualized access to network resources including wireless networking; and
- continuity of access to network resources away from school.

The truly crucial question of how to evaluate learning in this new ICT-created-and-supported environment is too detailed to be described here even at the most superficial level. Interested readers can find a comprehensive survey of related issues in Heineke and Blasi (2001).

5

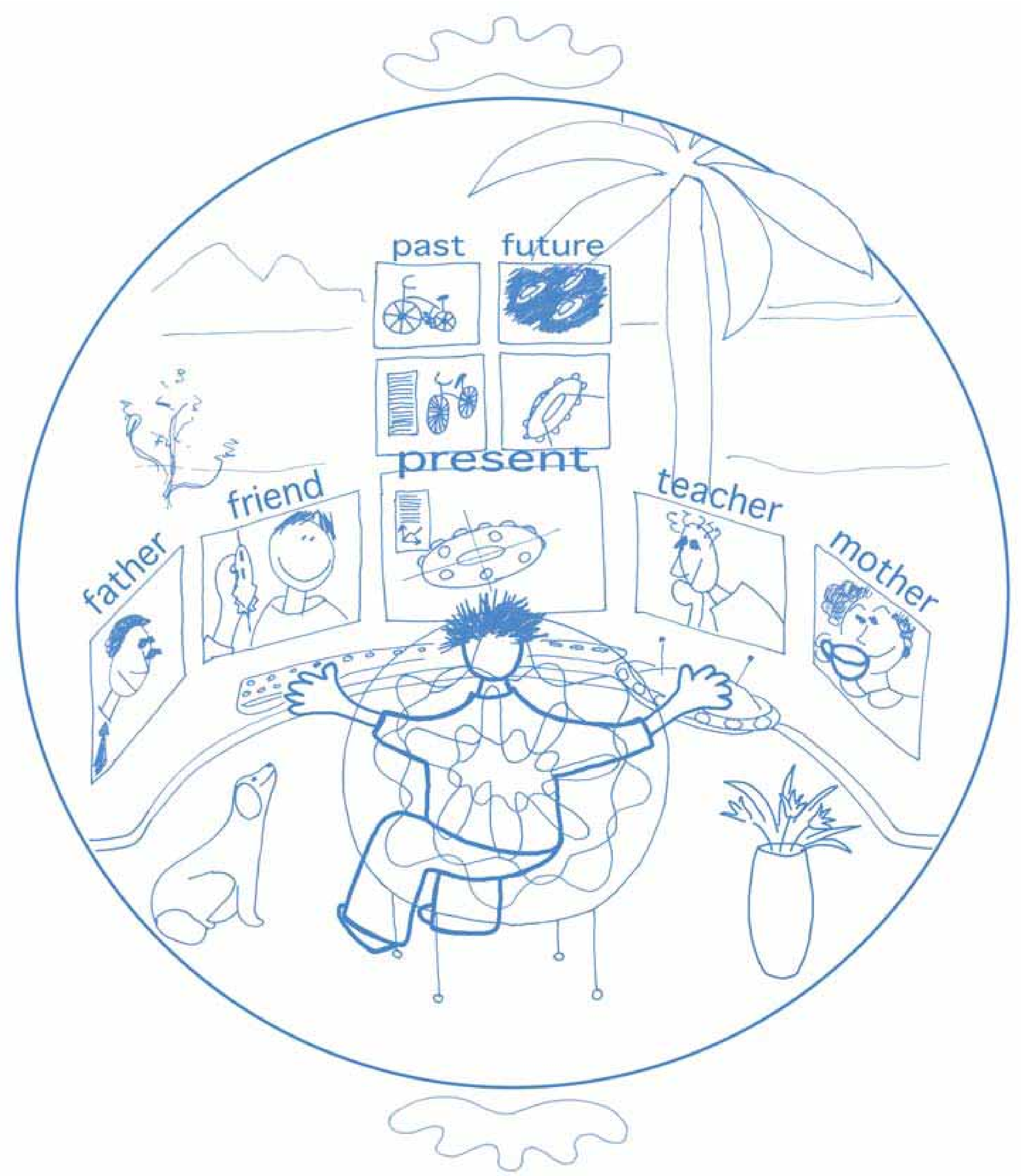
STRUCTURING THE SCHOOL CONTINUUM

PLACE OF ICT IN SCHOOL LEARNING ACTIVITIES

In the *new school* described in the last chapter, computers are no longer placed in isolated rooms with locked doors to be opened only by an ICT teacher. Instead, subject-area teachers, administrators, and librarians all use them and other ICT equipment whenever these are needed in their working places. Ideally, the same is true for students. In and out of lessons, they use computers when needed: in classrooms, auditoria and labs, in the library, in rooms available for project activities and homework preparation. Sometimes students use smart keyboards for taking notes at a lecture, or palm computers when going out of school to conduct environmental projects. At other times, students use digital cameras. Computerized equipment is also used to monitor students' health. The entire school is immersed in the *information space*. Computers in teachers' and students' homes (school laptops and notebooks, shared by teachers, is one option) play an important role in the learning environment.

Limitations and opportunities

When administrators and decision-makers think about using computers in schools, the most obvious obstacle is cost of hardware. Actually, this is not the case! There are other real limitations existing in almost all schools today, discussed below in this chapter in the section *Barriers for ICT in schools*. Our goal first is to consider the physical structure of schools in space and time and to discover both the limitations and the opportunities inherent in this structure.



The nub of the problem is that few school buildings would be able to contain enough desktop computers for every student in every lesson. The problem then becomes how, in an existing school, we create conditions in which everybody in the school can use ICT when they need to.

Most schools in both developed and developing countries are over fifty years old. Some have existed for over a century. Classroom spaces were designed to reflect the traditional instructional style with little, if any, thought given to investigation-based, group learning, let alone fibre-optic cabling. While some funding is available for renovation and rebuilding, the short-term reality for most schools is that existing spaces must be adapted to accommodate new learning technologies. New or (re-)designed schools, and old schools, are thinking how to create more flexible space for ICT use. Traditional technologies like pen, paper, and blackboard will continue along with the newer ICT, which means leaving enough space on each student's desk for writing as well for a monitor.

Ownership issues

To whom does all this hardware belong? In planning school space, we need to address this problem as well. For equipment, we have alternatives:

1. Personal responsibility, which leads to better maintenance, less damage, longer life, but less access for the wider school population.
2. Collective responsibility, with the opposite consequences.

In the traditional approach, the computer lab is closed when the ICT teacher is not present. Do we have any alternative? Can we have a teacher present for part of the time, and for the rest of the time have a teacher's assistant or a non-technical person to keep order, or even a student on duty? Should the custodian hand out notebooks to students who sign them out, with the proviso (and an alarm circuit) that they only be used in school? In any case, special security rules and regulations should be issued and good habits formed in schools. When planning the information space, we need to plan well.

Typical arrangements of ICT in classrooms

Here is a list of options for space arrangements of people and ICT in a typical classroom:

- The whole class listening to one person presenting from the front, possibly through telecommunication (Lecture).

Equipment needed is a computer with a screen visible by the speaker, together with a projector and screen. To demonstrate an object, conduct an experiment, or show videotapes additional equipment is needed. To speak in a big auditorium a microphone is also needed. A projector is useful in other situations discussed below.

- Whole class discussion of a theme with questions asked and answered (Discussion).

  Equipment needed is the same as above, with a computer screen available for someone to take notes. To record the discussion, you need audio-video recording devices.

- Individual work by all students in a classroom (Essay writing, Testing, Studying new software).

  Equipment: individual computers (possibly, notebooks) at all student places; a school network is also needed in most cases.

- Pairing or grouping at one table (Experiment).

  Equipment: one computer for a group, with additional equipment (sensors and interfaces, microscopes, and digital cameras).

- Dividing the class into halves, with one each group doing individual work in an audio-visual environment (Language Lab).

  Equipment: one computer per student with headphones, microphones, a network, preferably a language lab environment with some sound reduction.

- Moving between zones (Technology or Arts Workshop, Project Activity)

  Equipment: a few computers, scanners, printers, plotters, devices controlled by computer.

- Individual work outside classroom (Homework, Distant Tutoring).

  Equipment: A computer with Internet connection.

- Group work inside and outside the classroom – in a local park, a supermarket, swimming pool, family house (Project).

  Equipment: palm computers and recording devices.

There are yet further options. Let us consider some of the possibilities available. We start with the most typical situation today of desktop computers in a classroom, and then consider more advanced options of portable computers and other places in school.

Desktop computers and computer furniture

Today, the desktop computer is the major ICT device in schools as well as generally in the world outside schools. School principals, ICT-coordinators, and teachers have to confront the problem of space design for desktops.

The space design of the computer-equipped classroom reflects three different models:

1. A teacher's computer with a projector (used by students also).
2. Several computers for group work in parallel with other activities (in primary school, language and science labs).
3. A dedicated computer lab that provides ICT access to all students, or, if this is not possible, to half a class at a time.

Information flow in the classroom

Let us start with the visual channel of information. In the traditional school, this channel was important for both the student and teacher. To the student, it allows:

- seeing teachers and images as they talk; and
- seeing a text in a textbook or workbook.

To the teacher, it allows:

- seeing the process of writing or conducting experiments by students, receiving non-verbal reaction from students; and
- preventing students from seeing what other students are doing in exams.

As we discuss above, ICT can influence this visual channel in a major way. In classroom planning, we should carefully consider the following questions:

- Are there obstacles standing between a student and the teacher and the projector screen?
- Can we reduce ambient light to improve visibility of the computer and projector screens?
- Can we use computers for the teacher to send visual messages to students and to monitor student activities?

Of course, in existing schools, the aural channel of information transfer is considered even more important (remember the teacher's remark "You are not listening John/Maria/Martel").

What solutions are available?

Imagine a typical classroom of about 8 meters by 5 meters with one computer and a projector. To make conditions comfortable for seeing the screen image for all students, the screen needs to be 1.5–2.0 meters wide and about 1–1.5 meters above the floor.

The class network can be used to monitor student activities. Teachers can see on their screen all student screens, or the individual screen of any student.

The teacher should control lighting and especially sunlight entering the room. Special window coverings and electrical lights section to be turned off during large screen presentation should be planned. During projection, the room light should be bright enough (40-50 foot candles) for student interaction, not just dim for note taking, but no more than 3-5 foot candles of ambient room light should fall on the screen. This can be done by creating lighting zones in the classroom, setting apart the student seating area, the front presentation area, and the lectern/projector area.

Computer noise should be as low as possible; others should not hear the sound emanating from any student's computer.

Desks and their arrangements

Desk space is designed and limited to a single student with a (paper) notebook and sometimes a book. There is frequently not enough space left for a desktop computer. The CPU can be placed under the table. This creates some inconveniences: for example, most of the computers' diskette and CD-ROM slots, power button, and interface sockets are located on the front panel of the CPU box, but some sockets are on the reverse side and it is hard (but amusing for students, of course) to manipulate all of these underneath the desk. With the hardware-software escalation noted in Chapter 2, we have monitors with larger CRT screens (namely 17”), but their placement in classes has become more difficult than it was for 14-15” ones. Of course, LCDs are thinner and so more convenient in school settings. Their prices are coming down, and perhaps they already are the better choice.

The keyboard should always be at hand, and it needs plenty of space. Nevertheless, the normal position for a keyboard is below the normal height of a desk. An optional flat drawer unrolling from the bottom side of the desk is therefore preferable.

It is important that communication and power lines do not interfere with physical movements in a classroom or auditorium. For example, a portable projector is a good idea, but you should be very careful where you place cables so that students do not stumble over them during lessons. In many cases, wiring becomes a major problem in ICT installation, taking up a good proportion of the costs. Although not absolutely necessary, raised flooring allows for easier reconfiguration of classrooms.

Traditional classroom layouts work especially well when the computer is integrated into the desk because wires and cables can be completely hidden, allowing narrower aisles while facilitating access to network interface and electric outlets.

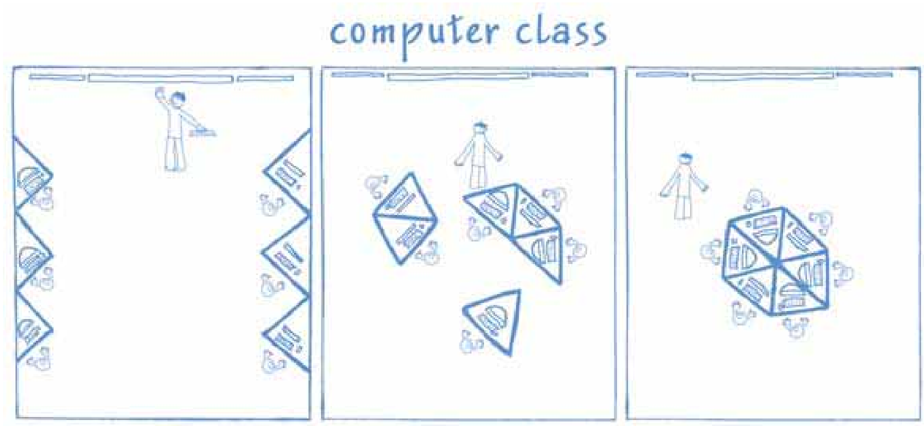
An interesting new design idea is to make the school desk triangular, which also helps solve the problem of changing the student’s object of vision from the computer to the teacher and back.

Desks in classrooms can be movable, to be reconfigured for different functions in the room. For example, individual triangular desks can be reorganized into hexagonal tables for group work.

Different layouts are used in classrooms oriented to the extensive use of computers:

- Rows
- “L” configurations

- "U" configurations
- Clusters of 4 desks
- Clusters of 6 desks



Computer chairs

Computer chairs that allow students to assume proper ergonomic postures should be selected. Students who spend many hours at a computer both at home and in the classroom run the same risks of cumulative trauma disorders as office workers, yet they have less control of the environments in which they work. Standard classroom chairs that do not meet these needs put students at risk.

Chairs need to possess the following attributes:

- height adjustability (preferably pneumatic). Ease of adjustment insures that students can achieve proper posture.
- back tilt. The facility to tilt a chair back is a useful feature that enables students to adjust eye-to-monitor distance within the space allowed.
- durability and tip resistance. Look for solid welds and heavy-duty mechanisms. A good test of tip resistance is to raise the chair to its highest position and hang a heavy jacket or book bag on the chair back.
- a broad seat and back design with adequate comfort with minimal sculpting. This design meets the needs of a large percentage of users. Although lumbar support and forward-tilt functions may be necessary in an office, it is more important to make users comfortable. Students usually present a greater range of body sizes than the office worker population.

Beyond desktops

There are alternatives to the familiar desktop computer, and here we consider some of these.

Portable computers (notebooks)

Some schools can afford to give students their own computer – one that is lightweight, small, and inexpensive, shock-, drop-, and water-proof and connected to a network in and outside school. Notebooks today:

- have full-functional operating systems;
- are more expensive than desktops;
- weigh about 3 kilograms, and can be damaged when dropped on a concrete floor; and
- are portable – you can use them in any lesson you need, not in the place where a computer is constantly mounted.

Schools should take the option of notebooks seriously. It is true that prices are nearly twice as high as for desktops. However, this is less serious a limitation in view of the costs of other hardware, networking, software, maintenance, and training.

Apart from cost, there are other discouraging factors for using notebooks that include:

- physical damage (by dropping or pouring liquid);
- thievery (of an easy movable and valuable object); and
- lack of personal responsibility (in the case of school ownership).

One solution could be to store computers on a cart or trolley that can be locked up at the end of the day. A notebook computer, printer, and LCD-projector on a trolley in a radio-network environment constitute a valuable combination in the case of limited resources. Of course, the level of interactivity and hands-on experience in this model is limited if you have only one trolley for a whole school.

Individual computers with limited power

Affordable alternatives to notebooks, discussed in *Major trends in ICT* in Chapter 2, are the following:

- smart keyboard;
- palm computers; and
- sub-notebooks.

A smart keyboard delivers the major text applications (text-editing spreadsheets, and email) and has a corresponding input device. They are functional in a school network or in association with a *real* computer. To reduce costs, internal memory, interfaces, and batteries are minimal. The result is still not cheap, because the product is not yet mass-produced. However, should a government decide to issue these to all schools in a country, prices are sure to fall substantially, to perhaps 10-20 per cent of a notebook.

Palm computers and sub-notebooks can provide interesting alternatives as well. Even today, these devices can provide certain critical applications like Internet connectivity for a small fraction of the cost of desktops.

At the same time, these and other *thin client* computers can all be made robust and unbreakable, they can be individualized, and they are less attractive to thieves.

There are two further affordable choices. The first was based on that early ICT classic – the calculator. Extended to being almost a computer, this tool is useful for mathematics, physics and ICT classes. A second emerging option is an ultra-portable projector about the size and weight of a camera that can be connected to a computer instead of its monitor. The price of these today is more than for a computer, but that is expected to come down.

Finally, in the near future we might expect wearable computers in schools. The computer here consists of a VR-helmet – output device and gloves – and a handheld input device. The computer is connected to the Internet, to other school computers, and to peripherals via a wireless network, or sometimes cables. Students will have these computers with them continually and use them in all lessons.

Distributed learning network in school

The school can be organized in such a way that the school's central information network is available in every room, which means an output device (monitor) and an input device (keyboard and mouse) with corresponding interfaces. There are also the options of stylus, finger (at touch screens), and joystick for Internet surfing.

In schools of the near future, we can imagine individual keyboards and helmets for all students, and many screens, mostly projection and flat-panel. The large projection screens in an auditorium will be used primarily with teacher or student presentations. Touch screens will be used for special occasions of choosing from a menu (including real school canteen menus).

The price for wired networking an entire school can be very high though costs can be reduced if some of the installation is done during school construction. Do not forget about power network and grounding. Wireless networks, infrared or radiofrequency in classrooms and in buildings, are less expensive than cable networks, and their reliability and information transfer rates are improving rapidly.

The presence of networked computers for out-of-class access in different places such as corridors, for instance, can be exploited productively in some schools, but may become tempting to vandals in other cases.

ICT everywhere in schools

As ICT become more pervasive, computer-based equipment will be integrated into every aspect of a school's operation.

Library and media centre

In most schools (at least of the European model), the library has for centuries been a place of less restricted, more individual, and more open work than a classroom. It has been the heart of our modern information civilization. In the last few decades, school libraries have begun to accommodate, not only books, magazines, newspapers, art creations, but also transparent media for projection, audio-cassettes, 16mm movies, then videos and CDs, and now, DVDs.

The natural expansion of the library's function is to provide ICT technology as well, including resources like high-speed Internet connection, satellite TV, collection of CDs and DVDs, plus a limited amount of paper for printing, and removable computer storage such as disks and flash cards.

However, there are problems connected with this most promising location. The first is space and number of available computer workstations. When librarians post up sign-up sheets, the usual finding is that:

- everyone shows up,
- if not, the reservation is cancelled and someone else comes instead,
- the timetable is fully booked weeks ahead, even with limits imposed of, say, an hour a day (three for teachers) with a maximum of three hours a week (6 for teachers).

This means that the technology is in demand. But what is happening with it? It is a good opportunity to ask users this question and provide priority access to those whose needs are greatest. Once you have data about usage, the next step is to apply for more ICT.

Computers for teachers

Let us come closer and look into a real classroom. Teachers are going to use multimedia projectors in lectures, which means they will also need:

- a computer as the source of video and audio signals;
- an extension cord to plug into the power line (assuming there is a socket in the class);
- a screen to project on (projecting on a wall can be poor quality; on a whiteboard, it can be even worse);
- a table to place a projector on;
- curtains on windows because sunlight interferes with projected images; and
- cables (most projectors today need sophisticated cables to provide an image both for the projector and for the monitor teachers are looking at so that they can stand or sit facing the class, though in the near future there will be more wireless connections).

Finally, imagine that a teacher has finished her lecture just as the bell rings. Students are running. Somebody trips on the cables... Fortunately, there are alternatives to such nightmares: ceiling-mounted projectors, wall-mounted electrical screens, wide-angle lenses, and light-dimmers. (Warning: if you turn the projector off before the fan inside stops, it can burn out.)

The arrival of even one computer in a classroom can have a profound effect on the way students learn and the way the classroom operates. Teachers integrating computers into the curriculum soon modify their class space to reflect the inevitable changes in student learning behaviour. Creating space in the classroom for computers and peripherals such as a printer, network connection, and large monitor initiates a rethinking process by the teacher, leading to re-evaluating how classroom activities and learning experiences work best.

Primary school

The model of a kindergarten or primary school classroom where children are involved in different, sometimes even unrelated, activities looks like gaining over the traditional school where all children sit in rows and are usually engaged on the same task. Computers (besides the computer-projector model) in quantities of one to ten can considerably enrich this multi-centre, multiple activities model. One of the possibilities here is to have a computer as a part, sometimes the centre of activity of a group of 3–7 students. Activities of different groups can be different or the same.

Foreign language lab

Another useful ICT installation in schools is the language lab. This has many of the features of the language lab that was popular before the computer era. The minimal model uses an audio source – a loudspeaker powered by a compact disk or magnetic tape player. A common problem is a different level of loudness for students who sit in different places in the classroom or who have other hearing problems. Individual headphones can solve this. The next step is to distribute the audio signal over an electronic network of students' headphones. We have now an opportunity for individualizing instruction but it brings an immediate problem of communication with the teacher.

The more sophisticated language lab gives individual audio and, then, video feeds to all students. Microphones are provided for students' feedback and recording, which can be monitored and checked by the teacher and individual learners (and, in an ICT environment by a computer speech-recognition system). To avoid disturbing others, students are placed into partly transparent, partly sound-absorbing carrels. These exist today, though they resemble our futuristic picture of students wearing VR-helmets. Indeed, language-lab helmets are already available.

In the language context, we recall that the computer can:

- integrate all types of information and communication;
- immerse students into virtual reality of another country and language;
- recognize human speech in some languages;
- supervize the learning process to a certain extent; and
- visualize and *audio-ize* for teachers the stage of progress of all students.

Language arts

The computerized classroom provides effective support for written and oral communication, and so it is desirable to have enough ICT for any language arts lesson. The typical problem here is the small number of computers per classroom. In fact, this is perhaps the major reason to look for portable computers with limited power (discussed above in this chapter).

Science lab

Specific applications of ICT in science learning are based on data collection and analyses done with sensors. A science lab can have, for example, six computers as part of a workshop for teamwork or individual data loading.

Palm computers (and, to some extent, data loggers) are more effective and provide greater flexibility with sensor applications in science investigations than do desktop computers. At the same time, at least one desktop computer is needed to run virtual experiments in virtual labs using other instruments.

Workshops of design, arts and crafts

Workshops and practice fit well with ICT. Therefore, in the arts and crafts class, workstations dedicated to specific activities can be designated. Students move from one activity to another at a different place in the classroom. Real-life projects are more natural and successful in these environments.

Music class

We discuss in previous chapters how ICT can help in music education. Let us repeat that the environment in music classes should support performance, recording, analysis and critical evaluation of the maximal variety of live voices, traditional and classical musical instruments and computer-designed music. The most universal peripheral here is a MIDI keyboard.

As in language labs, ICT must provide opportunities for individual work. Not all problems of ambient noise and interference with students' work can be solved with headphones.

Teachers' room

ICT in the teachers' room is an efficient way to support the information culture in schools and to invite more teachers to participate.

A teacher's workstation – a computerized system with a word processor, graphics editor, scanner, camera, modem, and printer – allows teachers to save time and to increase productivity in such activities as:

- preparing and updating daily lesson plans, making hard copy visualizations and handouts for classes, as well as individualized educational plans for slower students and students with disabilities or with special problems;
- presenting visual/aural content materials, tasks, and questions to the audience;
- maintaining grade books;
- compiling a data bank of exam questions;
- online inspection and correction of students' work on their computers; and
- keeping records, chronicles, and archives of all the above-mentioned events and proceedings with fast retrieval and easy access to any entry.

Dedicated computer lab

In most of the school computer labs of the 20th century, students learned how to use computers but were rarely asked to apply their skills outside the lab. We believe the situation in the 21st century will be different. The computer lab today is the space where:

- specific technologies are learned by students and teachers when needed in short modules;
- lessons in different subjects (testing, essay writing) can be given; and
- after-school projects and individual work with the use of whole variety of ICT are happening.

The advantages of using a lab are ease of planning and technical support. There is more responsibility, and so it is easier to achieve safety and maintenance requirements. In the computer-saturated school, there could still be reasons to keep the computer lab as the place of qualified support and the source of all types of ICT hardware and software for school needs.

Because there are rarely enough computers for all students in a class, a possible solution is for some students to work on computers while others work on non-computer activities related to the same project. This can require the collaborative work of two teachers. (See the *Two-teacher model* below.)

Virtual classrooms and open learning

In the future, more learning will occur outside school buildings. Creating virtual classrooms where students can log in and find course notes, resources, worksheets and teaching tips, enables students who are home-bound, out of school for sport or cultural activities, or on fieldtrips, to maintain contact with their coursework and teachers. This applies to non-traditional students as well as to older students, retirees, or those undergoing professional continuing education.

Many schools are pursuing this method of creating a virtual school, that is, an online community of students, staff and parents with Internet access at home or work. This networked community tears down classroom walls and enables teachers to utilize home computers to extend the school's capabilities. Online communications are enabled and students can work on projects from school or home. Students who are ill, or absent for other reasons, can maintain contact. This kind of networking also helps individualized learning. Virtual classrooms and virtual schools can be shared by different *real world* schools and supported from the outside. Today, you can find many virtual classrooms on the Internet. This concept of the virtual classroom leads us to the modern ICT interpretation of the idea and the term *open learning*.

School information space

There are other different places where ICT may be found in schools like the school principal's office and the custodian's room. We wish to emphasize that all these should be integrated: learning spaces of students, teaching spaces of teachers, and administrative space of school administration, are parts of a common school information space technically accessible to all participants of the educational process. The principal, looking for the administrative record of a student can move to her recent project work and send a message to her teacher.

Orphanages and other special schools

Orphanages, correctional schools, reformatories, and other types of educational institutions where children have limited access to the world beyond their walls are places where ICT can make a radical difference. ICT can provide a channel for free information flow, distance education, contact with peers from other, similar organizations and families, as well as with psychological help and support.

The same is true in a different sense for schools that might be special in different ways. For example, in schools for gifted children, contact with similar schools from other countries, as well as direct communication with the corresponding creative community provided by ICT, are important.

Implementing new goals of education in low-tech regions

In view of the swift progress in microelectronic technologies, it is remarkable that the basic computer environment has remained as stable as it has. The first Macintosh computer that introduced the multi-windows desktop and major applications about a quarter of a century ago had only 128K of memory and did not have a hard disk. Yet the screen metaphor of the desktop in which the user works now is the same as it was then.

What this means for schools is this: those with less powerful ICT or even none at all, can nevertheless develop new learning models that conform to the potential of ICT. In other words, schools can begin to teach a mastery of the new literacy before the full panoply of equipment arrives. The technology used can be quite simple – a camera with black and white film, a radio, a newspaper, an encyclopedia, pen and paper. For some countries it sounds historical, but for others this provides a practical way to a knowledge society through education. Sometimes, a chance to assemble or fix a transparent low-tech device can give more understanding of high-tech than applying an opaque high-tech device. One can even imagine a toy train, with its railway points and signal-posts, as a learning environment for hands-on learning of Boolean algebra and structural programming.

Equally useful would be asking first graders to collect the names, addresses and phone numbers of their classmates and create a sort of *Who's Who* to be copied and distributed to the class. The very experience of making oneself known to other people and getting the same message from them in return is a palpable metaphor for the World Wide Web. The impact of such an experience can be more meaningful than the short-time Internet connections of the uninitiated.

Another important issue worth noting in this context is that the fundamental science at the base of ICT was developed before the advent of computers. Its source was observation of information processing by humans. It has stayed essentially the same for at least 70 years and is now even more important. Therefore, this science is something that, independently of microelectronics, can and should be taught to prepare students for understanding information civilization and ICT irrespective of the level of computerization of their schools. Of course, this does not mean that ICT are not useful in schools, or are not useful for teaching computer science even.

We believe that real success can be achieved in education not only by affluent societies where a computer in every family is the norm, but also by those developing countries that respect and cherish their human potential and creative heritage. In the next chapter, we describe some approaches to teaching and learning computer science (informatics) that can be implemented with very different levels of technological support.

PLACE OF ICT IN CURRICULA

At every level of schooling, ICT are not a closed or self-contained subject to be taught and learned independently from other subjects. Rather, ICT are a subject that, by its very nature, should be treated as interdisciplinary, integrative, and cross-curricular. The project-oriented method of teaching and learning, introduced through the use of ICT, will help both teachers and students become more conscious of their own capacities and responsibilities.

Of course, some elements of ICT can be taught in a dedicated time. However, it is important to support learning by an immediate application of technology that is meaningful and relevant to students. In any case, introductory lessons in any specific aspect of ICT (constituting a module of learning) should not continue for more than a few hours (and, better, for just a lesson). However, even here, the task must make concrete sense for students right from the start.

The major module of intensive technical training is touch-typing, a skill for communicating between human beings and computers and which, naturally, needs fluency. Microworld-like environments allow children from the age of 3 upwards to learn and use ICT for usual applications (graphics and text editing), and for modelling the real world and multimedia implementation of virtual realities. The introduction to a microworld or any specific feature or application of it should not take more than few minutes before the first *action* of a child to achieve something.

Access to ICT

In planning their class schedules, different teachers should think about the information resources of the school and their access to them during their lessons. If the physical space of a school is seriously limited, the task of planning for ICT access is even more difficult.

Long-distance learning has its own special time structuring. Different options for synchronous and asynchronous learning are possible and supported by ICT.

Time when ICT are available

A common indicator of ICT development in schools is number of students per computer. However, another quantitative factor is even more relevant: the number of hours a week that computers are available for use. Of course, it is harder to optimize this parameter, than it is to put in a request for more hardware.

Nevertheless, we believe that any school can set as a goal to make ICT available to students and teachers 12 hours a day, 7 days a week. The implementation of this goal can also generate income for schools because this schedule would also allow the general public to come to school for ICT services when they are not being used by students and teachers.

PARTICIPANTS IN THE PROCESS OF CHANGE

In this section, we look at the process of change with regard to ICT from the early mainframe computers to the current individual workstations, and we examine the role of key participants in this change within school communities.

Early predictions

Back in the 1960s, it was proposed that the new rather bulky and expensive digital computing machines that occupied a whole room could perform, among other things, automated tutorial functions. The pedagogical community was startled and bewildered. Some excitedly predicted the decline, and even elimination, of the teaching profession by the onrushing Computer Based Programmable Education. Others were mesmerized by the sci-fi dreams of a huge artificial Super-Brain channelling a unified curriculum to terminals in every classroom. Still others envisioned direct electronic access to all data, information and expertise storage for anyone willing to get a private (self-) education. The established position of the teacher as a bearer of knowledge, mentor and preceptor was seriously questioned. A major project of the producer of giant computers, Control Data Corporation, was ambitiously called PLATO.

Barriers for ICT in schools

In the early years of the 21st century, personal computers, accompanied by peripheral devices, have been virtually declared obligatory for educational institutions in all economically developed (and many developing) countries. There is substantial evidence supporting the idea that the new information and communication technologies (that is, ICT) are already capable of bringing about spectacular positive change to the whole fabric of general education. The prospects for the foreseeable future are truly overwhelming.

At the same time, we should be extremely thoughtful and cautious in contemplating the exciting future. Schools and teachers face unprecedented pressure to get technology, get networked, and go online. At times, during this headlong rush to introduce new technologies, it is possible to forget what it is all for. To be sure, computers can raise student achievement in mathematics, languages, and other disciplines, but they have to be placed in the right hands and used in the right ways. The aim in the remaining part of this chapter is to paint a picture of what teachers and student roles might look like in an ICT-infused school.

The changes briefly sketched above have already occurred but only in a limited circle of pilot, magnet, experimental, and other especially selected exemplar schools. A popular view implies three main obstacles to the spread of these promising innovations:

1 the cost of ICT hardware, software and maintenance, although falling over the years, is still unaffordable to a majority of schools in many countries;

2 the (often unconscious) resistance of many educators to the intrusion of still obscure technological newcomers that threaten to alter drastically long-established and time-honoured practices and customs; and

3 the lack of teachers who are trained to exploit ICT proficiently.

Technology-rich curricula materials are therefore rarely implemented because students and teachers often have insufficient access to technology, and schools are unable to rearrange the curriculum to exploit the advantages of these materials.

Further reasons for slow progress to innovate are just as important as the obstacles just noted. These include:

- Low reliability. ICT hardware and software were initially designed and developed for non-educational purposes, and are thus poorly fitted physically for ordinary classrooms, especially in elementary schools. Available computers often do not work, which is aggravated by lack of maintenance support and inadequate software. This low and unreliable access to technology means that students do not get enough experience to master complex software tools, and teachers cannot assign tasks that assume ready computer availability.
- The rigid structure of the *classical* system of schooling (see *School as a social institution* in Chapter 3). Rooted in the educational paradigm of the 18th and 19th centuries, this kind of school could gain little from modern ICT unless it is radically transformed in its constitutive principles.

The last point is perhaps the most crucial. In fact, most educators are not ICT-resistant, but the system in which they work under undoubtedly is. Technology (information or any other) brings little benefit unless it is skillfully and thoughtfully conducted and managed by teachers to enhance students' capacity to learn. Never before has the mission of schoolteachers been so heavily loaded as today.

Taking account of all the problems of transforming schools, we consider now the changes in the roles of the key participants in the educational process.

Students

With the need for more independence, creativity, as well as the ability to engage in teamwork, the role of the individual in society is becoming more and more important. Today, it is natural to wish to design a school that is oriented towards developing these attributes, which can be done for all age groups, based on ICT.

Modelling the world beyond school

One of the natural features of learning by doing that is facilitated by ICT is the similarity between the educational activity of a student and the activity of an adult at work. Student-journalists and student-researchers, for example, can produce significant results, even if they are only eight years old. Similarly, middle school students (12 to 16 years old) can provide technical service, expertise and consulting in regard to ICT. Students can participate in choosing equipment and software, its installation, repair, and even the technical training of teachers. They can also participate in lessons as technical support experts. Teamwork and working with younger children provide many possibilities.

By using the computer as an environment, a tool, and an agent, to design, create, and explore model worlds, students get unprecedented opportunities to see, analyze, and reflect on every step of their own learning processes, thus acquiring mastery, not only of the subject matter, but also in the art of learning.

Collaboration and teamwork

The social climate in many academic settings is often fraught with competition and isolation. Where collaborative and cooperative learning opportunities are increased, achievement scores are known to rise, and students respect the contribution that each person offers, regardless of differences in ability, background, or handicap. Instead of fearing differences in one another, they look for ways to tap the unique and individual areas of strength for the benefit of all.

A collaborative approach paves the way for a radical re-shaping of the content and procedures of the general school curriculum. Practical implementation of these kinds of transformation become possible when supported by advanced ICT to create powerful learning environments.

Teachers

Teachers of ICT

ICT can and should be an integral part of most learning activities, and as available as pen and paper. Meanwhile, in many schools today, and probably for a time into the future, the only teachers with everyday access to ICT are teachers of a special subject called Information Technology, or Computer Science, or Informatics. These teachers can carry the important mission of being agents of change, not only in ICT, but also in the whole system of education since ICT are the instruments that can launch an important and general paradigm shift.

As was indicated above in the section, *Place of ICT in curricula*, we can imagine a combination of ICT with other (material) technologies. In this case, one teacher might naturally blend several technologies as a productive starting point for the integration of ICT into all learning activities. In fact, it is often the case that teachers of material technology, who start simply with an idea of applying technologies for human needs, make better, more creative use of ICT than teachers who start with the conception of the value of ICT (or programming) by themselves, but cannot necessarily see their possible uses in solving human problems.

Master teachers

The master teacher is one capable not only of instructing but also of constructing a role model for students. Master teachers look for ways to construct learning experiences that are both interesting and appealing to students, something that might provoke and inspire them to attempt to construct something similar by themselves in the hope of reaching the mastery and artistry of teachers, and, perhaps challenging them in the future.

Teacher support

In the everyday use of technology, teachers need to be able to get fast and reliable technical advice and have the help of suppliers of technology, technology resource centres, and other teachers and students within the school.

Special kinds of educational support are even more important because they affect the new model of teaching. Such support can be provided both personally and online by a special member of the school staff, by a technology resource centre or university, or by members of the community of teachers using ICT.

Different kinds of administrative support are also needed, including an opportunity to participate in ICT events, to buy supplies and use telecommunications, to upgrade technology, and to publicize and promote teachers.

The presence of enthusiastic teachers, together with the installation of hardware and software, add little if support is not present. The introduction of ICT requires establishing and coordinating an entire infrastructure of support. This infrastructure should be multifunctional and include:

- technical support,
- organizational support,
- being educational and multilayered,
- being present in the school,
- being present in teachers' and students' homes,
- being present in local resource centres and teacher clubs,
- universities,
- technology providers,
- national clearing houses, R&D institutions,
- international communities and organizations.

Teacher support can involve face-to-face and distance interaction, and all types of workshops and publications (including user groups and bulletin boards). The merging of government, foundations, non-governmental organizations, and informal grassroot efforts is the most effective strategy.

Technology coordinator and pedagogical advisor

Many secondary and even elementary schools today have a computer (or ICT) teacher, and an increasing number of elementary schools also have a person who supervizes the computer labs (classrooms equipped with computers). In some cases, this person is a certified teacher. In other cases, the lab supervisor is considered a technical support person and may not be a certified teacher. The Technology Coordinator position was proposed in the late 1980s to designate an educator at the school or district level who works to facilitate, assist, and consult on the effective use of a wide range of computer-based and digital-related ICT in teaching and learning. This person may also have duties as a non-ICT classroom teacher or as an ICT teacher proper.

Another person who can be useful in introducing ICT is a pedagogical advisor (e.g. another teacher), who can help with relevant lessons and in their preparation. In this case, the elementary school teacher learns hands-on how to use technology in new ways of teaching. With adequate financial support, this can be done on a regular basis, formalizing the two-teacher model.

The role of advisor with this responsibility can be held by a technology teacher, a subject-area teacher, a member of a technology resource centre or in-service support institution, university professors and students, or even by a student from the same school. Out of these experiences, general categories of participants can be discerned who support and promote ICT usage in school:

- The ICT-using, ICT-literate educator. Library media specialists fall into this category.
- The ICT teacher. This person may teach computer applications, hypermedia literacy, programming languages, and computer science to both students and teachers, taking part in group work with other teachers and in interdisciplinary projects.
- The technology coordinator.
- The pedagogical adviser.
- Certain students.

Two-teacher model and teamwork

An effective way to present technology lessons involves two teachers with different, complementary expertise: a regular teacher and the technology teacher. The two can work together in lessons where ICT are applied for a specific task. In such cases, both teachers become involved in mutual learning, which leads eventually toward an integrated curriculum. As a result, technology teachers help their colleagues bring high-tech tools deep into the fabric of *traditional* instruction (and provide, if necessary, on-the-spot troubleshooting). This, in turn, enriches the technology teacher's own understanding of related topics from different subjects. Elementary school teachers learn ICT along with their students; technology teachers learn important needs and applications for ICT and disseminate them further. This two-teacher relationship is really a microcosm of a learning school.

To make this model work on a wider scale, we need administrators who will permit the co-operative work of two (sometimes, even more) teachers in one classroom (generally with half of the class only) and, of course, with equal financial remuneration. The legalization of this option by authorities will make a big direct material impact and, even more importantly, a psychological shift in the consciousness of teachers and administrators (and the families of teachers and the community).

Possible team partners for the elementary school teacher include teachers from other schools, parents, and volunteers. Of course, there are teachers who work alone, and many successful examples of that kind exist.

Other stakeholders

Besides students, teachers, parents, and the community, there are other participants who play a critical role in the process of change: school administrators and higher education authorities.

School administrators

School administrators are more accepting of ICT in a school, when they use it themselves. Therefore, provision should be made for this. Moreover, information space of school management should be integrated with learning and teaching space. Information space should be accessible via telecommunication channels to students, teachers, administrators, parents and other members of the local community. Of course, there should be limitations on access and authority to change information.

Educational authorities

A school's ability to use ICT is based on the ability of its teachers. At the same time, most decisions are made at a higher level of administration, where money is allocated for school needs. Naturally, some decisions regarding the educational paradigm and general strategy are made at the national level.

The government that makes decisions on national or regional standards can support the introduction of ICT-based goals, targets, and standards in schools. Obviously, this cannot be done simultaneously and with the same depth in all schools (see *Zone of proximal development* below). However, the enthusiasm engendered among educators on receiving technology can be used to develop a vocal constituency for the broad introduction of technologies into the educational practice of these schools. Even in schools that are generally not enthusiastic and engaged in technology, a teacher or a student will be given a chance to become a catalyst for future change.

Educational authorities can combine approaches in formulating content and methods for an ICT agenda within a school system, region, or country. These include:

- Explicit formulation of new priorities and new models of learning in standards and objectives of education – a key factor in the process of introducing ICT. Some of these standards may refer directly to ICT while others may not.
- Inclusion of elements of the application of ICT into curriculum guidelines of different subjects.
- Introduction of courses on technology or ICT in which priority is given to new goals for education and applications of ICT in integrative projects with other subjects.

Educational authorities should provide quality software and educational support, which can be done on the basis of licensing for a region. Authorities can decide to concentrate support on a special project that is interesting to several schools, or on a system of projects.

Parents and the community

There is an obvious need for ICT in family and home education where they can provide the major media, content, and human communication options. Distance education (in and out of school) in elementary and secondary schools also needs human (teacher, parent) participation in close contact with the learner. Parents should recognize the need to build new levels of relationship with their children and should consider the computer as a vehicle for building, rather than an obstacle to, family cohesion, and, finally, the family's learning culture. In some cases, parents constitute an important force in support of ICT in school.

Clubs and community centres provide access to ICT for many young learners, especially in communities where an individual computer is a luxury. For socially disadvantaged children, who often are not involved in formal education, such clubs provide an opportunity to be integrated into society.

Resource centres and qualified personnel who work at several schools in a locality can be effective at certain stages of introducing ICT into education.

Schools part of wider learning communities

One of the main functions of schools is to provide an environment in which students can design and construct any number of physical and virtual worlds with which to interact and accumulate direct learning experience. This learning by doing links the mind and body and facilitates knowing, remembering, and the practical implementation of what is learned.

Connecting with the outside world

Any learning environment of the kind described immediately above must have varied connections to the world outside the classroom, including manipulative and construction kits that model the universe, society, and technology, observations of nature, and productive activities. These connections should extend to consulting with eminent scientists, engineers and artists, and inviting local political figures and entrepreneurs for roundtable talks, and to project planning with the students.

Zone of proximal development

The richly connected school of the future can be described by using the Vygotskian metaphor of *zone of proximal development*. The zone of a school consists of areas in which the school (represented by its teachers and the whole learning environment) is ready and eager to move forward – in our case, in using ICT. The zone also reflects the position of the school in the community of other schools. For example, a school has an IT-teacher who is discussing with a science teacher an opportunity to implement an environmental project connected with information that appeared in a local TV-broadcast and newspapers. They are optimistic about the reality of their plan because they have seen a similar project at a recent technology in education conference. They approach the principal who is supportive and mentions that another school in the same town is very strong in technology in science. The two teachers therefore come to the second school; they are inspired by the science teacher there and find out that they will need something called *sensors* and *palm computers*. They come to their state university for a summer course and negotiate leasing these sensors, partly from the university, partly from the second school… This entire story represents a move of the school in its zone of proximal development.

Determining the zone of proximal development is based on:

- achieved results;
- technical skills of teachers and students;
- project activity of the chosen schools;
- individual planning of all aspects of new technology introduction, including hardware configuration, curriculum and timetable changes, administrative applications; and
- development of communities of teachers and schools, including Internet user groups, clubs, seminars, publications, connecting with international communities, sources of information, scientists and other people who can provide first-hand information for school activities.

For the purpose of money allocation (region or municipal), decision-makers can use the model of the zone of proximal development and collect proposals from schools and impose qualification requirements. The simplest requirement for receiving ICT equipment is for schools to have an ICT-based curriculum, specified teachers, and a two- to three-year plan for the use of ICT for a given fraction of all lessons. They may also plan other aspects such as sources of teacher support. In this case, competition among schools usually turns out to be minimal. This procedure should be supported by follow-up plans.

No one model for all

The perspective outlined in this handbook – seeking changes in society, ICT, and education – is not the only model of development. We acknowledge that there are countries and communities with different sets of values, which give priority, for example, to tradition, discipline, uniformity, collectivism, and state control.

Nevertheless, ICT and education can support this set of priorities as well as others. It can even support and reinforce the teaching-learning process in traditional systems with new tools of visualization, presentation, and automatic test control of results. At the same time, we observe that the most productive use of ICT enables and requires a transformation of the traditional model of education.

Drawbacks of ICT

Besides the undoubted advantages of ICT, it is rather important to draw attention to certain drawbacks of ICT.

Computer games

Part of the attractiveness of computer games is based on having a feeling of control over a quasi-reality, being in the thick of the action, and the ability to raise self-esteem by achieving goals, power and success in the through-the-screen world (a desire to win, or win back), and a curiosity about the unknown. If something goes wrong, the person in control tries to fix it. In the worst case, this fixing is chaotic and essentially irrational. In that aspect, computer games are similar to other types of hazard games or stock market games. Another dimension of their attractiveness can be associated with purely psycho-physiological mechanisms and a reflexive physiological adrenalin reaction to moving images.

Some of this excitement takes place when one is getting accustomed to new software applications, or while creating programs (especially by hackers). Some programmers may perceive the world and events they are working with in an entirely irrational manner. The process of winning a game, or debugging the program they create, may depend on the positions of planets or some ritual actions of men! Loss of orientation and the destructive behaviour of a hacker are other negative consequences of ICT use. However, it would be unjust to blame computer-driven information culture for all negative phenomena of contemporary life connected with ICT. The cure for these problems lies not inside ICT themselves, but in building a solid moral orientation for youth in how they use this new information sphere. In other words, we must give them a good upbringing.

Unlimited access to information

The advent of ICT has encouraged, in some quarters, a more passive consumption of information, primarily in visual form, which is analogous to the passivity of TV-viewing. We have the mass production of low-quality texts, which are consumed in huge amounts. The Internet gives uncontrolled opportunities to publish and more uncontrolled access to such publications. Moreover, it gives children access to pornography and drugs, as well as to child abusers posing as e-pals.

How is society to deal with a young generation that spends so much time watching TV or reading tabloids, and now surfs sleazy websites? What has been done up to now? The answers some offer are not too encouraging. Restrictions have been proposed and introduced, both in families and educational institutions. For example, there are schools where computers do not have floppy-disk drives to prevent students from downloading games (and viruses). There are special Internet services, which, if you subscribe to them, will restrict students' access to dangerous and controversial sites on the Web.

However, these restrictions are really efficient only if students are brought up in an atmosphere of free cultural choice and are encouraged to say *no*, that is to refuse something of their own accord. Therefore, the answer we expect is the same as in other cases like drugs, for instance: a combination of technological restrictive monitoring, and controlling solutions with morals, tradition, and culture.

Losing traditional skills

We sometimes hear that students using computers are less proficient in arithmetic than their friends from non-computerized classrooms, or students of the pre-computer epoch (their parents). These statements have some truth to them. But it is also true that if we offer an arithmetic problem to an average adult while depriving them of a pocket calculator, they would manage this task worse than ordinary people did fifty years ago. We believe a change of priorities in life should influence a change of priorities in education. If one agrees with this, it means not only adding new priorities but also losing certain old ones.

It is perfectly clear that doing arithmetic mentally or on paper was more important in the 19th century than today. Everyone who now does calculations professionally uses a calculator. Many people use calculators while shopping in supermarkets or conducting business negotiations, and especially for calculating tax returns. If you do not use a calculator in a restaurant or supermarket, you will need the ability to add many small numbers and to estimate, not the ability to add or multiply two long numbers. Adroitness in quick and reliable quantitative approximation is more important than the capacity to make pencil-and-paper calculations slowly.

The educational consequence of this shift is for less traditional arithmetic in the classroom. If we compare the problem-solving ability of the traditionally taught student with a student who has been taught new literacy and is equipped with a calculator or computer, we would not expect the latter to achieve worse results. Another argument for traditional school arithmetic is that it develops certain more general skills such as logical thinking, or that it constitutes the basis for learning higher mathematics, which is important in its own right. However, this argument is not obvious and, perhaps, not even true. It is quite possible to organize learning mathematics in a more effective way, both for the general development of the student, and for the priorities of the new information environment.

We meet the same situation with handwriting, spell-checking, and memorizing facts. The old priorities are losing their importance. Is the new literacy good enough for the emerging world? We believe that the answer is unquestionably *yes*.

Health problems

Health problems are discussed in Chapter 2 under *Health problems associated with computers*. In the first stages of introducing computers into education, some parents and educational communities were concerned with the effects of monitor radiation and eyestrain. At present, most countries do not have special regulations that limit access to ICT for students for health reasons. We think that more research and investigation should be done at an international level and the results widely distributed, possibly through channels like UNESCO.

In addition to the health factors discussed in Chapter 2, we should consider such factors as comfortable lighting and furniture. At the same time, we can explore regulating students' activity, for example, by introducing physical exercises during computer lessons.

6

MATHEMATICAL FUNDAMENTALS OF INFORMATION SCIENCE

MAJOR COMPONENTS OF INFORMATICS IN EDUCATION

In this chapter we use the term *informatics* as unifying computer or information science and technology, as the term is used in some European countries.

We see informatics in education as having three interrelated aspects:

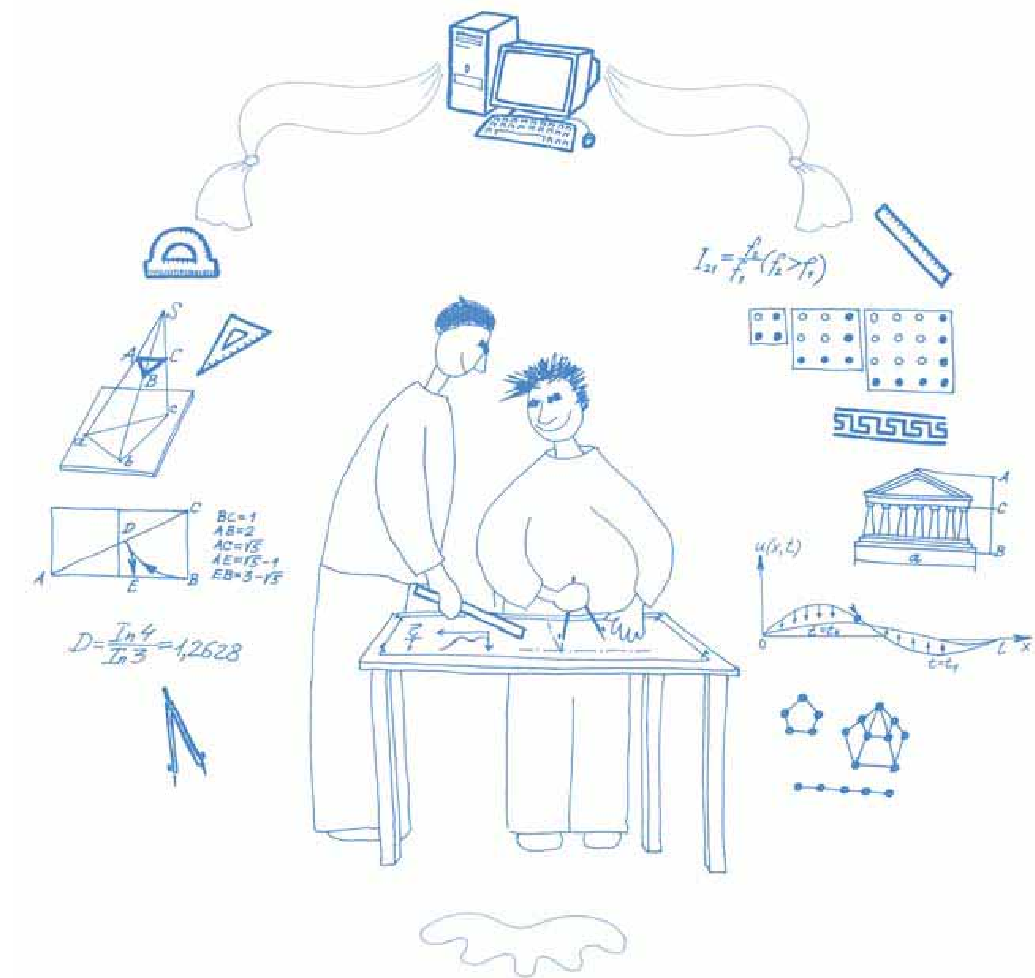
1 Fundamental, theoretical informatics.

2 ICT and issues in science and other fields of human culture related to ICT (including economics, ethics, ecology, aesthetics, arts, philosophy, and history).

3 Use of ICT in educational activities.

It is widely accepted that mastering ICT, like other subjects of study, is accomplished most effectively in a framework of activities that are relevant to students. Most of the important areas of the application of ICT and theoretical informatics are covered by this approach, and this is the major theme of the discussion in this chapter.

It is convenient to discuss the second component of informatics in education above first. Therefore, in the next section, *World of information*, we outline



the content of ICT applications to be learned in school as part of what throughout this handbook we refer to as the *new literacy* (and we separate it from the context of the subjects where it is taught). Next, in the section titled *Fundamentals of Informatics*, we explain briefly the first component of informatics in education above by detailing the content of informatics in its mathematical form. The discussion of the third component – the use of ICT in educational activities – is, of course, the major content of the whole book.

WORLD OF INFORMATION

The main content in learning informatics in school focuses around ICT. But there are many reasons to cover information processing in technological, biological and social systems, and their implications for our life as well. Therefore, in this section we discuss in a unified way, first, information objects; next, information processing by humans equipped with ICT; and, third, the information process in a broader context.

Information objects

Let us start with recollecting certain facts about information, which are touched on in the first section of Chapter 2. An empirical classification of information objects starts with a distinction between objects we perceive as a whole homogeneous entity and information objects where we perceive an inner structure as its fixed and permanent part.

The classification below into simple and complex information objects does not pretend any philosophical depth or completeness. It simply helps to classify information-processing activities that are elaborated in the following sections.

Simple Information Objects	Complex Information Objects
• number • text • image • sound • moving picture • three-dimensional object (considered as message)	• database • spreadsheet table • hyperobject (or hypermedia object) or combinations of the above

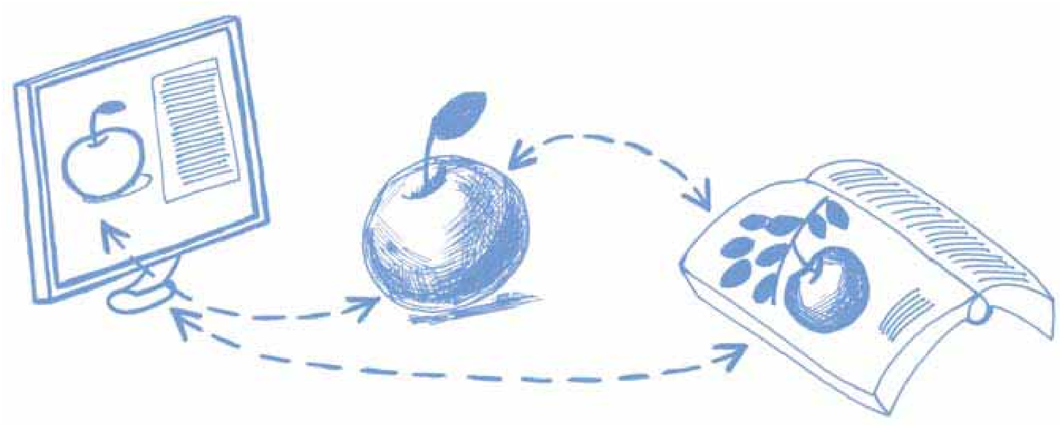
Integration of all kinds of information

At the beginning of the computer era, computers were mostly used for computation. Later, computers began to be used for text processing, and this continues to be the most popular application today. Texts, as well as sounds, images, and video can be presented in a unified way as sequences of zeros and ones. The important fact is that digitized images, sounds, texts, and numerical data can be processed with the same devices (computers), stored in the same magnetic, optical or other type of storage, and transmitted via the same telephone lines, optical fibres, or satellite radio channels. One and the same computer today can play the role of answering machine, fax, phone, TV receiver, or movie screen.

Hyperstructures of information

In many cases (for example, in oral speech, movies, and printed media), pieces of information are organized in a linear, sequential way, one phrase, episode, page, or encyclopedia entry, after another. At the same time, human memory and thought are organized in an essentially non-consecutive (non-linear) *connectionist* manner.

In some cases, people overcome this contradiction by placing information objects on a diagram with arrows and connections, or make references or links, or provide footnotes for the interested reader. Words marked, for example, in italics in an encyclopedia article link to related articles They also structure text by introducing chapters and paragraphs.



When we access information on a computer, we can go from a reference in one article to another article (even to a different book) in a split-second. Moreover, the reference can go to a different computer – even to a different continent – perhaps not in a split-second at present, but quite quickly.

This kind of so-called hypertext structure, which is technically easy to deal with, covers pre-computer reference structures and corresponds naturally to human thinking. All possibly relevant connections can be made, enabling anyone to make associations, establish logical relations, and create multilayered networks of meaning in accordance with individual thinking patterns.

When we extend this idea to other types of information – from text to images, video, and sound, for example – we get hypermedia objects, or hyperobjects, which connect together, not only various sources, but also different modes of information. The reference may thus take a reader from a graphic map to a sound file.

Information activities

Let us return to the list of information objects and see what people do with them. All learners, even the quite young, deal with information objects in several different ways. They:

- create: write, draw, pronounce, and build;
- search and find, retrieve, discriminate and choose: Internet surfing is the most popular and most controversial example; listening, reading, browsing in libraries, and watching TV are activities of the same type;
- fix or record an information object as a representation of reality: photograph with an ordinary or digital camera, record an interview or ask people to fill a form, measure temperature;
- process and modify: edit text, video, images;
- analyze: divide into parts or elements, compare, look for patterns;
- organize, present in a different form: compile or edit a hyperstructure from pieces of information, create a spreadsheet, a slideshow, visualize numerical data;
- communicate to others (e.g., make a screen presentation, post to an Internet site).

Learners also simulate, design, and control the following objects and processes:

- technological: material, energy, information processing; and
- human, including management of their own projects and planning activities, as well as information activities: divide and join tasks and labour; choose objects to record, photograph, draw; decide what to measure and how; construct plans for interviews.

The above list can be expanded, as is done below where we describe scenarios and projects of learning.

We stress that, in the school of the future, general ability in information processing will be among the important results of education, from memorizing facts to critical thinking, social management, and scientific research, using ICT as instruments.

There are important topics concerning social aspects of information activities of people such as copyright and privacy, the knowledge economy, and ICT in professions. We believe that all these topics should be covered in the proper time and place but best of all be based on personal experience, observations, and investigations of students themselves.

Understanding information processes

In the early days of computer use in schools, it was considered important to learn how computers work. Today, we realize that it is not necessary to have a background understanding of electronics and programming to use computers productively. At the same time, there are several reasons to include this kind of understanding in primary and secondary education.

The first reason is straightforward and pragmatic. You can apply ICT more effectively if you know how it works. For example, it is useful to know that you need electricity to power a computer, that computers talk to printers via this cable or that infrared channel, and so forth. One of the issues in this topic concerns quantitative estimates in ICT. Occasionally, it is helpful to know how many bytes a particular text being digitized will occupy, how many minutes of a compressed video will fit into available computer memory, how long it takes to transfer a picture via the Internet, and so on.

The second reason is that ICT provide a rich set of examples and applications for the mathematics of informatics. As might be expected, understanding the essence and inner logic of technology plays an important role in the effective use and coordination of its different applications.

Finally, there is a general and philosophical reason for including an understanding of information processes in the curriculum of primary and secondary schools. It helps students to develop an ability to conceptualize more broadly in various disciplines, and in life itself.

Forerunners and founders of informatics

A formal treatment of human reasoning began at least in Ancient Greece. Since the end of the 19th century, mathematicians and philosophers started the development of the mathematics of formal reasoning. In the 1930s, this development reached a peak in mathematics with Goedel's results on the completeness and incompleteness of formal reasoning, and with the work of Goedel, Post and Turing on completeness (universality) and incompleteness (noncomputability) of formal acting. In the 1940s, advances in electrical and later electronic engineering, as well as the demands of the military, led to the construction of the first automated calculators.

Universal computers were developed around 1950. Mathematical science was ready for this. As one example, the well-known Russian mathematician, Andrei Markov, published a complete symbolic code for a high-level language compiler accompanied by a complete formal proof of its correctness in 1947, in a several hundred-page volume. Mathematicians were also involved in the design and construction of the first computers (John von Neumann) and in their first applications (Alan Turing). In the late 1940s, Wiener coined the term *cybernetics*.

FUNDAMENTALS OF INFORMATICS

Here we use the term *mathematics of informatics* or *mathematical informatics* (just like mathematical physics or mathematical biology) to describe the area of mathematics used in informatics, and the area of applied mathematics working with models of objects and processes from this or that field. This complex of pure and applied mathematics produces definitions, constructions, and theorems applicable to information processing by humans, living organisms, social and technical systems.

The notions and concepts of mathematical informatics are as simple and fundamental as integer numbers. These concepts can be viewed as the natural basis for mathematics dealing with finite (computational) objects and, using the abstraction of actual infinity, for all mathematics. Today, it is clear that the basics of mathematical informatics can be included in the primary curriculum.

The content of mathematics of informatics and its applications for primary school may be different in some educational communities with different traditions of teaching mathematics and primary teaching in general. Applications and examples can differ more than the fundamentals. At the same time, an analysis of approaches taken by educators shows that, as in other fields of mathematics, there is much that is common and universal in the content of the mathematical basics for informatics.

Here is one possible way to introduce computer mathematics into elementary school. We start with basic notions, not trying to give them an exact definition – neither logically nor philosophically correct – but instead describing them in intuitive terms. These notions are introduced to students in the form of visual (graphical) and palpable (manipulative) examples. In that way, a general (non-verbalized) understanding arises in a student's head due to the inherent mechanics of cognition through direct perception and acting.

Major concepts of mathematics of informatics

Beads

The simplest objects are *beads*. These can be made out of wood, but more often they are drawn or printed on paper. Beads are of several forms (circle, square, and triangle) and colours (red, green, blue, yellow, black, and white). So, they have attributes, or properties. Letters of alphabets and other symbols are beads as well.

Strings

A *string* is a sequence of beads. There are first, second, third … and last beads in any string.

Other examples of strings are a string of letters in a word, a string of words in a phrase, a string of phrases in a tale, or a string of events described by a tale. A general source of examples is the one-dimensional timeline and the human wish to structure it by distinguishing specific moments or solid intervals.

Bags

Bags are another type of complex object. In constructing a bag, we take selected objects together. Thus, there is no order between them and we can take several identical objects. Bags are also called multisets.

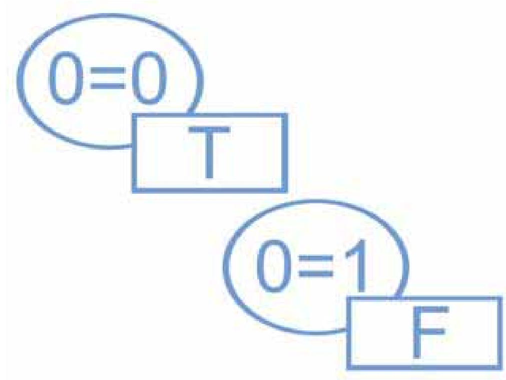
Names

Objects are given *names*; an object is the value of its name. We can use single letters as names; and names can have complex structure as well.

Truth values

Some natural language texts (strings of letters) have True, False, and Unknown as their *values*. Some texts do not have value.

More complex objects



We can make strings and bags out of strings and bags. For example, we can produce a bag of strings, or a string of bags, as well as bags of bags and strings of strings. Trees (in which the sequence of objects or events is branching) are also introduced as a class of objects. Of course, trees can be represented or coded by other objects (for example, bags of bags of bags), but the graphical representation is important for us. Trees reflect structures of classification, some linguistic structures, and structures of reference. Arbitrary graphs have a proper place. One-dimensional tables correspond to mathematical functions, and two-dimensional tables to operations. They are used also in many applications.

It is important that all types of objects have clear palpable and visual implementations.

Operations

Operations over strings and bags are introduced. We can concatenate strings in a string. Or, we can add together bags from a bag of bags. In this last case, we can also define union (maximum) and intersection (minimum) of a bag of bags. We can also concatenate a string of bags of strings to make a bag of strings. To concatenate a string of two bags, for example, we consider all possible concatenations of strings from the first and from the second bags. The last situation reflects multiplication of polynomials.

In the context of action (as in programming languages), strings correspond to sequential actions, and bags to sets of options or possibilities. There are also relations (predicates) over our objects. The simplest relation is being the same (identity). This relation is intuitively clear and can be introduced by graphical and material examples. There are other relations such as inclusion for bags, and succession of beads in a given string.

Logical connectives

Let us have a bag of statements. It is clear what it means when we say “All statements in this bag are true“. Now, the meaning of the statement “This statement is true for all objects in that bag” is clear as well. Similarly, we introduce constructions of existence (“there is” or “there exists”). Negation (“This statement is not true”) is introduced with caution as in some cases it is harder to comprehend.

Processes

Processes we are interested in are described as strings of states. Each state is an object (in our sense). Playing a game is an example of process. Trees and other graphs are used to describe possible runs of processes. Winning a game and winning strategy concepts are introduced in a general way. Analyzing a logical statement can be understood as constructing a strategy. Probability notions appear in practical examples and games.

Programs

The primitive components of *programs*, instructions, have as their meaning actions (operations) on states. In the construction of programs, operators as composition (subsequent execution), branching, and iteration are used. Variables are introduced first in the simplest form of global variables. Systems of functional equations defining a computable function are considered. Parallel processing, non-determinism, and probability also have their place.

Languages

We use the names of objects, operations, logical connectives, (program) operators, and other tools mentioned above to construct complex names. Parentheses (brackets) are the key instrument in such construction. Variables for objects and operations are introduced.

Machines

To describe program execution more clearly, abstract *machines* are introduced.

Specific approaches to program design (division of labour, top-down analysis, raising reliability of probabilistic computations) and practical algorithms (sorting, exhaustive search) are introduced (again, in visual and palpable contexts).

Needs in (semi-) formal proofs appear in analysis of games and of program execution (correctness proofs). Non-existence proofs by exhaustive search and diagonal construction are discovered.

The critically important component of the learning process is wide applications of major concepts, which include models of natural language, real games, searching in information sources, and individual and group design of meaningful software. These are considered in the next section.

Environments and applications

An understanding and ability to use the basic concepts of mathematical informatics can, and we believe must, be achieved in environments where computers do not play the leading role. To a large extent, we feel that computers can be absent altogether. For elementary school children, definitions can be presented through visual, tangible or kinaesthetic examples. We list here a few of these environments, as found in different educational communities around the world.

Sequential time and speech

Text originated from oral speech. Naturally, it is one-dimensional – as a record of sounds evolving in time. We represent text graphically, and on the screen, as a sequence (string) of symbols. It is convenient to arrange such sequences two-dimensionally on a sheet of paper, or on a computer screen as lines of text. The one-dimensional essence of text, however, is reflected in the operations one can conduct on it with a computer. You can, for instance, select any sequential (one-dimensional) part of the text, cut it, and insert it into any place in the text.

Therefore, our concept of string reflects human speech as well as human reflection on sequence of events and the physical one-dimensional time.

Non-ordered space and choice

We can see, or imagine, a collection of objects simultaneously and non-ordered. A possible next event, or action can be represented by that kind of collection as well. Sometimes a collection appears when we want to distinguish between some objects and everything outside. Such collections can contain many identical objects (like molecules in gas), or similar objects that we treat as identical. You can represent this situation in graphical form as a bag (an oval), inside which objects like symbols, strings, or other bags are placed.

Our concept of a bag thus reflects the physical world of objects and our human perception of it as well as opportunities of choice and combinations of objects.

Natural languages

Every human being has the ability to manipulate linguistic objects, to create new ones, to wonder and experiment in linguistic reality. At the same time, major constructions of languages of mathematics and informatics are based on natural languages. Consequently, reality of linguistic objects constitutes an important environment for learning informatics. Objects, regularities, and peculiarities of languages can be described and discovered by means of mathematical informatics.

Artificial formalized languages

The languages of algebra, logic, programming, interaction and games, and different combinations of these, are usually described in a semi-formal way, using notions of mathematical informatics (first of all as strings, bags, and trees). Traditionally, such languages are considered as sophisticated subjects. For example, in some countries it is argued that algebra should not be studied in primary school. However, the learning environments discussed here can actually help children to learn formal languages (including programming in icon-based languages) alongside their own written mother language – provided the formal language is used for fulfilling a task that is motivating to the student. There are further interesting environments using other artificial languages such as musical notes and road signs.

Tangible, palpable, movable objects

Students can successfully invent sophisticated information processing procedures dealing (that is, playing) with real objects. For example, operations on real bags of LEGO bricks can be enormously helpful in understanding the operations and algorithms of abstract bags. An emerging dimension here is associated with computerized (including pre-programmed, using feedback) control of different devices acting (moving, imitating industrial processes, or environmental control) in real space. Physical movements and movements of groups of students in real space can be used when mastering certain topics.

Graphical environments on paper or computer screen

It is well known that understanding the operations of structural programming, top-down program design, and other concepts of informatics can be learned effectively with *Robot-in-the-Maze* and other graphical computer environments where a simple *creature* is acting. Basic structures of mathematical informatics have natural graphical presentations as well. A very productive field for learning emerges in combinations of the physical world, its pictorial representation on maps and plans, natural language, and artificial language descriptions.

Real information processes

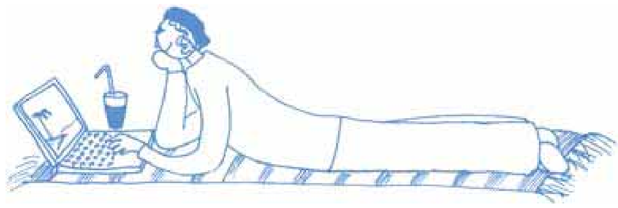
Building up a formal model of a vending machine or a metabolic chain of control in the human body can be an exciting task. Working on such models uses concepts of system, state, interaction, signal, control, and feedback. It is important that these concepts are treated, not in a generalized, abstract, and philosophic way, but as working instruments in real activities of students. The best approach here is thus project-based. The themes and topics of such projects may be as diverse as assembling and operating model cars and toy trains, turning out pop tunes with a synthesizer, drawing animated cartoons, or cracking the codes of mediocre computer games in order to make them more challenging to play.

Human behaviour

Human behaviour can be used for studying formal models for such activities as:

- playing games. Virtually all human games involve mental (information processing) activities. Many games use symbolic environments, formalized rules, random choices and chances, computational and combinatorial reasoning, and strategic planning in an interactive setting;
- planning activities (in projects) and executing plans, acting in groups;
- reasoning and communicating. Of course, these are major human activities. Mathematical informatics studies mathematical models and reflects important aspects of these processes. Among other tools introduced in this context are probabilistic and modal logic;
- learning, including learning mathematical informatics itself: studying, examination and analysis.

Information objects in a computer setting



Text, graphics, hypermedia, and spreadsheets, are all examples of information objects in a computer setting. Consequently, one of the natural ways, but not the only way, to learn mathematics of informatics is to involve practical applications of computers.

Computer programming and its visualization

In a different way from the environment of graphic objects above, we emphasize here the computational aspect with which electronic computers started. There are environments for studying mathematical informatics where effective results can be achieved due to a combination of learning programming with professional programming languages and visualization.

All the learning environments considered in this section can and should be involved in learning mathematical informatics. What is remarkable is that many of these environments were considered for years, and even centuries, to be beyond the frontiers of school mathematics. Problems from these areas were interesting and motivating for students, but considered more as recreational puzzles, not objects of systematic and serious study. Informatics integrates many of these environments and captures their often fundamental importance.

General and specific educational outcomes

The understanding and skills achieved in learning mathematical informatics are helpful in learning other subjects too, as well as being useful in everyday life. One of the important outcomes of studying mathematical informatics is acquiring a natural language with clear and unambiguous semantics. Students try to apply methods of formal reasoning and communication in different areas of life. Sometimes they fail, of course, because of the inadequacy of tools or other factors, but often they succeed.

Other skills that are developed in a framework of mathematical informatics and used in learning different subjects, as well as in a broader context, are classification and sorting, sub-dividing a task into smaller components, planning, and reflection.

7

ICT AND EDUCATIONAL CHANGE

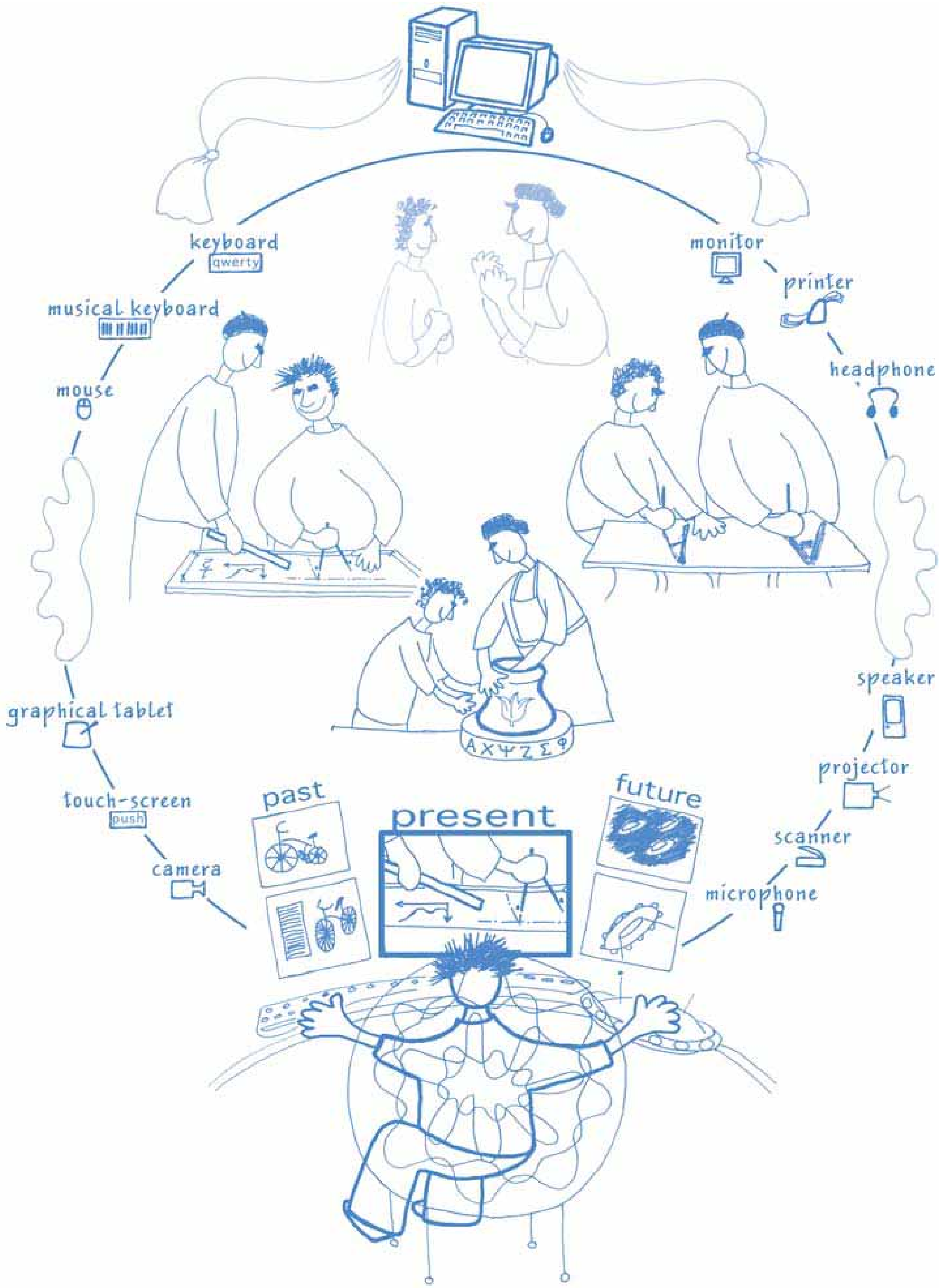
RESTRUCTURING THE FOUNDATION OF SCHOOLS

By permeating contemporary schooling with useful digital technologies, we can make profound changes in the whole existing system of education. However, change is a process, not an event. Just buying and installing hardware and software is not sufficient to make ICT into a genuine educational technology.

This task of implementing ICT in schools demands gigantic efforts, widely time-spread, and covering many diverse but interconnected fields – at the national, regional, and individual school levels. We are talking about restructuring the very foundation of schools, perhaps even greater than the one initiated by the invention of printing press. The utmost precautions must be taken not to destroy, or discard anything of value in current practice. On the other hand, we need to be aware of the really deep changes that have begun in education around the world, and which we must direct and manage with care and courage. This chapter examines strategies of change, stages and indicators of ICT integration, and dimensions of ICT development needed to transform education, and concludes with practical suggestions for planning.

STRATEGIES OF CHANGE

The age-old and seemingly endless debates on education reform, so much fuelled by the new digital epoch, gyrate around two diametrically opposed strategies.


keyboard
qwerty
musical keyboard
mouse
graphical tablet
touch-screen
push
camera
monitor
printer
headphone
speaker
projector
scanner
microphone
past
present
future
ΑΧΨΖΣΦ

The first strategy is directed towards a smooth, gradual improvement of the established system, with major repair where needed, and timely replacement of broken or outmoded components and procedures. This strategy of gradualism stresses the strength of tradition and claims to be a bastion of stability amid a chaotically changing socio-politic and economic environment. In fact, this strategy runs the risk of being an overtly conservative, even reactionary stand that may be vulnerable and shaky in the face of today's challenges and threats.

The second strategy requires a drastic paradigm shift from a classical system of education toward a new one built upon totally different principles. This futuristic strategy sees change as its foremost goal, and as a normal part of the life of a school. In breaking all ties with the past, however, the strategy risks impoverishing itself and its students by neglecting the immense riches of our cultural legacy.

The question is can we find something less risky and more reliable.

Between the two extremes outlined, there is a third strategy that might be called sustainable schooling. By remaining tradition-conscious and wary of orthodox options, the third strategy is nevertheless ready to make yet another explorative move towards the goals of 21st century education. ICT-related reform is essentially a teaching and learning enterprise on a grand scale. We must remember that we have much to learn, both before and during the process of ICT implementation. We are making an adventurous journey through the wilderness where previous travellers may sometimes feel they have gone astray. Thus, what we offer below is not a detailed road map, but rather a list of general travel tips to help us get along the road to our desired destination.

STAGES AND INDICATORS OF ICT INTEGRATION

In many countries and educational communities across the globe, attempts have been made to classify various stages of integration of ICT into general education; and then to determine indicators of ICT integration.

Stages

Several stages of ICT integration in schools have been identified (see, for example, UNESCO 2002b). It is the continuum of stages rather than the actual number of stages that is important:

The earliest stage is the presence of pre-digital (pre-computer) ICT only. We see development of information-communicative competence based on these pre-digital forms (photography, using encyclopedias and library resources) and information processing activities with texts and objects of the material world.

Following on from this stage, awareness of ICT is based on demonstration of ICT with occasional hands-on experience.

A subsequent stage is for some competence in ICT with opportunities to use them for a majority of students and teachers.

Further along the continuum is active and extensive use of ICT in learning and teaching across all subjects in the curriculum.

At the furthest end of the continuum, there is transformation of the school in all areas: curriculum, organizational models of work, and relations with the community.

What is important to note about these stages of ICT integration is that schools do not necessarily progress through them sequentially. It is quite possible for a school having only a few computers and with only a medium level of ICT-competence among teachers to begin a real transformation in one part of the curriculum, say, in History. Indeed, the normal pattern is for transformation to begin in one area and gradually permeate to all areas of a school's activities.

Indicators

The most popular indicator for the success of ICT in education today is the number of students per computer, no doubt because it is easily measured. An alternative indicator would be to consider the results of learning. The problem here is that it is much more difficult to evaluate the effects of a "would be" situation, that is, based on a hypothetical reorganized and correspondingly equipped school. An additional difficulty is that we expect ICT to be effective primarily in those fields and aspects of education that are not central or even non-yet-existing in the traditional school, but vitally important for modern society.

We have therefore a whole spectrum of options for indicators of ICT integration, which include the following, which we list with brief accompanying notes showing what information needs to be gathered for each indicator:

- Money spent

  Budget all monies corresponding to individual ICT programs within schools.

- Technology delivered

  Optimize the types and characteristics of equipment in accordance with school needs and claims.

- Technology installed

  Plan, fix, and check premises, communication (power supplies, grounding), furniture, lighting, theft-protection and insurance.

- Technology available for students and teachers in schools

  Provide personnel to support adequately learning and working activities of students and teachers, and possibly also members of the wider school community; on a 12 hours a day, 7 days a week basis.

- Technology service

  Contract for service, maintenance and upgrade of equipment and software.

- Professional development

  Develop human capacity within schools (in-service training of teachers, librarians and other paraprofessionals).

- Technology planned

  Document ICT implementation plans and exhibit these on school walls or over the Internet.

- Technology being used

  Document time spent, in record-books or on the school server, when teachers and students use computers and the results obtained in class work, homework, and group projects.

- Educational outcomes delivered

  Students are ICT-competent, they learn different subjects more effectively, and achieve higher order goals as independent thinkers, researchers, and creators. Document the results in students' portfolios, and record examination results and independent (including international) evaluation.

A more comprehensive discussion of performance indicators for ICT in education may be found in UNESCO (2003).

DIMENSIONS OF ICT DEVELOPMENT

At all stages of ICT development in schools, across different cultural and economic contexts and across different sized education systems, we can identify certain key dimensions. These include:

- Leadership and vision
- People
- Technology
- Practice

Let us consider these dimensions in more detail.

Leadership and vision

Encouraging citizens to understand and support change is an important component of any educational reform. In the case of ICT, this support and understanding is even more crucial. A positive attitude and active involvement is needed by all the following groups or stakeholders:

- national authorities, officials and legislators – to formulate goals and to allocate resources;
- educational authorities responsible for curriculum matters – to support new systems of educational goals, objectives, and content;
- school principals – to support their teachers and changes in the life of schools;
- teachers – to be brave enough to start;
- parents – to trust teachers; and
- the general public, journalists, NGOs – to understand and interpret what is happening.

All these groups need their leaders to work inside their sphere of influence and to influence and convince other groups and their leaders of actions in ICT-based educational reform. To do this effectively requires vision. In all successful implementations of ICT in schools around the world, a key dimension is always leaders with a strong commitment for ICT and a vision of how ICT can transform teaching and learning within schools.

People

For an ICT-based curriculum to be successfully implemented, another key dimension is people, which means:

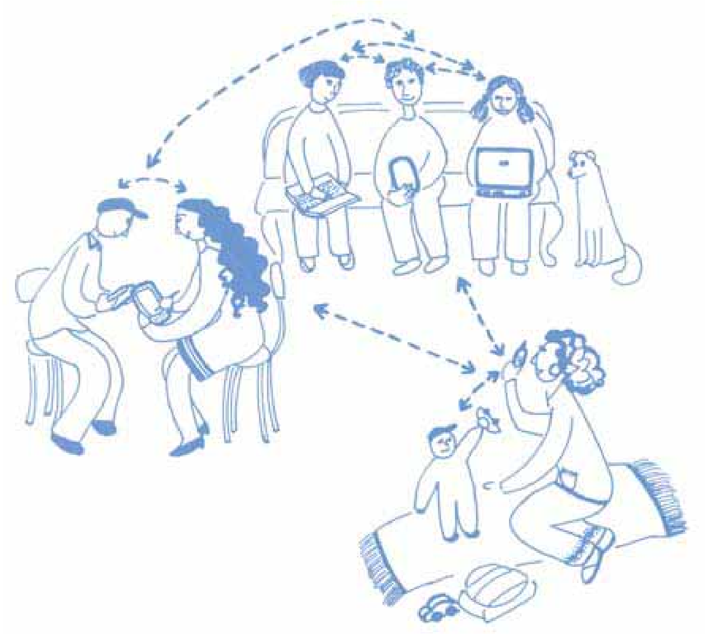
- Supporting teachers who are willing to change their teaching style, to learn new ways of doing things, to reduce the amount of knowledge they assume their students should memorize, and to encourage students to be independent learners within a collaborative environment.
- Incorporating ICT-based learning into teacher preparation and in-service training, relevant for teachers, with components of reflection on their learning and design of their teaching.
- Providing a framework in which ICT usage is accepted as an incentive for promotion.
- Building up a community of educators to share a common vision and experience.
- Supporting and rewarding interaction between teachers of ICT and all the school.
- Introducing a position of ICT-coordinator.
- Using students as appropriate for a technical and intellectual supporting labour force.

Technology

Technology might appear to be an obvious, although expensive, dimension in implementing ICT. Simply, buy computers for schools and sit back and watch for the results. However, as we have tried to show throughout this book, implementing ICT is a complex issue with many different facets.

For a start, equipment is not limited to computers only. We have already listed many types of technological equipment. There is a broad spectrum of pre-computer, or pre-digital technology, worth incorporating within an ICT framework in accordance with our educational goals. Digital devices associated with computers magnify its productivity and effectiveness in school. Too often ICT are thought of as involving computers only.

There is even more misunderstanding about educational software than there is about hardware. The most sophisticated hardware is useless without appropriate software. Investment in technology requires, then, investment in professional or educational versions of software: general applications software, professional applications software, teaching software on CD and DVD, and software systems for the control and management of learning.



The purchase of hardware and software involves also a consideration of:

- Space, together with furniture, power supply, local networking, and installation.
- Maintenance, plus support and upgrade.

Practice

Transforming education means not only changing textbooks and teachers' attitudes, but also altering the prevailing practice in schools, that is, the formal frameworks regulating the educational system. This, then, is another key dimension in implementing ICT in schools. Here are areas of school life that need most to be changed:

- roles of teachers, administrators and other employees, ICT-coordinators, two teachers in the classroom, certification and promotion;
- functions of space for learning activities, architectural and construction requirements;
- access to ICT;
- consumables and supplies; and
- forms of learning activities and evaluation: homework via the Internet; project-based learning; distance education; examinations with full access to information sources.

TRANSFORMATION OF EDUCATION

The four dimensions of ICT implementation in schools discussed above – leadership and vision, people, technology and practice – are essential in the process of transforming education, which is a key theme of this book. At this point, we simply list some of the areas where change is needed:

- goals and objectives;
- content and its sources;
- evaluation and assessment;
- structure of learning activity and interaction between participants;
- job descriptions and working habits; and
- awareness of parents and society.

All of these areas requiring change are discussed in some detail in preceding chapters.

PRACTICAL SUGGESTIONS FOR PLANNING

We conclude this chapter and this book with a few specific suggestions that can be helpful to all those involved in the education process in their planning to use ICT in schools.

- Use all ICT and pre-ICT spatial and visual environments to achieve the new literacy.
- Use technology across the curricula; introduce it with the co-operation of different teachers.
- Use ICT intensively in teacher preparation and in-service training.
- Buy the newest affordable technology, but do not reject donations of reliable equipment provided there are enthusiasts to support it technically.
- Do not lock computers in the computer lab and restrict them to the teaching of computer science and programming to advanced students.
- Create an information environment that incorporates libraries and laboratories and extends beyond their walls.

- Do not provide equipment to the poorest schools or to all schools equally, but to schools that are ready and eager to use them. Use resource centres for other schools to gain experience in and to prepare themselves for ICT implementation.
- Do not forget administrators – their personal use of technology is usually the key to understanding teachers' needs.
- Construct a new education using traditional in combination with modern local and global sources. Build up an informal community of teachers and connect to the international community, the national and international intellectual resources of scientists, industrialists, and officials via networks. Make schools centres of the new information culture.

In conclusion, the best advice we can give to all educational leaders and decision-makers was that given by Lao-Tzu in his immortal book *Tao Te Ching*:

> *The Master doesn't talk, he acts.*
> *When his work is done,*
> *The people say, "Amazing.*
> *We did it, all by ourselves!"*

REFERENCES

Anderson, J. 1993. *The New Literacy and Technology*. Keynote address to the International Reading Association Convention, San Antonio, Texas, April 1993.

Bederson, B., Shneiderman, B. 2003. *The Craft of Information Visualization: Readings and Reflections.* Morgan Kaufmann Publ., San Francisco.

Berdiayev, N. 1915. *Spirit and Machine*. Translated from: Н. Бердяев. Судьба России. М., **1994.**

Berdiayev, N. 1990. *Man and Cosmos. Technics.* Translated from: Н. Бердяев. Судьба России. М., **1994.**

Bibler, V.S. 1996. *Social Theory in the Historical Dimension*. Translated from: В. С. Библер. Мышление как творчество (Введение в логику мысленного диалога) М. **1975.**

Bissett, A. 2002. *Education for Ethics: CP.Snow's 'Two Cultures' Forty Years On*. [Online]. Available: http://www.ccsr.cms.dmu.ac.uk/conferences/ethicomp2002/abstracts/10.html

Bonta, P. 1990. *Building on Intuitions: Music Composition in a Logo Environment.* In Idit Harel (Ed.). 1990. *Constructionist Learning.* MIT Media Laboratory, Cambridge, MA.

Card, S.K., Mackinlay, J.D., and Shneiderman, B. (Eds). 1999. *Readings in Information Visualization: Using Vision to Think*. Morgan Kaufmann.

Eckert, P. 1989. *Jocks and burnouts*: *Social categories and identity in the high school.* Teachers College Press, New York.

Farnham-Diggory, S. 1990. *Schooling*. Harvard University Press, Cambridge, MA.

Friedhoff, R. and Benzon, W. 1989. *Visualization: The Second Computer Revolution*. Harry N. Abrams, New York.

Gardner, H. 1983. *Frames of Mind: The Theory of Multiple Intelligences*. Basic Books, New York.

Gardner, H. 1991. *The Unschooled Mind*: *How children think and how schools should teach*. Basic Books, New York.

Gardner, H. 1993. *Multiple Intelligences: The Theory in Practice*. Basic Books, New York.

Gargarian, G. 1990. *Music composing as problem solving*. In Idit Harel (Ed.). 1990. *Constructionist Learning*. MIT Media Laboratory, Cambridge, MA.

Gibson, W. 1984 (Reissue edition 2003). *Neuromancer*. Ace Books, New York.

Heineke, W.F. and Blasi, L. (Eds). 2001. *Methods of Evaluating Educational Technology.* Information Age Publishing, Greenwich, Connecticut.

Kosko, B. 1993. *Fuzzy Thinking: The New Science of Fuzzy Logic*. Hyperion, New York.

Moore, G.E. 1997. *An Update on Moore's Law*. Intel Developer Forum Keynote Speech (30 September). [Online]. Available: http://developer.intel.com/pressroom/archive/speeches/geni.93097.htm

Mumford, L. 1967. *The Myth of The Machine: Technics and Human Development.* Harcourt, Brace and World, New York.

Murphy, D. 1995. *Comenius: A Critical Reassessment of His Life and Work*. Irish Academic Press, Dublin.

Negroponte, N. 1995. *Being Digital*. Alfred A. Knopf, New York.

OpenOffice.org. 2004. [Home page of OpenOffice.org]. [Online]. Available: http://www.openoffice.org

Papert, S. 1981. *Mindstorms: Children, Computers, and Powerful Idea*s. Basic Books, New York.

Papert, S. 1993. *The Children's Machine: Rethinking School in the Age of the Computer.* Basic Books, New York.

Perelman, L. J. 1992. *School's Out: Hyperlearning, The New Technology, and the End of Education*. William Morrow and Company, New York.

Pick, K. *John Amos Comenius – Father of Modern Education.* [Online]. Available: http://www.waldorfhomeschoolers.com/comenius.htm

Resnick, M. 1997. *Turtles, Termites and Traffic Jams: Explorations in Massively Parallel Microworlds*. MIT Press. See also: http://web.media.mit.edu/~mres/

Rhodes, J. 1991. *Conceptual Toolmaking: Expert Systems of the Mind*. Basil Blackwell, Oxford.

Rieber, L. P. 1995. A historical review of visualization in human cognition. *Educational Technology Research and Development*. 43 (1), 45-56.

Scheler, M. 1958. *Philosophical Perspectives* (Translated by O. Haac). Beacon Press, Boston.Sternberg, R.J. 1984. *Beyond IQ: A Triarchic Theory of Human Intelligence*. Cambridge University Press, New York.

Stange, K. *Intertwining the two cultures in the year two thousand.* [Online] Available: *http://twstange.com/publications/intertwining2cults.html*

Sternberg, R.J. 1985. *Beyond IQ: A Triarchic Theory of Human Intelligence*. Cambridge University Press, New York.

Sternberg, R. J. 1986. *Intelligence Applied: Understanding and Increasing Your Intellectual Skills*. Harcourt, New York.

Sternberg, R.J. 1988. *The Triarchic Mind: A New Theory of Intelligence*. Viking Press, New York.

TCO. 2004. [Home page (English version) of TCO]. [Online]. Available: http://www.tco.se/TCO_english-index.asp

Toffler, A. 1970. *Future Shock*. Random House. New York. p. 6.

UNESCO. 2002a. *Information and Communication Technologies in Teacher Education: A Planning Guide* (Ed. P. Resta). UNESCO, Paris. [Online]. Available: http://unesdoc.unesco.org/images/0012/001295/129533e.pdf

UNESCO. 2002b. *Information and Communication Technology in Education: A Curriculum for Schools and Programme of Teacher Development* (Eds J. Anderson and T. van Weert). UNESCO,Paris.[Online].Available: http://unesdoc.unesco.org/images/0012/001295/129538e.pdf

UNESCO. 2003. *Performance Indicators for ICT Use in Education*. UNESCO, Bangkok. [Online]. Available: http://www.unescobkk.org/ips/ebooks/documents/ICTindicators/ICTindicators.pdf [Accessed 15 March 2004].

UNESCO-IBE. 1995. *Teacher Training and Multiculturalism: National Studies*. IBE, Geneva.

Vygotsky, L.S. 1978. *Mind in Society: The development of higher psychological processes*. Harvard University Press, Cambridge, MA.

Vygotsky, L.S. 1986. *Thought and Language.* MIT Press, Cambridge, MA.

W3C World Wide Web Consortium. 2004. [Home page of W3C]. [Online]. Available: http://www.w3.org

Whitehead, A.N. 1963. *The Aims of Education and Other Essays*. Mentor Books, New York.

GLOSSARY

Basic – a high-level procedure language, elaborated in 1964 by John Kemeny and Thomas Kurtz from Dartmouth College, USA. Initially the language was realized as an interpreter, which facilitated essentially computing and particularly program adjustment. Now there are also compilers of Basic. Basic suited the first microcomputers well since it occupied as little as 4-8 kilobytes of Operating Storage Device. The title dates back to Beginner's All-purpose Symbolic Instruction Code. There are many dialects: Basica (IBM), GW-Basic, MSX-Basic, Turbo-Basic (Borland), Quick-Basic (Microsoft), XYBasic, QBasic, CBasic, Basic-80, 86 and 87Basic, 387Basic (MicroWay).

Bit – a minimal unit of information that enables us to discern and choose between two opposite alternatives, such as 1 or 0, yes or no, light or dark, that is the presence or absence of something.

Browser– Tool used to access and manipulate information on the Web (e.g.- Netscape Navigator, Internet Explorer).

Byte – a unit of information that is equal to 8 bits.

CAD – Computer Aided Design – a system of automated projecting.

CAM –

1. Communication Access Module – a module of the access to connection channel.

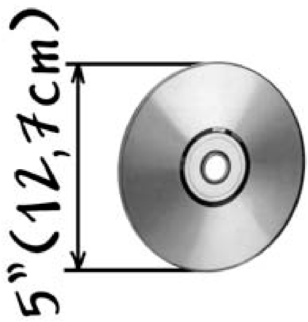
2. Computer Aided Manufacturing – an automated system of production and technological processes management.

3. Common Access Method – a standard access method for SCSI (Small Computer Systems Interface).

4. Content-addressable memory – associative memory. Synonyms – data-addressed memory.

CAI – Computer Aided [Assisted] Instruction – a package for learning in a subject or topic (e.g. mathematics or handling a spreadsheet). Modern CAI makes extensive use of multimedia tools.

CD-ROM – Compact Disc-Read Only Memory – a silver-coated optical disc that stores up to a gigabyte of information as an optical trace. A CD (Compact Disc) is widely used for storing music or text, whereas a CD-ROM commonly stores a range of multimedia. Previously, CDs were readable only but now also come in rewritable form. CD burners are becoming common peripherals.



Chat – exchanging information (a text dialogue) in real time; a conversation (on the Internet).

Chip – (from *microchip*) – a micro-scheme, crystal; general name of an integral scheme.

Computer Games – a category of software, computer games are sub-divided into several classes: arcade games, adventure games, and logical games.

Constructivism – A theory and teaching strategy holding that learners actively acquire or "construct" new knowledge by relating new information to prior experience. It contrasts with strategies that rely primarily on passive reception of teacher-presented information.

CPU – Central Processing Unit – a part of a computer directly accomplishing the machine's commands, a program. Comprises a register file.

CRT – Cathode Ray Tube – previously, a widespread display name.

Cursor – generally of two kinds: a text cursor and a mouse cursor. A text cursor is a twinkling symbol on the screen (usually a vertical line) showing a place to enter the next symbol. A mouse cursor is a graphical sign (usually an arrow) reflecting the mouse movements on the screen and the operations made with its help.

Cyberspace – **1.** virtual space created by a computer system. It can be shaped from a simple global network from electronic mail to the breaking worlds of virtual reality.

2. A term invented in 1984 by the writer William Gibson in his novel *Neuromancer*. Now, the word is used to denote a whole range of information resources accessible through a computer network.

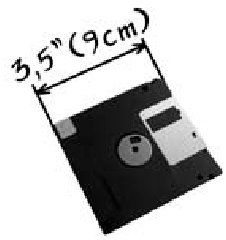
Digital Camera – a camera using a ROM matrix from which images are recorded to a non-energy dependent flash memory in digital form. Pictures already taken may be downloaded to a computer to be edited or printed through a standard port.

DVD – *see* Digital Versatile Disc.

Digital Versatile Disc – like CD is an optical disc but with the capacity to store 10GB or more information, more than sufficient to hold a full-length movie.

DVI – Digital Video-Interactive – the Intel Corporation standard. Provides a high machine level of pressure of whole-screen videos being recorded to optical disk (licensed by IBM).

Floppy disk – a removable magnetic disc, usually called diskette, for storing relatively small amount of computer-processed data and information outside a computer's body, and/or moving that amount from one computer to another.



GIS – Geographic Information System – a class of program systems connected with input, processing, storing, and displaying space data, such as locality plans and schemes.

GUI – Graphical User Interface

1. A machine creating a graphical user interface for the OS.

2. A program allowing execution of data visualization.

Hard Copy – a file copy or content of the screen on paper, film or other non-electronic carrier.

Hard Disks – a computer device directly accessible for storing and retrieving large volumes of programs and data.

HDTV – High Definition Television – a technology and standard of transmitting and receiving television signals with the capacity of 1125 lines, doubling the capacity provided by current technology.

Hyperlinks – active text image or button marked in colour on a web page, a click on which (a hyperlink activization) takes the user to another page or another part of the current page.

Hypermedia – an extension of *hypertext* to include other media such as sound, graphics, and video.

Hypertext – a term coined by Ted Nelson in 1965 before the Internet and the World Wide Web made it useful to refer to non-linear text containing *hyperlinks* that with the aid of a browser enable a reader to branch to other documents or other parts of the current page.

IC – Integrated Circuit – semi-conducting device comprising several electronic elements.

Interface – a system of hardware and software components responsible for transforming and converting electronic signals that carry relevant information into visual, aural and tactile patterns perceptible by human senses.

Joystick – a device held in the hand similar to a gearshift to control the cursor on screen, and used extensively in arcade computer games.

Keyboard – an indispensable part of computer which looks like typewriter's keyboard and serves mostly for alphanumerical text input.

LCD – Liquid Crystal Display – a type of display used in watches, calculators, flat screens, portable PC screens, and other devices. Liquid crystals can change their molecular structure, which allows the management of light flow to pass through them.

LED – Light Emitting Diode – a low consuming electronic device giving light when undergoing penetration of the electric light.

Linux – a freely distributed (non-commercial) dissemination of the UNIX OS on PC and other platforms.

Macintosh – **1.** A generic name for computers produced by Apple Computer Company, and commonly referred to as *Macs*.
2. A prefix in the names of software products denoting that the product is meant for the Macintosh PC.

Magnetic Tapes – Tapes with surfaces covered with magnetic material.

Microchip – generic name of an integrated circuit.

Microsoft – The biggest software developer in the world, founded in September 1975 by Bill Gates and Paul Alan.

MIDI – Musical Instrument Digital Interface – a standard protocol for coupling electronic musical instruments with a computer and software, developed in 1983.

Monitor – (display) an indispensable part of a computer, which serves to display visually the processed alphanumeric and graphical information on a screen, as well as to receive the user's working commands, given through the mouse or equivalent control device.

Mouse – a handheld control tool with one, two or three buttons to operate a computer by moving the mouse plastic body across the flat surface (usually table-top covered with a small mat called a mousepad), while watching the corresponding cursor movements and selecting appropriate controllable objects on the monitor screen.

Notebook – a class of portable computers of notebook size weighing less than 4 kg.

OCR – **1.** Optical Character Recognition – automated recognition (with the aid of special programs) of graphical images, symbols, printed texts (e.g. entered into a computer by a scanner), and their transformation into a format suitable for processing by text processors and text editors.
2. Optical Character Reader – a device to optically recognize symbols or automated text reading.

Optical Disks – see *CD-ROM* and *DVD*.

OS – Operating System – electronic instructions providing an environment for executing applications and providing access to computer devices.

Output – 1. Data of any kind sent from a computer system. A polysemantic word used as a noun, a verb, or adjective.
2. General name for data shown on a display device; also for data sent to another program or over a network.

Palm, or
palm-top – a tiny, thin handheld pocket computer.

Pattern – a distribution of events in a time and/or space continuum, which we can recognize and nominate, then compare to some other pattern and, finally, discern the former from, or identify with, the latter.

PC – Personal Computer – though the term *PC* is sometimes used to denote any personal computer, it often denotes a PC that uses the Intel processors. The term originates from IBM PC, produced in 1981 by the IBM Corporation as a computer to be operated by an individual, in contrast to mainframe computers.

Personal Digital Assistant (PDA) – A handheld computer that often includes pen-based entry and wireless transmission to a cellular service or desktop system.

Performance indicators – Descriptions of behaviors that demonstrate acquisition of desired knowledge, attitudes, or skills.

Pixel – a minimal addressable element of a double-raster image whose colour and brightness can be set independently from other points; refers to the capacity of the graphical adaptor and is usually given in pixels, for example, for VGA it is 640 x 480 in a 16-colour palette.

Portal – a website designed to provide integrated information in a particular field or fields. Usually contains references to other sites whose content meets requirements of the portal's visitors. Portals may be specialized focusing, for instance, on maritime archaeology, or general like certain search engines that offer a range of information services (weather, news, currency rates, and information directory).

Printer – a device that transforms the computer screen texts and images into matters printed out on paper or film (so called hard copies).

Productivity tools – Productivity tools refer to any type of software associated with computers and related technologies that can be used as tools for personal, professional, or classroom productivity (e.g. Microsoft Office, Apple Works).

Projector – an electronic-optical device, emitting a strong beam of light to cast the computer monitor images onto a large screen

RSI – Repetitive Strain Injury – a type of professional disease associated with working on a keyboard caused by overuse or misuse.

Scanner – an optical device for entering data of digital text or graphical information from a physical source (e.g. from a photo) into a computer. Scanners are characterized by the colour depth and dynamic range of colours recognized.

Search engines – Software that allows retrieval of information from electronic databases (library catalogs, CD-ROMs, the Web) by locating user-defined characteristics of data such as word patterns, dates, or file formats.

Sensor – a device producing an electric reaction signal to a range of phenomena: temperature, movement, tension, vibration, colour, magnetic field, concentration of certain chemical substances.

Server – a computer providing services, resources, or data to a user's computer.

Simulation program – A computer program that simulates an authentic system (city, pond, company, organism) and responds to choices made by program users.

SVGA – Super Video Graphics Array – a standard for graphics display and a video adaptor to realize it. Provides a greater capacity than the VGA standard.

TCO – Total Cost of Ownership – the term was first used in autumn 1995 in a report of the Gartner Group. TCO'92 – the first norms worked out by the Swedish conference of professional employees appeared in 1992 to regulate the parameters of display from the point of view of electronic security, electricity consumption, and electric magnetic fields influence.

Touch screen – an input device allowing a user to interact with a computer by touching pictograms or graphic buttons on a display with one's finger. Finding the coordinates of a surface touched is pinpointed by the conjunction of infrared rays net by a finger situated on the display surface.

UNIX – an open multi-user operating system developed in 1969 by Ken Thompson and Dennis Ritchie at AT&T Bell Labs, now realized on many computer platforms.

UPS – Uninterruptible Power Supply – a device comprising accumulators providing the power supply and security for a computer and peripherals in case of a decrease or change in power of the basic power supply source; also a means to save data reliably and automatically when switching off.

UXGA – Ultra Extended Graphics Array – a video graphic standard for the display extension 1600 x 1200 pixels.

VR – Virtual Reality – a complex modeling system of a pseudo-physical reality shaping three-dimensional visual worlds accessible to a user with the help of a powerful computer and such accessories as stereoscopic glasses, gloves, and helmet. Information about the activity of the user comes to the computer from devices registering a user's posture and movements.

VRML – Virtual Reality Modeling Language – a language allowing description of three-dimensional scenes that use animation and travel along the Web for different projects on the Internet. Initially it was elaborated by the Silicon Graphics Company and was called Virtual Reality Mark-up Language.

XGA – Extended Graphics Array – an IBM standard of 1991 on video graphics in the family of PC/2 machines; an adaptor and a micro-scheme realizing this standard. Supports a higher capacity (1024 x 768, 256 colours) as compared to VGA (considered as part of the SVGA family).

World Wide Web (WWW) – 1. The worldwide array of hypertext transfer protocol (http) servers allowing access to text, graphics, sound files, and more to be mixed together and accessed through the Internet.

2. Used loosely to refer to the whole universe of resources available using Gopher, FTP, http, Telnet, USENET, WAIS, and some other tools.

Index

Education for All (EFA) is the foremost priority of UNESCO – because it is a fundamental human right and a key to sustainable development and peace within and among countries. Achieving the goals set in Dakar and at the Millennium Development Summit entails a commitment to a triad embracing *access, equity* and *quality* in primary and secondary education. This Handbook is designed for teachers and all educators who are currently working with, or who would like to know more about, information and communication technologies in schools. The technologies involve much more than computers, and so the abbreviation we use for information and communication technologies – ICT – is a plural term to denote the whole range of technologies associated with processing information on the one hand and, on the other, with sending and receiving messages.

A major theme of this Handbook is how ICT can *create new, open learning environments*. More than any other previous technology, ICT are providing learners access to vast stores of knowledge beyond the school, as well as with multimedia tools to add to this store of knowledge. ICT are largely instrumental, too, in shifting the emphasis in learning environments from teacher-centred to learner-centred; where teachers move from being the key source of information and transmitter of knowledge to becoming guides for student learning; and where the role of students changes from one of passively receiving information to being actively involved in their own learning.