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Keys to Futures

Societal Reflections on Developing Key Technologies and Their Impacts on Human Qualifications

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Abstract

The study was aimed at defining and drawing up the most important future trends as regards the development of technology (key technologies) and analysing their societal impacts and impacts on human qualifications. The key technologies to be studied in the survey have been limited to information and communication technology, biotechnology and material and nano technology. In addition, combinations of these technologies, i.e. so-called fusion technologies, are also subjected to an analysis.

The methodology of the study is based on the Delphi method. The study was carried out in three phases. The *preliminary phase* comprised a theoretical-empirical study of the essential trends in the development of technology and a systematisation of the most important future key technologies. *The first Delphi round* comprised collection and analysis, based on the evaluation by experts, of the material on the future key technologies as defined in the study.

The main results comprise the analyses of the technological phenomena and technological theses, and the plausibility and the timing of theses. The following technologies and relating theses were deemed to be the most important ones: highly selective drugs, sensors, integrated technology, biomedical materials, photonic materials, 3G technology, intelligent materials, diagnostics and virtual reality. The main objective of the *second Delphi round* was to make an analysis of the societal impacts of the technologies deemed to be crucial during the first round on the basis of the evaluations by experts. The first main result comprises linking of the most important technological theses with the classes of professions and areas of education identified so that it is possible to study the change in professions and areas of education, technology by technology and thesis by thesis. The second main result is an analysis of the plausibility and timing of the new future professions created during the study.

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Preface

There is a saying that a beloved child has many names. When one is interested in exploring the future, some of those names could be ”futures studies, futures research, foresight studies, technology assessment” and so on, but whatever name is used it has become clear that there is a growing need for such activity in every sector of modern society.

This need became evident for the first time about thirty years ago, when a trendlike economic growth ceased and the most advanced companies started to use, for example, scenarios to support their strategy development processes. In the 1990s, governmental and other non-profit organizations also became ever more interested in applying the same kind of futures research methods already used in companies. Currently, there seems to be a real boom for such activity in the public sector in Finland, but it still remains to be seen what will emerge from this enthusiastic boom.

This research was carried out as a co-operation project between Ministry of Education and Ministry of Trade and Industry. It serves purposes of both Finnish Ministries. Firstly it is aimed to support planning and decision making in the Ministry of Education. As a technology foresight project it also serves the purposes of the Ministry of Trade and Industry, when the Ministry tries to assess the emerging technologies and finds the way to promote the creation and utilization of these technologies. The research was funded by the Ministry of Education and European Union and carried out in Helsinki University of Technology, Lahti Center. Two people did the hard research work: Anu Raappana, who started this project in August 2001, and, after she left on maternity leave in May 2002, Toni Ahlqvist who continued and completed it. Toni Ahlqvist also wrote the research report. Mika Mannermaa, docent, acted as a scientific advisor during the research process.

I especially want to thank Olli Poropudas from the Ministry of Education, Petri Honkanen and Seppo Kangaspunta from the Ministry of Trade and Industry, Jouni Marttinen from The Employment and Economic Development Centre of Varsinais-Suomi, and Paavo Löppönen from The Committee for the Future of the Parliament of Finland, who took part in the work of the steering group. The discussions in our meetings were inspirational, sometimes even provocative, offering new ideas and directions for researchers. However, the views expressed in this report are naturally purely those of the writers and may not in any circumstances be regarded as stating an official position of the organizations that have funded the project or been engaged in its steering group.

The research report also contains an article section, in which the future trends and themes of selected key technologies are investigated further. I would like to thank Risto Linturi, Pasi Pyöriä, Osmo Kuusi, and Ari Serkkola for their articles.

This research project can be described as an exploratory dive into the future. In the beginning, we did not know what was beneath the surface. Well, we still do not know, but we now have a good idea......

28.3.2003

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Contents

Figures

1 Introduction

It has become quite common for the futures researchers to state that after the 1970s there have been more revolutionary events than after the postwar decades of intense and trend like economic growth. Oil crises were just one of these phenomena in the 1970s. However, it appears that the revolutionary events have become even more common in the 1990s. And in the start of the third millennium, it is unlikely that these events will become more stable and predictable. Mankind is, now more than ever, in the situation where the future is full of potential for the realization of positive utopias, as well as catastrophic mistakes. New technology can further the building of the global society and offer solutions to environmental problems yet, at the same time, we are now capable of we are now capable of causing damage to culture and the ecosystem in the long run.

In the last three decades, the concept of futures studies has acquired a multitude of approaches, methods, and research which have some common elements, as well as significant distinctions. Probably the most widely applied methods have been the 'expert methods'. A particularly famous expert method is the Delphi technique. There are, however, other forms of expert methods: questionnaires, interviews, scenario work, strategic planning, etc. The advantage of expert methods is that they can be applied to many different types of research and planning situations, and, hence, they probably will remain one of the key methodologies in futures studies (Mannermaa 1996).

It is very important to note that the empirical object of futures studies is the present time through which the justifiable developmental paths are explored in a multidisciplinary sense. Another key issue is that futures studies is not actually a scientific branch in its own right, but a research branch which has its own unique characteristics and qualifications, like future-oriented interest, its unique way of presenting research questions and methodologies. Hence, futures studies should be considered conceptually more comprehensive than the tendency to make forecasts within many other scientific or econometric models. For example, in the field of biotechnology forecasts of the scientific and technological development are important ways of structuring the development of the field. However, such information can be utilized in the field of futures studies as a basic variable in the construction of scenarios. One of the key competences of futures studies is the transformation of fragmented forecasts and information into justified assessments of the future.

The basic interest of futures studies is instrumental. The objective is not to find a ”truth” about the future, but the pursuit of influence in the present. The pursuit of influence can be achieved either instrumentally, when results of the futures studies are utilized as instruments of planning and decision making, or more indirectly, when the results of studies provide material for societal discussion and action. Governmental futures reports or enterprises and communities making strategic planning in order to affect their development are an example of the instrumental pursuit of influence. Examples of more indirect influence are the ”collective” effects provided by influential publications like *Limits to Growth*, UN demographic forecasts, or publications of some influential author. Though these effects are impossible to measure in concrete terms, the indirect effects are much more considerable in a global sense compared to the research focusing on the direct application of knowledge.

The basic objective of this study is not to predict, because actually realizable futures cannot be exactly forecasted. Instead of seeing the future as monolithic and deterministic, the focal point of this study is to see the future as a plurality, future*s*, as a multitude of alternatives to be mapped. Instead of making direct forecasts, the objective is to provide large-scale "manuscripts" of the future, whose value is not determined by their probability to become realized. The value should be determined through the actions and thought processes resulting from the preparation to meet the challenges proposed by these manuscripts. Therefore, the manuscripts provided can be significant even though there is little likelihood of their being realized.

The main goal of this study is to *characterize the most important developing technological trajectories (key technologies) of the future, and analyze and form conclusions about the societal, educational, and professional impacts of these trajectories*. The starting-point of the study was the *construction of synthesis concerning the societal impacts of key technologies*. Therefore, the study has covered a vast field and so it is clear that quite strict emphases and limitations have been unavoidable. The technological division utilized in the study sought to cover the central implications of the most important technologies in the future, although striving for societal synthesis has necessitated that the emphasis of the study remain at a somewhat general level considering the massive amount of detail modern technologies comprise. Detailed analysis would certainly require a different and more limited approach. It should also be mentioned that more detailed studies on information and communication technology and biotechnology already exist (see, for example, Kuusi 1991).

The methodology of the study is based on the Delphi technique with special emphasis on expert interviews. In general, the report is structured like an academic study (theory > methodology > empirical material > conclusions), but, occasionally, some results from the interviews are utilized more widely in order to break up the “traditional” structure. For example, some issues and quotes are treated in the theoretical part and some quotes are used before the actual analysis of the interviews. However, all the material is presented as coherently as possible taking into account the holistic nature of this study.

Finally, a couple of notes about the actual topic of this study: technology. This study seeks to weave a somewhat solitary path covering the “whole chain” of technological action from the hardware to human capital. When the structure of a study moves from the technological sphere towards the societal sphere, there are always pitfalls awaiting the unsuspecting traveler. One of the most fatal pitfalls is the descent into mere technological determinism. The study at hand seeks to avoid this pitfall by *not* considering technology as a societal outsider, as a totalistic object with definite boundaries, and with its own inner logics. Instead, the study approaches technology as part of social action, as part of the complex tissue of society (see Wise 1997). This principle which informed the study from the beginning to end, even when some of the unavoidable generalizations seem to break this principle.

2 Dialectics of Technology and Society

If one was to collect a sample of answers to the question “what is historically the most crucial thing or essence that has made *Homo sapiens* the fastest spreading species and the biggest threat to Earth” from people in Western information societies, the answers would very likely revolve around the concept of “technology”. Actually, this hypothesis could be quite viable even without the sample. It is also quite possible to state that the development and application of different technologies has been the most crucial thing in mankind’s attempt to control and manipulate its environment.

Painting with broad brushstrokes, it can also be argued that there are at least three ways of understanding the interconnections of technology and society. Firstly, *technology can be understood as a kind of comprehensive frame of societal development*. For example, the popular thinker of science and societal development, Jeremy Rifkin, has made a broad statement that technological development is taking mankind through the era of fire towards the era of biotechnology. Arguing this, Rifkin defines the “nature” of era as constructed of certain all-pervasive prime technology. Until the start of the third millennium, this prime technology was fire and now it is quite rapidly changing to biotechnology (Rifkin 1998). Of course, other theorists of societal development could emphasize the accumulation of information and the societal effects of information technology (for example, Castells 1996, 1997, & 1998). Furthermore, other views on societal development would probably characterize different eras based, for example, on different technological innovations and applications. Differences in interpretations can have multiple variations. Yet it can be argued that developmental characterizations like these reflect the notion of technology as a comprehensive frame for societal change.

Secondly, *technology can be understood literally as being “technical”*. This is a quite common “Western” understanding developing as a result of the tireless efforts of thousands of specialists around the world. The notion of speciality is crucial: technology is comprehended as a kind of societal outsider manipulated by specialists comprehending an absolute value in itself, which conditions the economic and societal development and is itself the absolute meter of economic and societal development. Technology just is, it develops and there is no point messing with philosophical trivialities of technological development. The general logic states: just enhance it. In this view, the connection of technology and society is structural: technology is a structure outside society conditioning the development of society through the separate ladders of development (a simplified version of this could be: a certain technology is developed > a certain activity is changed > technology is applied in production and everyday life > society is changed). It can be argued that the linear ladder theory reveals more about certain patterns of thought than about the actual dynamics of technology and society. It tells a teleological tale about a society which develops towards some unknown developmental climax. On the other hand, the linear ladder theory is a very convenient way of building a tale about societal development, because of its appeal to “common sense” sprung from a modern scientific and technocratic rationale.

Thirdly, *technology can be understood as the contextual outcome of dialectical processes of social and physical, material and societal structures*. The dialectical approach emphasizes the conceptual construction of technology and society as a complex. It seeks to trace the contextual genealogies of this complex and uncover the embedded geometries of power within the complex. This framework informs the notion of technology throughout this study. However, the notion of technology is not emphasized in the contextual and genealogical sense, but in the endeavor to understand technology as a nexus of social and physical dimensions. Therefore, the empirical part begins with the analysis of the materialities of technology and moves towards societal implications. The pursuit of this approach is not an easy task, especially in the meager space of an empirical report. So, one should acquiesce to the sentiment that even the slightest tremors in the taken-for-granted ground of technology have more chance of breaking ground than none at all. Therefore, the rest of this theoretical part will clarify some key points in the dialectical understanding of the relationships between technology and society.

2.1 Technology as a thing, technology as a logic

> Technology, as a mode of production, as the totality of instruments, devices and contrivances which characterize the machine age is thus at the same time a mode of organizing and perpetuating (or changing) social relationships, a manifestation of prevalent thought and behavior patterns, an instrument of control and domination. (Marcuse 1998: 41).

The quote above is from the text originally published in 1941 in the famous journal of the Frankfurt Institute for Social Research *Studies in Philosophy and Social Science*. What makes the text interesting from the present point of view is its characterization of technology as a social setting, a network of practices, patterns of thought, institutions, organizations, and finally a mode of production. Marcuse argues that the nature and impact of technology is fundamentally defined by its social dimension, its role as an organizer of ”thought and behavior patterns” and as ”an instrument of control”, instead of characterizing technology simply as a way of producing something. Hence, technology should not just be seen as a way of manipulating material in order to put together a product, but as a form of rationale, a dominant and preferable way of thinking and finding solutions to everyday, as well as more exotic, problems. Taken to the very extreme, one might argue that technology is not about a certain way of producing things or finding the most efficient solutions to problems, but about a certain path of rationalization. Thereby, a dialectical understanding of the interconnections between society and technology starts with the realization that technology is not just a material manifestation of production, a *thing*, it is also a systemic pattern to frame thoughts, a *logic*. A study concerning the implications of technology could approach this basic dichotomy in two ways: by concentrating on the material side of technology and ignoring the social side, or by handling these questions side by side, dialectically.

Besides Marcuse, one of the most interesting critical analysts of technology as a logic is the French philosopher, Michel Foucault. Foucault depicted the epistemological consequences of the techno-logics through the definition of *techne*. At the end of an interview by some architects, Foucault defined the notion of *techne,* taken from the Greek roots for ‘technology’, *techne* and *logos*. Foucault characterized *techne* as ”a practical rationality governed by a conscious goal” (Foucault 1984: 255). The keyword in Foucault’s definition is ‘rationality’ that is specially connected to the rationality of government, to the will to govern and control. In this sense, Foucault was trying to develop a concept that could grasp the social nature of technology as “an instrument of control and domination”, to further quote the extraordinary passage from Marcuse. In defining the concept, Foucault was very conscious of its problematic relationship with the quite limited concept of technology:

> The disadvantage of this word *techne*, I realize, is its relation to the word “technology,” which has a very specific meaning. A very narrow meaning is given to “technology”: one thinks of hard technology, the technology of wood, of fire, of electricity. Whereas government is also a function of technology: the government of individuals, the government of souls, the government of self by the self, the government of families, the government of children, and so on. (Foucault 1984: 255–256).

Although Foucault was speaking first and foremost in the context of architecture, I believe that the continuation of the passage has a very important message for the social studies of technology. The passage continues:

> [I]f one placed the history of architecture [or the history of technology] back in the general history of *techne*, in this wide sense of the word, one would have a more interesting guiding concept than by considering the

> opposition between the exact sciences and the inexact ones." (Foucault 1984: 256).

Reading between the lines, Foucault arrives at the same conclusion as Marcuse: the intriguing aspect in the study of technology is not the characterization of different technologies as a means of producing something but the very peculiar way in which the social and physical dimensions of rationality are combined in the concept of technology. Thus, the most fruitful path to study the relationship between technology and social setting would be to analyze a certain rationale springing from technology, the ways through which a certain mode of production is shuffled along the structures of society, both physically and socially.

For Foucault, technology as a physical means of production was just one form of technology he was interested in. He approached technology broadly as a matrix of practical reason, a way of learning about ourselves (Foucault 1994: 225–226). Technology and sciences were games of truth and power where different vocabularies and rhetorical tactics are exploited in order for people to understand and, indeed, manipulate themselves. There was no monolithic concept of technology; there were plural technologies shifting from the material towards the individual (Table 1).

Table 1. Foucault's characterization of technologies (adapted from Foucault 1994: 225)

Definition	Characterization
Technologies of production	production, transformation, and manipulation of things
Technologies of sign systems	access to signs, meanings, symbols, and signification
Technologies of power	objectivization of the subject, determination of the conduct of the individual, submitting the individual to certain ends
Technologies of the self	"[technologies of the self] permit individuals to effect by their own means, or with the help of others, a certain number of operations on their own bodies and souls, thoughts, conduct, and way of being, so as to transform themselves in order to attain a certain state of happiness, purity, wisdom, perfection, or immortality" (Foucault 1994: 225).

In the essay *The question concerning technology*, Heidegger approached technology as a means to an end which leads to the enframing of the social being (Heidegger 1977). Defined this way, the concept of technology covers Marcuse and Foucault's notions of the social roots of technology *and* the notion of technology as a physically productive force. In this sense, the intertwined Moebius-band of technology as a social and physical dimension can be analyzed as a dialectical agent affecting society and being affected by society.

Thus, it can be argued that technology and society can be studied through *double dialectics* meaning that technology *per se* is understood as both social and physical settings that cannot be separated from one another (figure 1). It connotes that technology has both physical dimension, technology as thing, and social dimension, that is, the conceptions and definitions of technology are based on contracts between people. This means that certain technology has a certain meaning and utilizability only in relation to its users. A further example of technology as a logic is the technological discourse connected to regional planning, where a certain projected essence or supposed transformative quality of technology can regulate the regional development plans. Therefore, it can be asserted that technology in itself has the double dialectic of social and physical, discourse and tool.

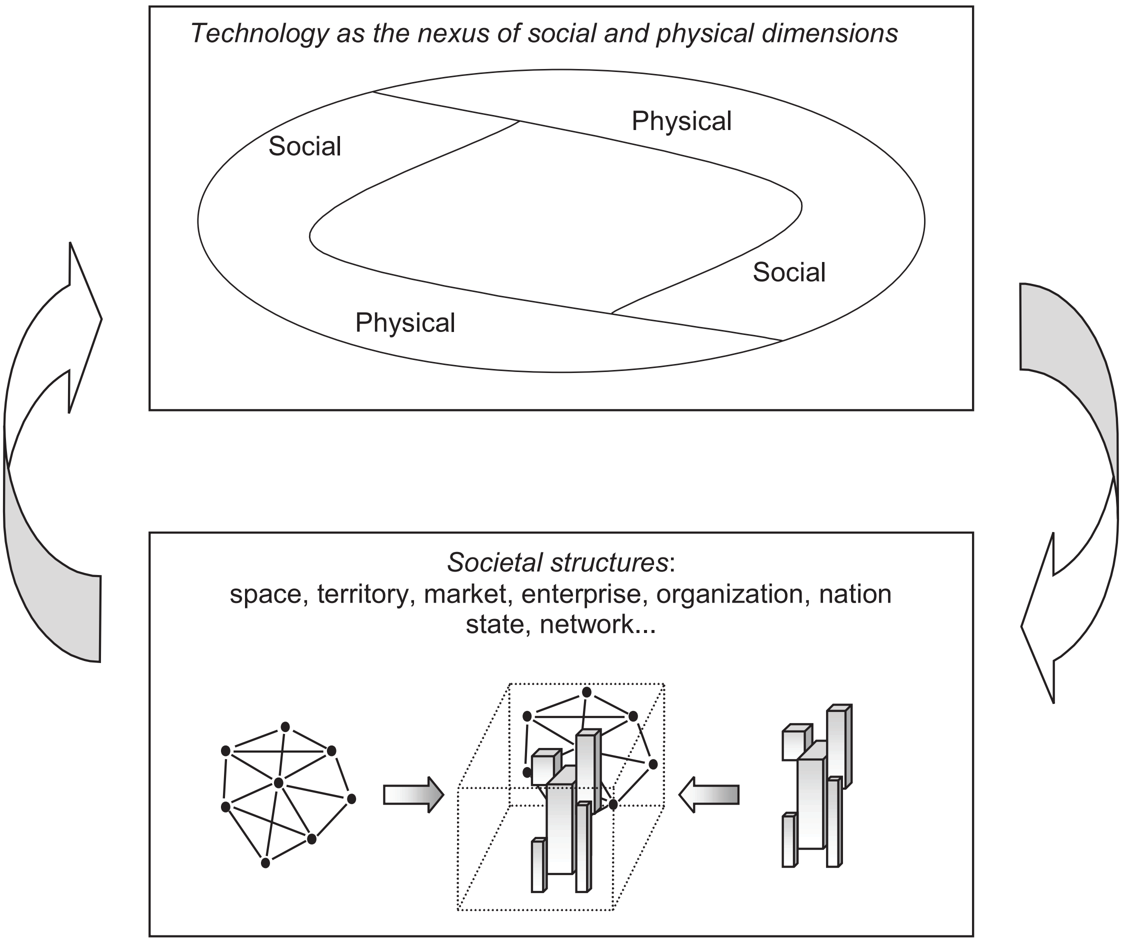

Figure 1. The double dialectics of technology and society

The double dialectic of technology is connected to another dialectical loop of technology and society. The double dialectical mode of technology has further impacts on the structuration of society, to quote the terminology in Giddens. On the one hand, the tool-oriented nature of technology provides society and the global market with infrastructure and objects of exchange. On the other, technological discourse is profoundly changing the ways in which the structures of society are understood. It must also be noted that this loop is not unidirectional but dialectical: societal dimension structures the development of technology. Understanding technology as a continuous dialectical process opens up new opportunities for critical studies of technology (for an excellent general presentation on the matter, see Lash 2002).

2.2 The wave of the information society

As many theorists have formulated, through different terms and varying concepts, (see, for example, Bell 1973, Gershuny 1978, Masuda 1983, Stonier 1983, Castells 1989, Lyon 1988, Harvey 1989, Jameson 1991, Drucker 1993, Lash & Urry 1994) the societal development in advanced industrial countries is leading towards an information society, where the major driving forces are the development of ICT (information and communication technology), the rapidly increasing use of new de--vices, and, most recently, the developing field of nanotechnology (Figure 2).

According to Manuel Castells, the information society emerged in the 1970s with the technological turning point triggered by microchips (see Castells 1996, 1997, 1998). The core of the information society is formed by the technologies of information processing and communication: the logic of information technology is the basis for the development of the information society. At the same time, information and knowledge came to represent the most essential elements both as production factors and as products themselves. The key issue to understanding the information society is not the role of information *per se*, but its self-cumulative nature and its use in the creation of understanding, and the development of information and communication technology.

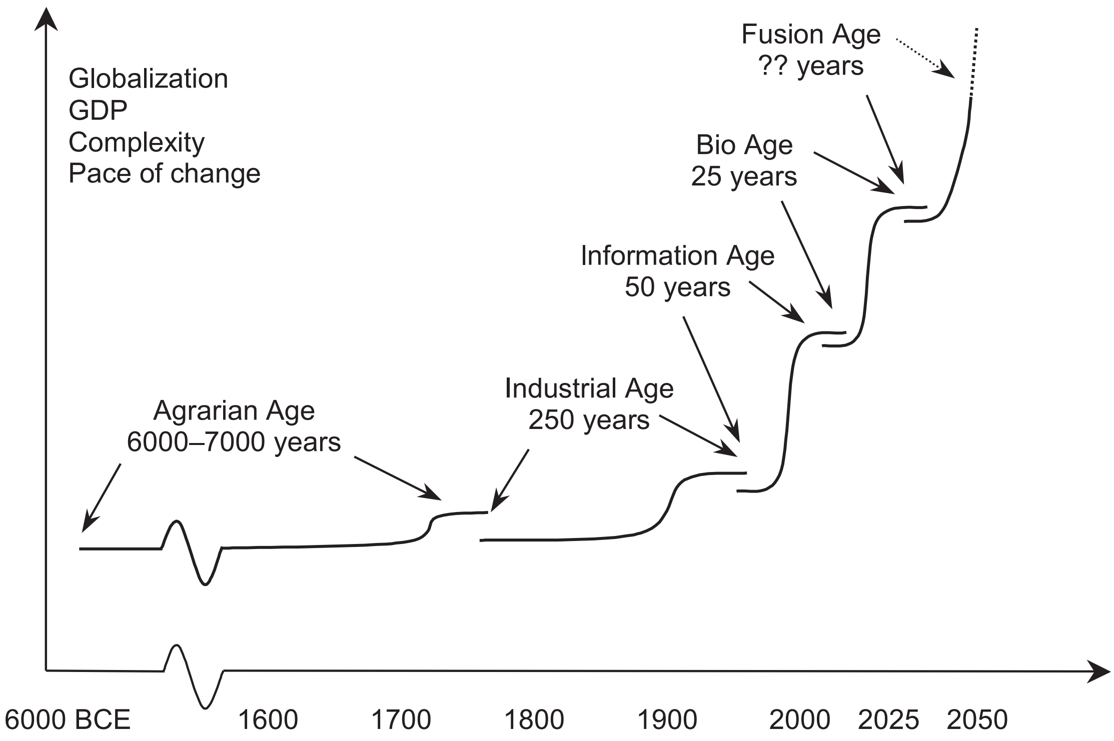

Figure 2. Big waves of societal change (Mannermaa 2002)

Thus, the driving force in the information society has primarily been based on technology as a *physical thing*. The development has emphasized, for example, the growing efficiency of computers, the construction of technology, and more efficient network connections. Mannermaa (2002) argues that the information society includes both agricultural and industrial societies. However, the information society complicates the picture by adding many emergent features like the increase in the amount and forms of information and the rise in the level of interlinkages (see Schienstock & Hämäläinen 2001). Following this argument, it can be stated that the information society will be more complex than earlier societies because of the emerging new features. The increase is expressed not just in the level on complexity, but also as emerging new operations and organizations, as a new level of hybridization between the quantitative and qualitative aspects of the processes. It can be argued that the development of technology has been shifting towards the *social* notion, towards the primacy of content and communicative applications (Negroponte 2003). It can be stated that in the pioneering countries of the information society, for example, the USA and Nordic countries, the content applications have been growing in importance as a driving force of technological development. This is connected to the changing demands of consumers. For example, the decision to buy a mobile phone is increasingly dependant on the services provided, not on the mere hardware (see Figure 1).

Furthermore, it can be argued that along with the intensity of rising content, the notion of maximum mobility will also have a crucial impact on the future of information and communication technology (Mannermaa 2002). This has also been characterized by the new coalitions forming on the basis of the market expectations of new mobile communications. Two main competitive blocks have been formed. The first block is formed by Microsoft, which has announced that in future it will focus more on the applications of mobile computing and consumer products instead of software development. Microsoft's power is based on an almost monopoly in the world of personal computers. It seeks to exploit this monopolist advantage by maximizing the interoperability between its mobile and more "static" systems. The competing block is the coalition of mobile phone producers (Motorola, Nokia, Samsung, Siemens, and Sony-Ericsson) based around the software developer Symbian (HS 2003). The future battle of giants in mobile communications and mobile computing might be fought by these blocks.

2.3 Scanning the next wave: biosociety hypothesis

Reflecting on developing technological trajectories, biotechnology and nanotechnology have also risen in significance along with information and communication technology. For example, in the February 2003 issue *MIT Technology Review* lists and characterizes 10 emerging technologies changing the world. These are wireless sensor networks, injectable tissue engineering, nano solar cells, mechatronics, grid computing, molecular imaging, nanoimprint lithography, software assurance, glycomics, and quantum cryptography (MIT Technology Review 2003, see Table 5 in this study). On this basis, it might not be too suggestive an hypothesis that the next societal phase after the information society is already in its embryonic state (Mannermaa 2002).

This next stage is based on the societal implications of biosciences: biotechnology, genetic engineering, applications of nanotechnology, etc. Mannermaa labels the emerging societal phase 'biosociety' and argues that it is an even more complex form of society than its predecessors. Agrarian society was based on agricultural technology. The technology used was aimed at the satisfaction of basic needs (food, clothing, shelter, etc.). The next phase, industrial society developed and used the technology of mass production. This meant that not only the basic needs, but also more tangible ones were satisfied. The information society got its label from its technological basis, from information and communication technologies. In the information society, the central emphasis is laid on intangible needs: that of communication, culture, learning and entertainment, and other immaterial needs.

In the biosociety, the main emphasis is also on the intangible needs, but the *technological basis* and *technological capacity* will also transform. Technologies in the biosociety will be more comprehensively based on manipulating biological processes and mimicking biological processes. According to Schwartz, Leyden, and Hyatt, the basic philosophy of biotechnology drives the change:

> What is biotechnology? It is human technology that emulates or leverages biological processes that nature has perfected through evolution over millions of years. Nature has evolved an amazingly complex and elegant system that is so far beyond what we humans have come up with that we may as well just start copying it as fast as we can. (Schwartz *et al.* 1999: 191).

Connected with modern information technology, this development will lead to vast and far-reaching opportunities in medical research, as well as in manipulating life itself. For example, Fukuyama and Stock argue that many of the opportunities will definitely open up through basic research, because of the general impetus of extensive input into the research into biotechnology (see Fukuyama 2002 and Stock 2002). Indeed, bio*technological* research and development is being carried out intensively all over the world in developed societies. However, very little research has been done considering the prospects of the bio*societal* developments. It is almost ironic that at a time when technological applications of biosciences are developing at a rapid pace, the empirical and theoretical knowledge about the societal implications is still so minute that it is almost an exception to the general rule.

2.4 Riding the big wave: towards the fusion society?

In the 21st century, developing biotechnology and genetic technology have already been the catalysts of major scientific and economic endeavors. Hence, it is sensible to make a hypothesis of biotechnology as the new fundamental technological dimension of societal development leading to the biosociety. The characterization of the societal waves as “definite” and “clear cut” is a very difficult task as this interesting quote from the expert interviews illustrates:

> *I think that the biosociety is a variant of the information society. It is captivating in the sense that it will touch all of us. It is like the transformation between the propeller airplane and jet airplane. The same technology becomes more efficient. Nanotechnology will also be fused into the biosociety. (interviewee)*

Indeed, this quote probably captures the essence of the technological future to come: more and more technologies are converged into systemic “totalities”, which melt and fuse the traditional categories and boundaries of technologies. On this basis, Mannermaa makes a further hypothesis about the societal form emerging after the biosociety: fusion society (see Figure 2). Fusion society will have the main characteristics of the previous societal development phases like the biosociety, information society, and industrial society, but the most characteristic feature separating it from the previous (yet still “subordinately” existing) societal forms will be its *systemic nature*: interactions between different technologies, technologies and the environment, economy and society (Mannermaa 2002). However, much research is needed before the technological and societal consequences of this fusion society can be elaborated. One must also bear in mind that even though such big wave glances towards the futures are very important, for example, in constructing scenarios, there is always the chance that the turbulent and contingent nature of the future plays an unanticipated trick on the humble observer of technological trajectories. But the lack of certain ground is what basically makes observing so interesting.

3 Methodology, Data, and the Composition of the Study

The general aim of the study is to *evaluate the impact of emerging new technologies in the contexts of societal development and vocational education*. Emerging new technologies are here defined primarily as the applications of information and communication technology, content production, biotechnologies, material and nanotechnologies, and technologies emerging from the fusion of these technologies.

The special aims of the study are

1. To analyze the contemporary knowledge about the emerging technologies and their impacts on societal development and analyze the educational policies connected to information and communication technology, biotechnology, material and nanotechnology in the context of the emerging biosociety (literature, expert interviews).

2. To produce estimations through literature, expert interviews, and the futures barometer about the most significant emerging new technologies, for example,

    - technologies based on content production and technological convergence (the convergence of information management, entertainment, speech, images, etc.)

    - the emerging technologies of biosociety (biomedicine, genetic engineering, nanotechnology, fusion technologies, e.g. the fusion of microelectronics, optoelectronics, and molecular biology).

3. To provide assessments about the central technological phenomena and estimations about the developmental trajectories of these technologies.

4. To estimate the future impact of the most significant technologies on the transformation of labor.

5. To give inferences and recommendations to the development of vocational education.

3.1 Principles of the Delphi technique and futures barometer

The methodology of the study applies the Delphi technique, which is one of the most utilized research techniques in futures studies (for a detailed analysis of the method, see Kuusi 1999). Simply stated there are three basic principles characterizing the Delphi technique: the presumption of expertise, iterativity and the technique's relative independence of space and time (Mannermaa 1996).

The starting point is *the presumption of expertise* and, furthermore, anonymity of expertise. Basically this presumption refers to the notion that there is real expertise to be found in the world and experts can make better estimations concerning their field of expertise than laymen. The *notion of anonymity* refers to the implementation of the Delphi technique, for example, as a questionnaire: the group of experts is chosen in advance to fulfill some purpose, but reporting the results of the studies should deal with the data as one sample of experts.

The second principle is *iterativity*, which is one of the most distinctive characteristics of the Delphi technique. It is also the reason of why the Delphi technique is usually carried out in two rounds. Iterativity in this case means that the experts are given feedback from the first round of results in the form of questionnaires, interviews, or group sessions. The feedback given can be, for example, information about the average results or about the variation of results. After presenting these first round results, the experts can modify or alter their estimations and explain the deviating values.

The third principle, *relative independence of space and time*, refers to the wide applicability of the Delphi technique. It can be applied, for example, to the mapping of the possible future developments of society, technology, firm, or certain group of people. The methodology *per se* stays the same, only the experts and questions vary. Therefore, the Delphi technique is especially good in situations, when decisions affecting the future have not been made, that is, the future is not a direct continuation of the past, and in evaluating the societal and technological development trajectories, the change in the environment of the firms, institutions, etc. in the long run (10–15 years).

The futures barometer is a methodology based on the Delphi technique. In the futures barometer, all typical presumptions of the Delphi technique are made: the presumption that the problems of the study can be approached and solved through expert questionnaires, iteration gives useful insights, etc. The futures barometer provides basic material for discussion about the future. Results will not give direct information about the future (they are not predictions), but will tell about the future expectations and future insights of the group of experts. These studies produce a kind of trend-anticipation material even evaluating the development of certain restricted cases. Hence, the material produced through executing the futures barometer form a good basis for scenario work or strategic planning, for example, in a particular firm (Mannermaa 1996).

3.2 Composition of the study and the formation of key technological groups

This study was completed in three empirical phases. The *first* phase was the preliminary phase where the *general technological paradigms* and *actual key technologies* were defined through expert interviews and the literature. Scanning the technological paradigms was to form a basis, a primary vision, for the detailed characterization of key technologies. After the formation of the paradigms, the definition of the key technologies could be described as follows: literature exploration > experts interviews > creating lists of probable technological trends > definition of key technologies. Technological paradigms and key technologies were identified on the basis of the literature and expert interviews made in Fall 2001. The most important literary sources were the National Technology Agency's (TEKES) reports and the *State of the Future* report from the United Nations' Millennium project (http://www.millennium-project.org). Other of interest literature was (Ahola & Kuisma 1998, Ahtee *et al.* 2001, Ball 1998, Dening *et al*. 2001, Hjelt *et al.* 2001, Hill & Glasgow 1999, Lievonen 1999, Meristö *et al*. 2002, Miles & Keenan 2000, Rautiainen 1999, Saranummi 2001, Toivonen 2001, Tuomaala *et al*. 2001, Tuomi 2001, and Yu & Siegler 2000). Three basic technology groups were formed on the basis of collected information:

- Information and communication technology (ICT)
- Biotechnology
- Material and nanotechnology

Lists of technological innovations and their detailed characterizations belonging to the basic groups of information and communication technology (ICT), biotechnology, and material and nanotechnology were formed as the primary result of the first phase.

The *second* phase was the first round of the Delphi technique where an Internet-based questionnaire was sent to various experts. The objective of the first round was to gain expert opinions on technological theses and phenomena constructed through the preliminary phase. During the first round, structured expert interviews were also made. The orientations of the experts concerned the fields of research and development of technology. The *third* phase was the second Delphi round. In this phase, the impacts of technological trajectories constructed in earlier phases were tested in the fields of education and societal development. The second Internet and electronic questionnaire was sent to experts. Structured expert interviews were also made in the third phase. Mainly societal experts were interviewed in the third phase.

4 General Paradigms of Technological Development: Collected Results from the Interviews and Literature

4.1 Information and communication technology

A massive expansion of markets and products was experienced in the field of the ICT industry during the 1990s. The huge rise in the volume of production and, above all, the anticipated future value of the ICT products lead to the global overheating of the markets. One started to hear speculation about an information technology "bubble" referring to the overestimations of the developments in markets and technology. The bubble finally burst at the end of the 1990s and the start of the new millennium. This lead to a massive stock price fall and lead the ICT industry into a state of stagnation from which it has not recovered.

Nevertheless, it might be argued that the ICT industry is probably becoming structurally more stable and balanced. Here the structural change of the ICT industry refers to the shifts in the balance between technical know-how and knowledge content. "ICT is currently going through the process of normalization and is becoming an ordinary customer-oriented business", as one interviewee said. There are, however, quite a few problems to overcome before the structural change of the ICT industry might be completed. The competitive edge has already started to shift from the hardware-technical competence towards the software-knowledge centered approach. One of the interviewees reflected on this structural change saying "it remains to be seen, if there are too many engineers produced at the moment [in Finland]. There are no longer takers for the flood of engineers".

According to the results of the interviews, the following four trends will be important in the development of ICT: continuing informationalization of work, developments in information management, intensification of entertainability and a kind of leveling down or "democratization" of information. One of the most pervasive trends of the future will be the continual *informationalization of work*, that is, the need for "symbol analysts" will also remain high in the future. One of the interesting themes raised in the interviews was the more competitive nature of work. Work environments will become even more "Darwinist" when people are hired for short-term project vacancies. Two basic issues will still be the cornerstones of future work, as one interviewee noted. The first key question is "the availability of the workforce". In order to create enough new inventions to keep the economy viable, there must be a capable workforce in the market. The second key question is "the state of the workforce". If the "Darwinist" battle of the fittest employees becomes harsher then "somebody has to take care that current 30-year-olds are not burnt out until the age of 50", as one interviewee aptly put it. The ICT competencies have become a few of the most general qualifications of the contemporary employee. This trend will intensify in the future and ICT competencies are not just part of the same group of general qualifications like social skills, language skills, communication skills, etc. but even more profound: the actualization of many of the general qualifications requires the implementation of information technology.

Another key trajectory is the *developments in information management*, especially in interfaces and search engines, search robots, and personal "avatars". These "avatars" or intelligent agents play an important role in the creation of the information management systems, especially since the driving force of the development is to create mechanisms to cope with large amounts of information that might contain much "noise". These search robots will be particularly requisite in the utilization and structuring of databases containing large amounts of data. One of the key notions in information management is visuality linked with the new mobile technologies and high-bandwidth connections. Different positioning applications and contemporary 3-G techniques will probably shift the balance of communication towards visuality. What kind of communication hybrid springs from the combination of text, speech, and images in the mobile platform still remains to be seen.

According to preliminary interviews, one of the key features in ICT will be the *intensification of the entertainability*. It will manifest in the classical realms of entertainment in a sort of reality-orientation: for example, more emphasis is given to "concrete realism" in the development of computer games. Another important trend is the development of games for mobile platforms. But the entertainability is affecting not just games or realms considered entertainment *per se,* but also the fields of official and business services. In general, this emphasis of entertainability reflects the demand for more user-friendly and approachable applications of technology. A comment from the interviews sheds light on this issue: "previously the device was built and only then has it been considered where to apply it. Now it must be the other way around. No more technology for the sake of technology".

Alongside the demand for entertainability is the *trend of "democratization" and internationalization*. According to an interviewee, basically,

> *anybody can establish her own TV-channel on the Net without having to purchase a digi-tv-license or expensive infrastructure. Foreign content will spread to Finland easier and faster. It means that domestic actors must learn more and more to compete with quality. (interviewee)*

One of the important features connected to this trend is the pluralization of direct marketing. As one interviewee noted “marketing will reach e-mail and mobile phones, so that the receiver will get paid for reading the advertisements.” This possible trend of getting paid to read the advertisements will be a result of the unification of production and products: there are no significant differences between products provided by different manufacturers, and differences in quality will also be quite minimal. One view was that this development will lay emphasis on marketing: “those media which have a functioning direct marketing system are successful”.

4.2 Biotechnology

As a concept, biotechnology is as wide as information and communication technology. Basically anything from the enhancement of washing powders to medical diagnostics, modification of plants, cloning, etc. is considered biotechnology. OECD has defined biotechnology as ”the application of science and technology to living organisms, as well as parts, products. and models thereof, to alter living or non-living materials for the production of knowledge, goods, and services”. (http://www.stat.fi/tk/yr/ttbio_en.html).

One of the interviewees characterized biotechnology as a medical research field:

> *Biotechnology is a branch of research which requires intensive cooperation between its various application fields. It is about the study of very complex phenomena at the genetic level which does not move an inch without the most effective information technology. (interviewee)*

Among the interviewees there were differences of opinion concerning biotechnology as the next big boom after ICT. The greatest reservation sprung from the issue that making products in the field of biotechnology is very “slow”. The actualization of products will take about ten years of research, development, and testing on average. And still there are many uncertainties involved: there can be a change in the political environment which blocks the development of the product, the application of the product might have unanticipated consequences impossible to predict, etc.

Considering the long research and development phase of the products, the fundamental question in the economic applications of biotechnology is funding. The biosector is very capital intensive and requires long-range investments. Research and development in the field of biotechnology needs financers willing to pay for the possible future value of the products and take the chance that the R&D process might not succeed after all the investment:

> *One way for a small biotech company to make a profit is by selling the expected value of a product to a larger company. The development of the products stays with the small company. In the course of the development process, the large company pays down payments and milestone funds. (interviewee)*

For example, in Finland one of the key financers of biotechnology has been SITRA (Finnish National Fund for Research and Development), which is a public foundation under the supervision of the Finnish Parliament. According to an interviewee, SITRA thrives on finding research issues not on the contemporary agenda. In the 1980s, SITRA had a huge impact on the creation of markets for capital investments. Today, there are about 40 funds which compete with SITRA.

As long as the quite strict restrictive policies are applied in the field of biotechnology, the formation of large-scale "hypes" as seen in the ICT sector will not loom on the immediate horizon. The issue will be quite different if the political climate changes, or a major breakthrough or some other unanticipated thing happens. For example, one interviewee discussed the interesting possibility of the rise of new ”bio-induced commodities”. In the same vein, the American futurist Richard Oliver has characterized the combination of the biological and advanced materials sciences as the coming age of "bioterials" (bio-materials). According to Oliver, chemistry and physics were the drivers of technology in the 20th century. But in the 21st century

> the biological and advanced materials sciences are creating a new economic engine – 'bioterials' technologies – that will dramatically drive the economics of the twenty-first century… In less than a generation, virtually every company will be a bioterials company – either an integral part of the development and use of the technology or dependent on it for survival and success. (Oliver 2000, 1–2.)

If these ”bio-induced commodities” or ”bioterials” would be as applicable and as generalisable as, for example, mobile phones, these commodities would have huge market potential. However, the nature of these commodities is hard to imagine from the contemporary perspective. It must be noted that product development of biotech industry might not replicate the highs and lows of ICT. On the contrary, the biotech industry might be successful, *because* its slow product cycle will generate a more wavelike form of development instead of incremental steps and hypes.

Excursion I: regional aspects on biotech industry

There are considerable regional differences in the adoption and development of biotechnological products. For example, the rough global distribution of profits in medical industries is 60 percent in the United States, 30 percent Europe, and 10 per cent Japan. During the interviews, different regional aspects of the biotech industry were collected. This chapter gathers these aspects into a qualitative comparison between Europe, the United States, and Japan. This comparison aimed at gaining a deeper understanding of the regional characteristics influencing the development of the biotech industry. The results of the comparison can be subdivided into two groups: historico-societal and politico-economic.

There are differences between Europe, the United States, and Japan in the adoption and reception of biotechnology. These differences sprung partially from *historico-societal reasons*. Generalizing from the arguments of the interviewees, the reason that Europe has a longer tradition Western science than the United States and Japan raises differences in the reception of biotechnology. According to one interviewee, ”Europeans can quite easily be made to believe that they have already reached the technological optimum and whatever [technology] is drawing near should be investigated with maximum caution”. Generalizing from the interviewees, the people of the United States do not see themselves as having fulfilled any technological maximum although the USA is the leading country in biotechnological research and production. Somehow, the United States approaches biotechnology in a more modest way and see itself as more at the start of the technological curve despite the successes. According to one interviewee, this attitude reflects the technology belief, which the interviewee sees as one of the factors behind the biotechnological success of the USA. This technology belief is manifested through the idea that every consequence of the adaptation of some invention does not have to be known in advance, because these problems can be solved anyway through science and ”rational thought”. This argument resonates nicely with another interviewee who argued that

> *Europeans can quite easily be made to believe that the basic building blocks of the ideal world exists somewhere in the past [and] if you take the best working bits of the ideal world in the past and combine them with the best parts of modern society that would be the actual ideal world. (interviewee)*

Hence, for Europeans the ideal world would be an improved version of the past rather than the future. According to the same interviewee, for example, Green parties in Europe are underlining such logic.

The *politico-economic reasons* are based on the conception of the interviewees that biotechnology is entrepreneurial science *par excellence*. Therefore, the most important discoveries and inventions are made in small and medium-sized enterprises and research laboratories. A typical feature of biotechnological research is that about four-fifths of the most important discoveries are made by research groups of 3 to 30 people. Large multinational companies enter the picture when the commercialization of the product is at hand. For example, one interviewee referred to the discussions with GlaxoSmithKline's research representative who said that most of the research can and should be outsourced in future because of the more innovative nature of small enterprises and research groups. Thus, the interesting question is why is research and development more fruitful in small companies? According to the interviewees, the reason can be found in the concepts of *creativity* and *flexibility* (see Negroponte 2003).

> *[The research] is [successful] because stretching the frontiers of science requires creativity. Creativity does not fit well into the large structures where certain rules must be adhered to and where certain limits cannot be crossed, even though large companies usually pretend that they have an open environment for creativity. (interviewee)*

However, sometimes large companies even encourage the most creative researchers to spin out and perform the projects independently with financial help from the large company. Quoting one interviewee, large companies are beginning to realize that "if you give these people total freedom, the likelihood that their minds will be maximally productive is much higher than within the large company".

Comparing Europe, the United States and Japan. According to the interviewees, the situation in Europe regarding the net sales of the biotech industry can be compared to the United States ten years ago. The pioneer firm Genentech started in the 1970s in the United States. The first products were available at the end of the 1980s. To generalize, the phase of products and applications is just starting in Europe. The industrialization of modern biotechnology got its momentum in the United States even though quite many of the important discoveries in modern biology are made in England. The United States has become the leader because it was where modern biotechnological research was practically founded. Currently, a general scientific level compatible with the USA already exists in Europe, but many North American companies are much more advanced in the development of products and commercialization. Therefore, European companies are in quite a vulnerable state compared to the American ones. One reason the North American biotechnological industry and research is so competitive is that there is much funding available through private foundations and corporations.

In Europe, the number of firms in biotechnological research and production rose dramatically at the end of the 20th century and the start of the 21st. Currently, the number of firms in the field is higher in Europe than the United States, but the European firms are considerably smaller if the turnover rates are compared. This is because biotechnology as an entrepreneurial business is still quite young in Europe and the actual ”selection of the fittest” firms is still largely unexecuted. The European Union (EU) has started to play a very important role in the field of technology. One of the most significant impacts the EU has had is the increase in cooperation between research groups across Europe. The most significant impact the EU has had is on the enhancement of cooperation in the search for research funding. One serious problem raised in the interviews is the highly bureaucratic nature of the European Union's funding policy. The bureaucracy of DG-12 headquarters in Brussels was compared to the Moscow Committee of Science and Technology with the emphasis that the European Union's standards are even much more bureaucratic. The second problem in the EU research funding was the idea of multilevel cooperation in the projects, that is, connecting large networks of university research groups, private research groups, small and medium-sized enterprises, and large enterprises. Interviewees commented that as a principle it is very good, but in reality the system does not work properly, because

> *none of the truly competitive biotechnological corporations will join the international consortium with really cutting edge information, because this kind of large consortium leaks like a sponge. Secrets are not secured within this kind of structure. (interviewee)*

According to the interviews, one solution is to design more focused and smaller projects. Such a procedure would keep the number of actors in the project networks within certain limits and trust among them can be formed much quicker. The second solution presented in the interviews would be to fund strictly academic projects. The procedures and technologies developed in these projects could then be sold to the private sector.

In the context of the European Union, the interviewees reflected on the discussion about the concept of BioEurope (bEurope) much in the same vein as the already established eEurope. The discussion considered the model of bEurope and the different opportunities it had. As one of the interviewees expressed

> *bEurope should be a convergence of different cultures, humanities, social sciences, and medical sciences. It should not be as overwhelming as eEurope which tried to make everyone conform to the same mode of speeches and acts. There is the risk that the biosociety will not be promoted and fostered if the push is too hard. (interviewee)*

It was emphasized that bEurope should not be launched like eEurope, as a top-down conceptual framework to which everybody must adapt. Instead it should be promoted as a bottom-up process, which emphasizes the actual economic potentials.

For many interviewees, Japan is a kind of interesting enigma. Firstly, some interviewees see that Japan has very good opportunities in some special sectors of biotechnology. Secondly, some are still portraying Japan as an industrial copyist and license buyer instead of an original inventor of technologies and procedures. Many interviewees noted that Japan has considerably intensified its basic academic research and this will eventually lead to the decline of the second option at the start of this chapter. Interviewees saw that the most crucial shortcoming in the structure of Japanese biotechnology is that the relations of industry and the academic world do not work properly. This has much to do with the rigid hierarchical structures in both industry and research. The rigid hierarchies considerably undermine the effective adaptation and utilization of technological innovations compared to, for example, the United States. One interviewee gave an interesting insight into the state of Japanese biotechnological research: Japanese basic research might leap totally over the ”genomephase of development” and aim straight ay proteomics, to the research and development of protein technologies. One reason for this argument might be that the Japanese have 50 percent of the patents in the field of carbonhydrate metabolics.

Excursion II: some societal implications of the developments in genetics

> *I quote Winston Churchill: this is not the end, this is not even the beginning of the end, but this is the end of the beginning. (interviewee)*

The central contemporary advance in biotechnology has been the sequencing of the human genome. The level of information has increased vastly: from the level of one or two percent to almost hundred percent. One interviewee compared the results of the sequencing to “a telephone book, where you can find everyone who has a phone, not just those with a certain model. A couple of years ago we had just one hundredth of a page to read but now we have almost a complete book”. Another interviewee made the analogy of sequencing to “alphabets” and “the anatomy of genes”. Generally, the sequencing of the human genome might reflect a return to systems thinking. According to one interviewee, it is time to “get back to systems biology in which one tries to understand the functioning of the biological systems and interconnections between cell and organism”.

According to the interviews, the most rapid results of the sequencing will probably show in diagnostics. One interviewee predicted a new rise for the medical industry.

One basic thing that might cause this is the possibility of shorter spans in the development of pharmaceuticals. On average, the development of pharmaceuticals takes 8 to12 years. There is a chance that the amount of utilizable genetic information will enable computer modeling instead of time consuming experimental work. The utilization of computer modeling would considerably shorten the first stage and make the total time about 6–8 years.

There is a difference between monogenetic diseases and other hereditary diseases. Monogenetic diseases are very rare and much information is already attainable. One of the promising applications is the recognition of receptivity genes of the more "common" diseases, for example, blood pressure, diabetes, asthma, rheumatoid arthritis, several neurological diseases, maybe ultimately mental illnesses with certain biological base mechanisms, such as Alzheimer's. The medical industry strongly supports the research of these diseases and the best case scenario is that after the mechanisms of the diseases are unraveled, systematic, engineer-like planning of pharmaceuticals can be started. There are also ethical issues involved: the highest economic interest are in those diseases which are the most difficult diseases according to public opinion. These are also the diseases with the highest market value.

According to an interviewee, history has quite effectively shown that when enhancement of health is set as a primary target the development of pharmaceuticals has been very efficient and relatively cheap. Such examples are the prevention of infectious diseases with vaccination, treatment of premature infants, etc. It must also be remembered that everything is not about genes. As one interviewee noted in technical language: "Fenotype is genotype and the impact of the environment to the genes. Genes are flexible, genes are just a possibility".

4.3 Material and nanotechnology

Molecular Alley may be superceding Silicon Valley (Mulhall 2002: 35).

Richard Feynman's classic lecture given at the meeting of the American Physical Society in 1959, *There's Plenty of Room at the Bottom* can be considered a start to the discussion about nanotechnology (see Mulhall 2002). There he described the possibility of manipulating materials at the molecular, nanosized level proclaiming that building things atom by atom is not restricted by the laws of physics in general. The field of nanotechnology is quite young and the terminology to characterize nanotechnology has not yet been fully standardized. Some include different biological processes (for example, in genetics) in the sphere of nanotechnology, some include only material technologies, some chemicals and molecular structures (Mulhall 2002: 39). But the importance of the field of nanotechnology is emphasized for example, in the United States through the National Nanotechnology Initiative established in 2001 between the Universities of Columbia, Cornell, Rice, Northwestern, and Harvard (Mulhall 2002: 36).

One of the breakthroughs in the field of nanotechnology is the invention of nanosized machines. For example, scientists from Bell Labs and the University of Oxford have made DNA motors. DNA-motors are

> devices, which resemble motorized tweezers, are 100,000 times smaller than the head of a pin, and the techniques used to make them may lead to computers that are 1,000 times more powerful than today's machines. (http://www.lucent.com/press/0800/000809.bla.html)

The inventors might have great expectations of this technology as a potential replacement for a manufacturing method for integrated circuits. This nanosized device could replace the traditional transistor technologies and have great potential because of its small size. According to Bell Labs' physicist Bernard Yurke "DNA is an ideal tool for making nanoscale devices". Physicists at MIT and Harvard and companies like Sun Microsystems are experimenting on artificial atoms – atoms which can be modified artificially. "Such atoms, when stimulated electronically or optically, allow the creation of programmable matter: substances with properties that can be adjusted precisely and repeatedly." (Mulhall 2002: 36).

High expectations are laid on the applications of material and nanotechnology from the perspective of technological fusion. The fusion technology springing from the combinations of nanotechnology and electronics can be called *nanoelectronics*. The field of nanoelectronics consists of nanosized electronic applications, for example, molecular transistors. It has been investigated whether these molecular-scale transistors – that are only a billionth of a meter in size – could be integrated with silicon-based circuits and thus build a link between old and new computing technologies. The fabrication of these molecular-scale transistors may lead to the development of smaller, faster, and cheaper computer chips in the future.

Another example from the emerging field of nanoelectronics is the nanotube plant built by Mitsui, which is aiming at the mass production of carbon nanotubes. These carbon nanotubes are expected to have an impact on applications in fuel cells and automotive bodies. These developments are paving the way for the new "nanotechnology of nature" described by Michael Gross (Gross 1999).

The fusion of biotechnology and information technology, *bioinformatics*, is also already well on the way and more fusion technologies are very likely to emerge in the near future. For example, the understanding of structure and the functioning of human brains, how to simulate the brain in information technology and how to build as hard a material as bone. In medicine, for example, functional or intelligent polymers will be of crucial importance. Functional polymers can be utilized, for example, in controlling the doses of medicine. According to the press release of the American Association for the Advancement of Science, James Ellenbogen of the Mitre Corporation pronounced that the development of nanoelectronics is ahead of its “schedule” and “some of today’s research is nearing the stage where it could be turned over to industrial production”.

4.4 Technology, expertise and ethics

The ethical issues of modern technologies are quite often on the public agenda, especially in the case of biotechnology. The issue of ethics has also been raised by analysts of technologies (see, for example, Fukuyama 2002 & Stock 2002), as well as philosophers (see, for example, Launis 2001 & Takala 2000). The topic of ethics has become so important in many studies and research that part of the funding for the development of technology is already channeled to the research of the ethical consequences. For example, approximately 5 percent of the public research funding provided by the European Union in the field of biotechnology provided in different countries is channeled to research of the ethical and social consequences of these technologies. Another example is the ethical consultants utilized in the different levels of European government, for example, in EuropaBio, the organ for the development of biotechnology. The EU has been quite active in the field of biotechnology and started different programs and forums. For example, a forum called *Temporary committee of human genetics* was launched in 2001. This forum consisted of specialists, laypeople, patient organizations, members of national parliaments, NGOs, etc. Another example is the ELSA initiative (ethical, legal, and social aspects of research) in the fourth framework where the agricultural and biomedical fields have been on the agenda. According to the interviews, one problem might be the fact that the ethical discussions in the bioindustry are not so thorough because of the direct economic interests involved in the issues.

The points of view on the ethics of technology and the role of experts were collected from the interviewees. The point that caused the broadest consensus was the view that the most important role for experts is to anchor the public discussion to facts and the realities of science and research. But a quite uniform opinion reigned also over experts being as lay as anyone else in ethical questions. One interviewee commented that the situation where the discussion has not been anchored to realities has created “some kind of protest spirit” in Europe, which

> *is now focused on biotechnology where horror scenarios can be made up. For historical reasons, the general attitudes towards biotechnology are very cautious in Europe. (interviewee)*

The general view among the interviewees was that in the context of the European Union much more discussion is needed. The problem, of course, is that ethical discussions have direct political tendencies. For example, Green parties in some countries have taken the resistance to Gmo-plants in the direct political agenda. Interviewees were concerned that, for example, the discussion of bioethics tends to have mystifying tones. As one interviewee noted:

> *Facts should be cleared first. The viewpoint that genetic technology is absolute evil cannot be the basis of a sensible discussion". In this sense, interviewees claimed that there is quite a "medieval" atmosphere towards the discussion of the ethical issues of technologies.*

In the interviews, there were several alternatives mentioned in order to provide information for the basis of citizen discussions. One interesting basic level solution would be to widen the concept of education. One way to widen it would be to provide up-to-date information of developments in natural and social sciences, technologies, environment, and research in the elementary level at schools. The information about the contemporary world is, thus, brought alongside the classical education. As one interviewee noted, for example, in Finland Nokia has had a huge influence in "adapting" and "teaching" people the wonders of information technology. As the interviewee claimed: "Now would be the right time to educate people [in biotechnology] like Nokia "educated" the Finnish people in the case of mobile phones". An interesting proposition connected to the education in contemporary events is to teach primary systems thinking: one should teach issues at the global level and make pupils consider the implications of different actions. One crucial issue in this sense for the scientist is to make the information accessible so that it can be taught in schools and the basic issues understood by the undedicated laymen. As one interviewee noted, this is probably the most crucial current challenge, for example, of both electronics and biotechnology. A very important question was raised by one interviewee: how to do all this and, at the same time, avoid the "oligarchy of experts"?

5 Key Technologies of the Future Systematized

In this chapter, the results of interviews in the first round are combined and presented. The basic method of the section was forming the technology lists. These technology lists were formed in an interactive and overlapping process by the experts, which consisted of forming the lists of technologies, checking, and reformulating them. After several rounds of checking and reformulating, the main aim of the lists were finally considered to be achieved[1] and the "final" list of possible key technologies was formed. The combined results of the technology are presented in Table 2. The formation of the technology lists structured the completion of the first and second Delphi rounds. What follows is the short characterizations and depictions of the above-mentioned key technologies and the trends involved in their development on the basis of interviews and literature. The characterizations are divided into the three main technology groups of information and communication technology, biotechnology, and material and nanotechnology.

Table 2. Result of the preliminary phase: the key technological trajectories of the future systematized

Information and communication technology	Biotechnology	Material and nanotechnology
• Advanced data storage	• Artificial organs	• Biocompatible polymer surfaces
• Artificial intelligence	• Biochips	• Fuel cells
• Computerized healthcare	• Biomimetics	• Functional polymers
• Distance learning	• Cloning	• Intelligent materials
• Electronic paper	• Genetic engineering	• Miniaturization
• Human computer interface	• Genetic therapy	• Sensors
• Modular software	• Targeted pharmaceuticals	• Superconducting materials
• Neural networks		
• Optical computers		
• Intelligent agents		
• Ubiquitous computing – UbiComp		
• Applications of virtual reality		

1 The lists collected from the experts were beginning to reach unanimity and it was decided that this was the "saturation" point for collecting the technology lists.

The following section presents a short characterization of each of the key technological trajectories defined in this study. The aim of the section is to present and discuss the key notion of each technological trajectory.

5.1 Information and communication technology

Advanced data storage (ADS) refers to the changing technologies in saving information and data. Contemporary information systems and modeling codes capture, store, manage, and explore huge amounts of data and this puts pressure on developing data storage technologies. ADS consists of keeping records, archiving, preserving and exploring results, granting access to and disseminating new findings, as well as providing back-up capacities (http://www.media.mit.edu/). Conceptually ADS is actually at the very core of the information society: the "eternal", distributed, and global memory is one of the key factors separating the information society from the previous societal forms. In an agrarian society, a person could basically move to another town in order to wipe their past away. The "wiping of the past" was partly possible in the industrial society. In the information society, this is no longer possible because of the global memory[2]. There is much research going on in this field (see, for example, the list of web pages at the end of the references). New fields of research emerging in this field are, for example, high performance storage systems, data management tools, support for high performance, data mining, data processing, visualization, data formats, and data interoperability.

Artificial intelligence. The field of artificial intelligence was born in 1950 when Alan Turing described a new agenda for computer science in the paper *Computing Machinery and Intelligence* to be applied in "game playing, decision making, natural language understanding, translation, theorem proving, [...] encryption, and the cracking of codes" (Kurzweil 1999: 68). Turing is also famous for the test bearing his name that he proposed in 1950. It is, according to Kurzweil (1999: 373): "a procedure [...] for determining whether or not a system (generally a computer) has achieved human-level intelligence, based on whether it can deceive a human interrogator into believing it is human". Practically, the development of artificial intelligence means interactive communication with computers, for example, through speech, touch, and expressions. In the 1980s AI was the catchword for the emerging information economy, when rising software companies started to launch their products onto the markets. A described, for example, software made for business management. After that the use of the concept of AI has been slowly drifting down-

2 I am indebted to Mika Mannermaa for this notion.

wards, because of the unreal and unfulfilled promises the first pioneers predicted. But if and when these promises are fulfilled, the adoption of AI will probably have massive proportions. Therefore, artificial intelligence still remains a very important developmental trajectory of information and communication technology.

Computerized healthcare means medical systems that are automatized or mobile. To the field of computerized healthcare, one can also count the emerging field of distance medicine, for example, surgical operations performed at a distance. Theoretically, distance medicine will enable a doctor performing the operation to be located in New York and the patient can be in Paris. Another example of computerized healthcare is the concept of the home hospital that arose in the interviews. The idea of the home hospital is assistance from a distance. The patients have expert assistance (doctors, nurses etc.) near them all the time, yet non-physically. One idea of the home hospital is to develop technologies so that a patient, who cannot make a phone call, can communicate with medical experts. Voice control is one of the most important trends in this sense. Another kind of technology can also be connected to computerized healthcare: sensors, wireless communication, enhanced reality. 3D virtual modeling can be utilized in the characterization of an individual's organs or in the depiction of the apartment of the patient in the home hospital system.

Distance learning can be defined as: "the acquisition of knowledge and skills through mediated information and instruction, encompassing all technologies and other forms of learning at a distance" (http://www.usdla.org). Generally, distance learning refers to the utilization of different communication technologies for teaching at a distance, for example, interactive videoconferencing, which can uti--lize either point-to-point or point-to-multipoint connections. There are basically three forms of interactive videoconferencing: small room videoconferencing (1–12 participants) at all sites seated around a conference table, classroom videoconferencing (allows all participants to be seen in the monitors) or desktop videoconferencing (utilizes the system of a personal computer and videoconferencing software). Generally, these systems are already available in the more technologically advanced environments, for example, universities. The mobile technologies are very important to the future of distance learning enabling guest lectures, for example, on field and research trips.

Electronic paper (e-paper). The Xerox researcher Nick Sheridon invented electronic ink in the early 1970s experimenting with alternatives to the computer screen (http://zdnet.com.com/2100-11-517601.html?legacy=zdnn&chkpt=zdnntop). The idea was based on microscopic balls that were half black, half white. The balls rotated after an electrical charge was applied and cast light or dark images. When voltage is applied to the surface of the sheet, the beads rotate to display either their black sides or white sides. Images of pictures and text are created when a pattern of voltages is sent to the paper. The image will remain until the voltage pattern changes. The sheets are filled with millions of microscopic capsules that show either dark or light images in response to electrical charges. This was the prime idea of epaper, writable and erasable. Electronic text is to be reflected on thin, flexible sheets with the look and feel of paper (http://www.media.mit.edu/ micromedia/elecpaper.html)

Modular software. A software module can be defined as "a portion of an application program that can be designed, developed, and tested relatively independently of the rest of the program". It also means that the system can be separated and connected together without causing any changes in the system (http://www.pcwebopaedia.com/TERM/m/modular_architecture.html). Modular software is a rapidly expanding form of making programs because of its applicability.

Neural networks. The notion of neural networks springs from the need to simulate the human brain and from the need to study the processes of the human brain. According to the DARPA Neural Network Study, "a neural network is a system composed of many simple processing elements operating in parallel whose func--tion is determined by network structure, connection strengths, and the processing performed at computing elements or nodes" ((http://www.ida.his.se/ida/enns/, http://www.inns.org/inns/, http://www.cis.hut.fi/research/). The neural network does not utilize a digital system which calculates zeros and ones. Instead it constructs connections between processing elements. The basis of the idea is the formation of a network, a configurational totality that effects the whole process. Neural networks were developed in the vein of artificial intelligence: the dream of creating intelligent computers capable of learning by trial and error and by training. Currently, neural networks are applied in voice recognition systems, image recognition systems, industrial robotics, medical imaging, data mining, and aerospace applications.

Optical computers. The development of optical computers is based on the approaching physical limit of the current silicon-based chips. Optical computers might be one solution. As Michael Martinez from ABCNEWS.com wrote "Optical Computers Could Make Silicon Obsolete" (http://abcnews.go.com/sections/tech/Daily News/photons990521.html). An optical computer is a device that uses visible light or infrared beams to perform digital computations instead of electric current, which flows at about 10 percent of the speed of light. The apparent slowness of the electric current has been one of the issues leading to the evolution of optical fiber. Basically, developers of optical computers might develop an apparatus that can perform operations 10 or more times faster than a conventional electronic computer[3]. One of the key advantages of optical computers is that light beams can pass each other without interaction, unlike electric currents. This possibly enables the planning of two-dimensional circuitry. Electric currents need three-dimensional wiring. In the optical computer of the future, electronic circuits and wires might be replaced by optical fibers and films, making the systems more efficient with no interference, more cost effective, lighter, and more compact. For example, NASA, MIT, and private companies are performing research in the field of optical computers.

Intelligent agents. MIT Media Laboratory's Software Agents Group defines agents as "computer systems to which one can delegate tasks" noting that they "differ from conventional software in that they are long-lived, semi-autonomous, proactive, and adaptive" (http://agents.media.mit.edu/). According to Feldman and Yu (1999), the common criteria in defining the intelligent agents are: *autonomy* (the user and agent participate in a cooperative process in which both communicate, monitor events, and perform tasks to meet the goals, that is, the agent is a "personal assistant" for the user), *adaptiveness* (agents learn to react and interact with their external environment, users, other agents, etc. so that their performance improves over time), *collaborative behavior* (agents should be able to work together to establish which agent will carry out each task, and how they will merge the information they collect for presentation to the user), and *mobility* (the ability of agents to migrate in a self-directed way from one host to another on a network, such as the World Wide Web, in order to perform their assigned duties).

Ubiquitous computing is a framework described by Mark Weiser in 1988 at the Computer Science Lab at Xerox PARC (http://www.ubiq.com/hypertext/weiser/UbiHome.html). The key ingredients in the original formulation of the ubiquitous framework are to activate and computerize the surroundings of people and make use of the tacit knowledge of the people by connecting a person in the office to "hundreds of wireless computing devices [...] of all scales". The main idea of Weiser was to make computers invisible so that they are everywhere and make them an organic part of everyday practices. Thus, as a concept ubiquitous computing is quite close to augmented reality (see below). Weiser's vision is basically a statement of the network society: every worker is continuously connected to hundreds of computing devices and sensors which can be utilized without any particular effort. Furthermore, Weiser has emphasized a concept of "calm technology" as part or an application of ubiquitous computing. The notion "calm" refers to the embedding of

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3 Still it cannot compete with the more futuristic wave of computers, that is, quantum computers. It is not yet certain, if promises of quantum computation can be claimed on the larger scale. However, quantum computers have already been built, but their memory is still very low .

computers in the familiar and, therefore, a “calming” and easy environment. The concept of calm technology accentuates the notion of peripherality in three basic ways: computers are both situated more peripherally, computers reinforce the information content of periphery, and they connect the periphery to the center so that the importance of location is seemingly abolished. It must be noted that Weiser uses the notion of peripherality in a double sense: it refers to the place, action (for example home or office), and location in the space of larger information network. One of the applications utilizing calm technology is the video conference (http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm). Beside the technological problems, there are many societal implications to be discussed before implementing Weiser’s vision. The most important issues deal with personal liberties and ethics: are people ready to accept the fact that they are constantly interacting with and constantly monitored by hundreds of computational devices. If one makes a blind leap towards the Weiserian dream one might land in the Orwellian nightmare.

Applications of virtual reality can be utilized in many environments and problems. The traditional view of utilizing virtual reality highlights its possibilities in spatial modeling, for example, regional planning, architecture, and modeling and simulation molecular structures in 3D. One of the emerging applications in-between reality and virtual reality is the field of augmented reality. Augmented reality means combining a virtual object with real environments. For example, one could roam in ancient ruins equipped with augmented reality technology (glasses, garments, etc.) and see virtual models of the old buildings in their actual place. Another application is connected to entertainment: games of tomorrow could fuse reality and augmented reality in a sense that the player is moving in a real environment and, for example, chasing virtual objects. Augmented reality might be one key part of ubiquitous computing. The “plain” virtual reality can also be applied to many fields as seen in Table 3.

Table 3. Applications of virtual reality (adapted from http://archive.ncsa.uiuc.edu/Cyberia/VETopLevels/VR.Apps.GrandChal.html)

Field of application	Description
Cosmology	simulation and modeling the structures of the universe
Material sciences	modeling chemical reactions in order to create the next generation of superconducting materials
Molecular biosciences	modeling the structures and interactions of the smallest biological molecules
Relativity	simulation of the gravitational ripples when two black holes collide in order to search for objects predicted by Einstein's theory of relativity
Weather forecasting	creation of more long-term forecasts, simulating structures of hurricanes and tornados
Manufacturing and industrial design	faster design of manufacturing products
Education	distance learning, "global schools"
Environmental monitoring	studying circulation dynamics of the seas
Medicine	"diving" inside the human body

5.2 Biotechnology

Artificial organs. The development of artificial organs is a very promising field in biotechnology. There are journals devoted to the field, for example, *Journal of Artificial Organs and Artificial Organs*. Some uses for artificial organs already developed are presented in the list below (adapted from http://www.nlm.nih.gov/hmd/manuscripts/asaio/icao.html):

- Artificial Blood
- Blood Pressure Determination
- Blood Pumps, Piston
- Blood Transfusion
- Bloodletting
- Heart, Artificial (Total Heart)
- Heart, Artificial Assist Devices
- Heart Valve Prosthesis
- Hemofiltration
- Hemoperfusion
- Implants, Plastic, etc.

- Kidney, Artificial (Hemodialysis)
- Organs Preservation
- Oxygenators
- Plasmapheresis

The subject of artificiality has also been discussed from the societal point-of-view by Stock (2002). Stock elicits the division made by the artificial intelligence theorist Alexander Chislenko, that of cyborgization and fyborgization. Cyborgization refers to the machine components fused within bodies. Fyborgization is a neologism standing for “functional cyborgization” which means that nothing is permanently fused or embedded within bodies, only the desired properties are added. The components or gadgets can be wearable or portable. This means that no ultimate changes need to be made to bodies. The position Stock takes is present in the following quotes:

> Only a true believer could imagine that we are at the threshold of tying into our cerebral hemispheres to gain new sensory and computational power. Even serious conceptualization of a workable network of electrodes capable of generating a sufficiently flexible, nuanced, and predictable linkage with this organ is a distant possibility, and no amount of head-waving about the awesome future of computers can change this (Stock 2002: 22).
>
> It might seem that we would want to implant devices that augment body functions such as vision and hearing, but there are strong reasons not to. We can upgrade, repair, and replace fyborgian devices more easily and link them more flexibly than cyborgian ones (Stock 2002: 25–26).

Biochip can be defined as “a collection of miniaturized test sites (microarrays) arranged on a solid substrate that permits many tests to be performed at the same time to achieve higher throughput and speed” (http://whatis.techtarget.com/definition/0,,sid9_gci211664,00.html). Generally, a biochip can be described as “a glass chip imprinted with thousands of different nucleic-acid sequences for use in genetic analysis” (Gates 1998). During the interviews, biochip technology was characterized as follows:

> *The chip technology has developed as laboratory researchers have tried to get smaller and miniaturize those procedures which were formerly done with A4-sized gels and filters. As a product of this development, there is a thumbnail-sized piece of glass which is examined with a microscope and image analysis. (interviewee)*

However, it should be noted that a chip is a measuring technology like a ruler or scales. For example, a genetic biochip can also be used as a kind of "test tube" for chemical samples or parts of the structures of DNA (deoxyribonucleic acid). One interviewee compared the biochip to megahertzes in information technology. Biochips were in the central role in the identification of the human genome in the Human Genome Project. The future of biochip technology seems bright. It can be said that a whole laboratory has been put on a chip. This will change the concept of the biochip: nowadays, they are merely diagnostic tools, but these "chip-laboratories" can perform experiments, for example, reading blood tests according to some analytic principle. Ultimately, this technology will make laboratory work more efficient, quicker, and cheaper (Gates 1998).

Biomimetics (imitating life) is an approach which utilizes and simulates structures and solutions present in nature to solve human problems (http://www.bfi.org/Trimtab/spring01/biomimicry.htm). Biomimetics can be defined as a three level ap--proach, which combines modeling and imitating structures of nature, ethical appreciation of the solutions created by evolution and learning from it (http://www.biomimicry.org/). In short, the logic of biomimetics can be applied to materials and processes (Table 4).

Table 4. Examples of the applications of biomimetics (adapted from the list presented at http://www.biomimicry.org/)

Biomimicking materials	Possible applications
Abalone mussel nacre (mother of pearl coating)	"Hard coatings – for windshields and bodies of solar cars, airplanes. Lightweight but fracture-resistant."
Blue mussel adhesive	"Underwater adhesive – sets underwater and does not need a primer, initiator, or catalyst to work. Could revolutionize paints and coatings, and enable surgeons to operate without sutures."
Blue mussel byssus (The tether attaching the mussel to a solid surface)	"Composite materials – a collagen/silk mix with a blended, rather than abrupt, interface between the two materials. Design idea for composite materials (e.g., in robot arms) that need both toughness and flexibility."
Dolphin and shark skin	"Submarines – Hull material that deforms slightly to shrug off water pressure. Same with airplanes and air pressure."
Elastin, the elastic protein in heart muscle	"Intelligent materials – materials, fabrics, fibers that stretch and contract in response to heat, light, chemical changes."
Fish antifreeze	"Organ antifreeze – new ways to freeze human transplant organs without injury."

Orb-weaver spider silk	"A way to manufacture fiber without using high heat, high pressure, or toxic chemicals. The fiber is stronger and more resilient that anything we now have; could be used in parachute wires, suspension bridge cables, sutures, protective clothing, etc."
Sharks, sea anemones, and other marine creatures	"New antibiotics, fungicides, etc. – marine creatures, which live surrounded by pathogens in the sea, are full of novel defenses."
Slug mucus	"Can absorb instantly up to 1500 times their weight in water. Can also "clean and jerk" and so might be helpful in molecular machines."

Biomimicking processes	Possible applications
Bat and marine mammal navigation	"Navigation – recent research suggests that many animals use a combination of magnetism, the sun, stars, and sight to navigate, including homing pigeons, pets, salmon, even monarch butterflies."
Cell membranes	"Super filters – desalination and chemical separation devices."
DNA	"Computer in a thimble – DNA's shape-fitting and self-assembly powers allow it to solve mathematical problems that have so far stumped conventional computers."
Forest	"Permaculture – design of edible landscapes using three-or-more-story cropping."
Hibernating bears	"Medicinal wonders – Bears sleep 6 months without urinating, and yet do not poison themselves. Clues to fighting diabetes."
Human tongue and ear drum	"Telephone speaker and receiver – Bell's original design was biomimetic."
Natural selection	"Genetic algorithm – software that "evolves" its own solutions, getting better and better with each generation of ideas."
Neurons and other kinds of cells	"Jigsaw computing – A new computer processor based on the lock-and-key match-ups between organic molecules. Jigsaw computing would blow our digital, silicon model away."
Purple bacteria with a protein that kinks and unkinks in response to light	"Organic computer memory – A new kind of computer switch that opens and closes in response to light."

Cloning is one of the most talked-about issues with genetic engineering in biotechnology. According to the definition of the Human Genome Project researchers, cloning means "copying genes and other pieces of chromosomes to generate [...] complete, genetically identical animals. [...] The resulting organisms are identical twins (clones) containing DNA from both the mother and the father." (http://www.ornl.gov/hgmis/elsi/cloning.html). But, for example, the famous and now late Dolly sheep was not produced from two parents, it carried the genes of only one parent. Cloning is, therefore, a valuable method for research and reproduction. With modern biotechnological methods, it is now possible to clone mammals; mice, lambs, cows, etc. Interestingly, during this project, news about cloned humans was circulating from different sources. For example, the company called Clonaid presented news about the cloning of a human. It declared that the first human clone was born on 26th December 2002. Clonaid is funded by a religious cult called Raelians, who believe that humans were cloned from aliens walking the earth 25,000 years ago. Later it was announced that the news of the cloning was an "elaborate hoax", just a trick to provide publicity for the religious cult (http://www.newscientist.com/hottopics/cloning/cloning.jsp?id=ns99993234). During the interviews made for this project, the general notions of cloning were collected. Most of the interviewees emphasized that cloning will most likely be a very marginal societal phenomenon. Many stressed that in the large-scale evolutionary picture cloning is actually not such a big issue. As one interviewee aptly put it, cloning is not so much an evolutionary question, it is a civilization question: what are the limits of society and how much scientific experimentation will societies handle? Another very thought-provoking characterization was the notion of cloning as "Spartan":

> *I define cloning as "Spartan" technology, a way of totalitarian regimes to produce a caste of similar warriors. I believe, however, that [Western] societies are basically more Hellenistic than Spartan: we have faith in the cosmos and we are used to being face to face with death and our mortality. The Hellenism refers to the thought that a lost human life is not the most important one. The most important is the one still living. (interviewee)*

Genetic engineering is used to take genes and segments of DNA from one species and put them into another. Genetic engineering is actually a set of techniques to cut DNA either randomly or at a number of specific sites. Once isolated one can study the different segments of DNA, multiply them, and splice them next to any other DNA of another cell or organism. It is possible that genetic engineering will have significant impacts on breeding. It will be possible to design super plants, which, for example, give much higher yields per hectare than their predecessors. Genetic engineering will have effects on animal husbandry as well. One example would obviously be the production of milk and meat. With the help of genetic engineering, it will be possible to create a cow that produces much more milk than cows today, even the ones pumped up with hormones.

An important societal issue connected with genetic engineering is the possibility of a "genetic passport", a kind of personal identification card, which presents the personal genome of humans. The issue was raised during the interviews with interesting results. The genetic passport has its advantages and disadvantages. Advantages include the possibility of exact results in medicine and tailor-made treatments. The illuminating example of one interviewee is worth quoting at length:

[In future] when you go to the hospital, they [doctors] will make relatively comprehensive research, for example, with chip technology. Then they scan dozens of genes according to the symptoms. For example, if the symptom is dizziness then the neurological gene pattern is scanned. If the symptom is pain in joints then the rheumatoid arthritis gene pattern is scanned. The results of the scannings are taken into account in the total diagnosis of the patient just as hemoglobin, red cells, white cells, etc. The scanning information adds one element to the data. The basic idea is that the more criteria there are the better the possibility for a diagnosis. For example, there will no longer be just rheumatoid arthritis, but a rheumatoid arthritis which is connected to gene X's so-and-so mutation, which is interconnected with gene Y's mutation, etc. Medical procedures are selected according to the specific characteristics of the disease. (interviewee)

Indeed, the advantages of the genetic passport would surely be connected to the more efficient and more accurate diagnoses and treatments. As Dan M. Roden of Vanderbilt University School of Medicine has written in the story published in the Science News Online: "The real hope is that down the road, you'll have a gene card that says what your risks are, a genetic profile that says how you are likely to respond to a variety of exogenous stressors, like mental stress, drugs, aging, diet" (http://www.sciencenews.org/20020914/bob9.asp). The disadvantages of the genetic passport would be connected to the Big Brother syndrome continually cropping up in the information society and even more so in the biosociety. The interviewees were concerned about the possibility of the emergence of a new kind of eugenics and probable technological illusions connected to the notion of optimal chromosomes and the easiness of genetic manipulation. One interviewee opposed these ideas from the perspective of evolutionary theory:

"Biodiversity" within species is against a genetic passport. There is a mutual illusion that some kind of optimal genome can be defined. That somewhere would be a man with a 100 percent genome. None of this exists and ever will. Evolution is based on the notion that an optimal genome cannot exist. (interviewee)

Indeed, there is still much basic research to do before genome functioning is understood. For example, one interviewee noted that there are many "black boxes" in the basic information about genetic material: unsolved issues cover such complex areas as the basic logic of genetic recombination, construction and folding of proteins, and the total "system biology" of molecules. One key issue to be solved is the "mystery of black matter" in the genome, because genes represent only 10% of the total mass of the genome. One speculation might be that genes are not the only factors regulating the expression of genotype. As an interviewee noted: ”Why are we carrying such a vast amount of genetic material, if it has no meaning?”

Gene therapy is closely connected to the issue of genetic engineering. Genetic therapy may involve the insertion of normal copies of a gene into the cells of people with a specific genetic disease. There are two types of possible gene therapy: somatic therapy and germline gene therapy. Germline therapy means, for example, growing the healthy cells and tissue based on a person’s own stem cells in the germline, cells that are totipotent (capable of changing into the cells of any tissue in the body). Somatic therapy means therapy considered with cells other than stemcells, that is specialized cells. Clinical trials based on somatic gene therapy have been undertaken for very severe genetic disorders (e.g. adenosine deaminase deficiency). Germline gene therapy is not practiced widely because of the obstacles it still has: ethical issues linked to the manipulation of the genes of sperm or egg, it is expensive, it has not been widely tested in humans, etc. There is still much hype surrounding the issue of gene therapy and stem cells. As one interviewee said: “the stem cell hype is quite the same as the situation with monoclonal antibodies 20 years ago”.

An interesting societal issue connected to gene therapy and genetic engineering is the extra-chromosome hypothesis presented by the technological visionary and enthusiast Gregory Stock (2002). Stated briefly, Stock declares that if humans would add a ”new chromosome pair (numbers 47 and 48)” to the genome, it would open vast possibilities for human genetic manipulation. It would enable the injection of huge amounts of genetic material, of targeted expression of the properties inserted in extra-chromosome and better regulation of these properties (Stock 2002: 66). Stock calls the extra-chromosome the ”universal delivery vehicle” for any kind of genetic material. The interviewees were all very skeptical of Stock’s vision and said his vision is still ”very far in the future”. Moreover, it was estimated that extra-chromosome technology, if ever realized, will remain very marginal technology. One interviewee also estimated that ”Stock’s book can only be written in America”, because of his firm belief in the liberating power of technology.

Targeted pharmaceuticals. Another issue linked to the developing genetic engineering and genetic therapy techniques are targeted pharmaceuticals. Genetic technologies are important for the development of pharmaceuticals because genes adjust the metabolism of medicines. The “targeting” of the targeted pharmaceuticals is usually also based on particular receptors, that is proteins on the membranes of the cells (http://www.sciencenews.org/20020914/bob9.asp). The field researching the development of personalized and tailored pharmaceuticals with the methods of genetic technologies is called pharmacogenetics. As one interviewee expressed it:

"When we go to the shoe store we all won't buy size 37 shoes. At the pharmacy we do". At present, targeted medicines are most widely applied in the treatment of cancer, but there is also much scientific work going on in other fields.

The combinations of the afore-mentioned technologies with ICT will generate the most possible breakthroughs in the field of biotechnology. As George Poste put in the *Nature Biotechnology* e-journal: "We stand on the threshold of a new era in which molecular biology will shift healthcare from its current reliance on largely empirical interventions to increasingly rational procedures designed to address specific molecular pathologies" (Poste 1998, http://www.nature.com/cgi-taf/DynaPage.taf?file=/nbt/journal/v16/n1s/full/nbt0598supp_19.html). Also the mapping of the complex expression patterns of genetic circuits and the whole "system biology" of humans, as one interviewee noted, will be the key challenges of the future. Poste also categorized the most prominent immediate combinations of biotechnology and ICT, which provide the most promising and most immediate views on applications and development of entrepreneurial potential:

> first, the design of systems architecture and hyperlinking tools for large-scale, heterogeneous distributed databases; second, the creation of novel algorithms for data mining in bioinformatics, cheminformatics, and population genetics; third, the assembly of comprehensive clinical databanks and their use for large-scale genetic association studies to define robust gene-disease risk correlations; and fourth, the development of encryption methods to protect proprietary data and to assure the privacy and confidentiality of clinical information (Poste 1998, http://www.nature.com/cgi-taf/DynaPage.taf?file=/nbt/journal/v16/n1s/full/nbt0598supp_19.html).

Furthermore, the general challenge is to integrate and cross the dividing lines of the different genres of knowledge Poste calls molspeak (molecular biology and other research datasets), medspeak (clinical medicine), and nerdspeak (computer sciences).

5.3 Material and nanotechnology

Biocompatible materials. One of the key technological trajectories emerging in material technology is biocompatible materials, that is synthetic materials which can be effectively and safely combined with biological material. There are multiple possibilities in future in the research field of biocompatible materials. The most important field of study in biocompatible materials deals with surface interactions of the two materials, the organic and inorganic (or synthetic). The focus has been directed particularly towards biomedical applications. For example, research on binding blood protein surfaces to the surfaces of synthetic materials utilizing photolithographic patterning presents one direction for the study on the surface interactions of different materials (http://www.mpip-mainz.mpg.de/documents/projects98/ C3.htm). Another future possibility might be more progressive and safe artificial tissue produced partly or completely from synthetic, biocompatible materials (Baltimore 2001, 42–55; Lievonen 1999, 51–52; Ball 1998, 9–24.) Another way to produce tissue is biotechnological, for example, applying genetic engineering to produce tissue from the stem cells of the body. In future, it might be possible to cultivate tissues *in vitro*. Biocompatible materials will form an important part in the process of tissue cultivation, particularly in the protection of implanted tissues and the enhancement of growth (Lievonen 1999: 52). For example, expanded polytetrafluoroethylene (ePTFE) is a very common chemically-advanced material used in implants which contact blood and tissue (http://www.ipfdd.de/research/res16/ a3/a3.html). Still another example of the applications of biocompatible materials is the emerging possibility of producing synthetic-like material biologically. It might be possible to grow plants that produce material with the properties of plastic except this material will be totally biodegradable (Schwartz *et al*. 1999).

Fuel Cell refers to an electrochemical energy conversion device which, for example, converts hydrogen and oxygen into water, producing electricity and heat in the process. It resembles a battery that can be recharged while drawing power from it. A fuel cell does not use electricity for this process, but hydrogen and oxygen (http://science.howstuffworks.com/fuel-cell1.htm). However, another source implies that a fuel cell is unlike a battery in the sense that the fuel cell does not require recharging. Instead it is more like a generator producing energy as long as fuel is supplied (http://www.fuelcells.org/whatis.htm). Fuel cell technology might provide one alternative energy source substituting for fossil fuels in the future. There are multiple types of fuel cells which are based, for example, on phosphoric acid, proton exchange membrane, molten carbonate, solid oxide, alkaline, direct methanol, and zinc (http://www.fuelcells.org/fctypes.htm).

Functional polymers are linked to the construction of biocompatible and intelligent or smart materials. For example, research on functional polymers emphasizes the self-organization of synthetic materials (Antonietti 2003). The starting point for the formation of self-organized materials is by encoding special functions to the material structures (length, shape, geometry, etc.) through the manipulation of chemical structure and patterning of the polymers. According to Antonietti (2003), “the ultimate goal is the ability to control the arrangement and interactions of nanoscale objects by functional interfacing" meaning the regulation of both the common operation and the flow of information between a group of objects.

Intelligent materials (or smart materials) can be generally defined as materials which respond to physical stimulus without any external information processing. The term "intelligent materials" or "smart materials" is not definitive and can be defined in multiple ways. There are also other properties characterizing intelligent materials: unexpected or novel properties of materials, reversibility, recyclability and wide applicability (Greaves 1997). Basically, intelligent materials can be divided into two groups: the "classical" intelligent materials and "transformers of material properties". The classical notion of intelligent materials emphasizes the classification of materials by their properties and the response they generate. The response is usually through change in the length or shape of the material. The academic community utilizes this approach to a large extent. The second group, "transformers of material properties" comprises materials responding to a stimulus with a transformation in some material property, for example, electrical conductivity or viscosity (http://smartmaterials.info/materials/overview/introduction.html). The intelligent materials capable of transforming properties can be used as sensors. Generally, intelligent materials can be applied to a variety of fields, for example, research on medicine, biotechnology, and industrial processes. More commonplace solutions are also sought: the future fabrics might have intelligent properties (http://www.tekes.fi/uutisia/uutis_tiedot.asp?id=1769). It must be noted that the terms "smart materials", "intelligent materials", "active materials", "adaptive materials", and, to some extent, "actuators" and "sensors" are used somewhat synonymously characterizing the same phenomenon (http://smartmaterials.info/materials/overview/the_definition_(maybe).html).

Miniaturization means basically the research and design of smaller technologies and smaller devices through the means of advanced material and nanotechnology. Pivotal examples of the effects of miniaturization are the developments on nanomachines, nanotubes, and nanopumps. The production of nanomotors has huge potential, if ever realized in mass production. Nanomotors are "100,000 times smaller than the head of a pin" and might pave the way for the development of computers that are "1,000 times more powerful than today's machines" (http://www.lucent.com/press/0800/000809.bla.html). The construction of carbon nanotubes is another potential application. A carbon nanotube is a rather simple device: it is constructed of a sheet of graphite rolled into a tube and blocked with fullerene caps at each end. The properties of the carbon nanotube have potential for a wide variety of applications because of its strength, low density, high electrical conductivity, and high thermal conductivity (Files & Mayeaux 1999). The research in the field of carbon nanotubes is showing much promise, however, the slow production of these nanotubes is one of the most crucial objections to the broad and consequential research in this field. Another promising field is the fusion of nanotechnology and electronics, nanoelectronics. The field of nanoelectronics consists of nanosized electronic applications, for example, molecular transistors only a billionth of a meter in size. Molecular transistors show much promise for the production of smaller computer chips in the future (http://www.bell-labs.com/news/2001/november/8/1.html).

Miniaturization of technology will also have interesting impacts on medicine. For example, one probable nanotechnological innovation might be the video pill, a mixture containing a camera, battery, and transmitter. The main idea is that the patient will swallow this video pill and it will transmit direct a documentary from the entrails of the patient. Several projects in academia and the commercial sector are combining the life sciences, information technology, and mechanics to create bleeding-edge biotechnology applications that are capable of radically changing the medical world. In other medical fields, such as the development of pharmaceuticals, the miniaturization of technology also brings benefits. Various tools, like the biochip, have been invented to speed up the processes, ease the research, and make it cheaper (Gates 1998). One very interesting application of miniaturization is connected to biomimicry, namely the emerging research field of biomimetic microelectrical mechanical systems. The promise of this field is to develop mechanical "components" that "mimic and learn from biologicy to automate minute procedures, like drug delivery on the molecular level" (Gates 1998). These have already been developed by researchers in the University of Tokyo. Moore's law[4] in information and communication technologies has pushed research in the field of ICT towards continuous miniaturization. As Peercy notes, Moore's law is fundamentally a thesis on economic efficiency: miniaturization is a challenge industry is forced to face with continuously rising investments in research and development (Peercy 2000). There has also been another driving force of miniaturization: the demands of consumers, which have been widely affected by the side-effects of Moore's law and enthusiastic marketing promises of the information and communication devices (Conway 2001). The drive towards two-way (send-and-receiving) mobile computing devices such as personal digital assistants and pocket PCs has been one implication reflecting the "burden of miniaturization". Indeed, the miniaturization of different processes might be a very important developmental trajectory in the future (Yu & Ziegler 2000). However, the most basic problem must

4 Moore stated that for the silicon-based circuits, the number of transistors per square centimetre is doubling every 12 (later moving closer to 18) months (Peercy 2000). However, since Gates' article was published there has been serious doubts about the realism of Moore's thesis. Actually it might be that "Moore's law" is just a myth with no relevant empirical basis (see Tuomi 2002).

still be crossed: the problem that most of the developments in nanotechnology are still at the theoretical level.

Sensors can be defined as the interface between the real world and information systems which measure the degree of accuracy and efficiency of measuring in some device or process (http://www.microsens.ch/summary1.htm). Sensors can be applied, for example, in environmental control, detection of gases, industrial process monitoring, and multi-sensing (ie. executing multiple sensoring tasks at once). Manufacturers can combine different aspects of material technologies in planning the sensors,, for example, biocompatibility, special functionality and, the intelligence of materials. Moreover, when molecular biology, microfabrication, and microelectronics are fusing then the *in vivo* production of biosensors monitoring the implants might become possible. Research in materials can produce a large variety of sensor molecules which can be utilized in devices. These developments will further expand the applicability of sensors tracing toxic materials. They could also make possible the real-time monitoring of the substances in the body. When these prospects are combined with emerging trends like genetic engineering, targeted pharmaceuticals, biocompatible materials, etc., they will open new angles to develop tailored and personalized pharmaceuticals and medical procedures (http://www.nature.com/cgi-taf/DynaPage.taf?file=/nbt/journal/v16/n1s/full/nbt 0598supp_19.html).

Superconducting materials are materials which conduct and transmit electricity with almost no resistance and loss of energy. There are many applications for superconducting material. For example, using wires made of superconducting materials could make computers considerably faster than today and lead to significant savings in both energy and money. In the pages of *American Science Foundation* there is a good example characterizing the nature of superconducting materials:

> Imagine a ballroom filled with many dancers. In normal material, all of the dancers are moving in different directions at different times, and much of their energy is spent bumping into each other. In a superconductive material, the dancers are synchronized, moving in unison, and therefore can spend all of their energy on the dance and none on each other. The dancers represent the electrons of each material, chaotic in the normal setting and well-ordered when the material is superconductive

(http://www.nsf.gov/od/lpa/news/publicat/nsf0050/materials/tomorrow.htm).

It must be noticed that the theory is actually more complicated than this presentation, but it gives an interesting description of superconductivity. Superconductivity was first discovered in 1911 by the Dutch physicist Onnes when he cooled mercury to almost absolute zero (http://www.ornl.gov/reports/m/ornlm3063r1/contents.html). Since then scientists have been debating about superconductivity, however, its application has been limited by its need for extremely low temperatures until the mid 1980s. The ceramic superconductor was discovered in 1986 that could perform superconductivity at higher temperatures. This led to the emergence of a new research field called high-temperature superconductivity. This new higher temperature superconductivity also (theoretically) made possible all kinds of applications that could not be considered in the previous low temperature “phase”. Contemporarily one of the key applications is medicine. Superconducting materials have made possible the construction of magnetic resonance imaging that can be applied to scanning the body. Other key applications are, for example, computers, electronics, communications, transportation, and advanced power systems.

5.4 Alternative paths to the future of technologies

The rest of the chapter presents short insights into the alternative views on the future of technologies. These alternative views are presented as a reference to the empirical results of this study. The first alternative is *MIT Technology Review*’s vision about ten emerging technologies that might have extensive influences in the near future (Table 5). The second reference is not actually a vision of the future, it is more the making of the future. This reference is based on the adapted list of *MIT Medialab’s research and development activities* (Table 6).

Table 5 presents the ten most central technological trajectories summed up in the article in MIT Technology Review in February 2003. According to the article, these technologies are “completely new [...] that could soon transform computing, medicine, manufacturing, transportation, and our energy infrastructure” (http://www.technologyreview.com/articles/emerging0203.asp). Furthermore, these are technologies in which active research is already performed. If MIT Technology Review’s list of emerging technologies is compared to the results of this study there are discrepancies, particularly in technological details. Basically this is because of the different orientations: the focus of this study was to map developing *technological trajectories* as large-scale phenomena and base the results on empirical data, whereas the approach in MIT Technology Review emphasized *specific, minute technologies* described in journalistic style. Furthermore, it should be noted that many of the technologies presented in the MIT Technology Review’s list are aggregates, that is, they bear the marks of fusion technologies that cross the boundaries of large technological trajectories.

Nevertheless, the different orientations do not suppress the possibility of comparison on the trajectorial, large-scale level. In the following compact comparison, *MIT Technology Review's* emerging technologies are categorized in the technological groups utilized in this study. Technologies fitting the ICT group are grid computing, software assurance, and quantum cryptography. The definition of grid computing has links with the technologies of advanced data storage, modular software, and ubiquitous computing. It must be noted that the goal of the grid computing applications is to connect different technological platforms to ensure the maximum interoperability and mobility as discussed in the theoretical chapter of this study. Software assurance is more specific software technology and, in principle, it might form the basis of all programming procedures. Quantum cryptography, although an interesting and, if realized, groundbreaking solution, was not emphasized because of the report's focus on developing *technologies* and their *societal impacts*. In this sense, applications based on quantum effects are interesting and will have a vast influence if realized on a larger scale, yet still on a more theoretical than actual level.

Following MIT Technology Review's list, glycomics is the only technology that "purely" fits the biotechnology group. Glycomics might be characterized as one research branch in the wide field of molecular biology that will have a huge impact, if pharmaceuticals based on the research in glycomics are developed. However, all the research branches in biotechnology are intertwined and utilize the basic research in genetics and genetic engineering. In fact, the actual products that glycomics might produce are targeted pharmaceuticals. Technologies fitting the group of material and nanotechnology are: wireless sensor networks, nano solar cells and nanoimprint lithography. Wireless sensor networks combine the notions of sensors and miniaturized computer technology in order to provide a grid of nanosized sensors. A nano solar cell is a technology based on the notion of intelligent material and nanoimprint lithography is a method to embed the nanotechnological features in different materials. The most interesting technologies in MIT Technology Review's list are technologies that could be labeled fusion technologies, that is, fusing different technical properties in imaginative ways. The first technology is injectable tissue engineering which is an imaginative mixture of biotechnology and material technology. The electronic actuators (mechatronics) utilized in cars are an innovative combination of ICT and material technology.

Table 5. "Ten emerging technologies that will change the world" according to MIT Technology Review. (Adapted from http://www.technologyreview.com/articles/emerging0203.asp)

Emerging technology	Description
Wireless Sensor Networks	"Research on wireless networks made up of thousands or even millions of sensors. These networks will observe just about everything, including traffic, weather, seismic activity, the movements of troops on battlefields, and the stresses on buildings and bridges – all on a far finer scale than has been possible before."
Injectable Tissue Engineering	Development of "a way to inject joints with specially designed mixtures of polymers, cells, and growth stimulators that solidify and form healthy tissue".
Nano Solar Cells	The utlization of nanotechnology "to produce a photovoltaic material that can be spread like plastic wrap or paint. Not only could the nano solar cell be integrated with other building materials, it also offers the promise of cheap production costs that could finally make solar power a widely used electricity alternative".
Mechatronics	In the near future hydraulic cylinders in cars are replaced by electromechanical actuators, ie. mechatronic systems. The emerging new innovation is to develop a "software that can identify and correct for flaws in real time to make sure the technology functions impeccably".
Grid Computing	Currently emerging grid computing enables the linking of almost any kind of system: "databases, simulation and visualization tools, even the number-crunching power of the computers themselves". This could mean a new level of computer networking connecting supercomputers, "ordinary" computers, palm computers, and even mobile phones.
Molecular Imaging	Molecular imaging ("a number of techniques that let researchers watch genes, proteins, and other molecules at work in the body) utilizing magnetic, nuclear, and optical imaging techniques. In this way molecular imaging could be used to unravel the causes of disease.
Nanoimprint Lithography	There are no effective ways to produce nanotechnological devices effectively. Nanoimprint lithography refers to the simple process of "stamping a hard mold into a soft material" through which "features smaller than 10 nanometers across" can be embedded into hard materials like steel. The method could become the solution for the easy fabrication of nano features.
Software Assurance	The development of error-free programs. The key idea is to make a "pseudoprogram" utilizing "pseudocode" and test its functioning before the program is actually not even programmed..
Glycomics	"Sugars play a critical role in stabilizing and determining the function of proteins through a process called glycosylation, in which sugar units are attached to other molecules including newly made proteins. [...] By manipulating glycosylation or sugars themselves, researchers hope to shut down disease processes, create new drugs, and improve existing ones".
Quantum Cryptography	Quantum cryptography could provide a way to secure information transactions. "The technology relies on quantum physics, which applies at atomic dimensions: any attempt to observe a quantum system inevitably alters it". Quantum cryptography is still more a theory than actual application.

The MIT Media Laboratory was founded and made famous by Professor Nicholas Negroponte, who emphasized the convergence of computing, publishing, and broadcasting as a basis for the research in Medialab. The Laboratory also combined other areas in its studies and developments, including cognition, electronic music, graphic design, video, holography, and human-machine interfaces. Table 6 presents the second alternative view on the future of technologies adapted from list of MIT Medialab's research and development activities (http://www.media.mit.edu/publications/). It should be emphasized that Table 6 presents the year when the developing of the technological application started according to Medialab's comprehensive list. This is to avoid the overlapping of topics and thus the Table can serve as a kind of mirror for the short-term "evolution" of research and development activities. If one could draw a synthesis of this short four year period of research and development activities, it could be said that the direction of topics has moved from the "immaterial" aspects of immersion, virtuality, and networks towards a more "material" emphasis fusing virtual and immersive approaches.

Reflecting on the results of this study, the applications Medialab has dealt with can mainly be categorized under the key technologies of ubiquitous computing, virtual reality, and intelligent agents. Technologies especially dealing with *ubiquitous computing* presented in this study are (characterizations can be found in Table 6): lazy fish, affective computing, a holo-haptic interface system, luminous room system, expressive synthetic characters, intra-body signaling mechanisms, new ways of joining the physical environment, and cyberspace and nami, which also has common ground with grid computing, an idea presented in the earlier Table adapted from MIT Technology Review. The second key technology resulting from the research and development activities of Medialab is *virtual reality*. In particular, notions of holo-haptic interface system, luminous room system, digital town center, wearable computing, and intra-body signaling mechanisms fit the notion of virtual reality defined in this study. Many of these applications could also be linked to augmented reality, technology that embeds virtual objects to physical environments. The third key technology resonating with Medialab's applications is *intelligent agents*. Examples are affective computing, hive, expressive synthetic characters, and autonomous agents. Further analogies can also be made: advanced data storage & a way to use atomic force microscopy to create "write-once" terabit-per-square-inch data storage, artificial intelligence & autonomous agents, material technology & a new technology to mass produce super-cheap transistors, sensors & expressive footwear, and applications of Epaper. It should be emphasized that many of these applications are illuminating examples of fusion technologies, combining in an innovative and "fuzzy" way the approaches of virtual reality, intelligent software and materials, sensor and material technologies, and artificial intelligence.

Table 6. Selected and adapted list of MIT Medialabs´s research and development activities (adapted from the http://www.media.mit.edu/publications/)

1997–1998	1998–1999	1999–2000	2000–2001
• ***Electronic Paper*** ("which combines all the great attributes of paper, but adds the benefits of digital technology. For example, real paper that can display video images"). • ***Lazy Fish*** ("the newest development in electronic field sensing technology, where a miniature electronics board [...] will [...] allow the user to interact even with everyday objects with just a wave of the hand"). • ***Affective Computing*** ("which will give "emotional intelligence" to computers, making them more "reasonable" when it comes to interacting with people. Affective computers will be able to sense what delights or frustrates you, or even figure out if it's a good time to interrupt"). • ***A holo-haptic interface system*** ("which combines computational haptics and electronic holography in [...] the interactive, holographic workstation that operates in real time"). • ***Project Lighthouse*** ("focuses on developing hands-on, immersive learning environments to explore how the computer and other technologies can be used to radically change the way we learn"). • ***Luminous Room system*** ("turns an ordinary architectural space into an interface between people and digital information-pictures, text, or even live video").	• ***Advances in printed PCs*** ("could eventually transform your traditional paper notepad into a $10, computerized paper pad, complete with Internet connection"). • ***A wireless "digital town center"*** ("capable of providing even the most remote and underdeveloped areas of the world with telephone, e-mail, and Web access"). • ***Hive, a Java-based application infrastructure*** ("links "thinking things" together, eventually allowing your refrigerator to tell your cell phone that you're low on milk"). • ***Wearable computing*** (" in which [...] we move beyond PCs and laptops, and wear our computers as we would eyeglasses or clothing. Such clothes could have augmented memory, where "to do" lists flash before a user's eyes, or where online information – even an entire book – can be displayed on demand"). • ***Expressive synthetic characters*** ("inhabit virtual environments and interact autonomously in response to users' actions, appearing to have minds of their own"). • ***Intra-body signaling mechanisms*** ("turn your body into a data network. Now your eyeglasses and wristwatch can become displays for your shoe computer, and familiar gestures can take on new digital meanings as you exchange business cards through a handshake or unlock a doorknob by touching it").	• ***A way to use atomic force microscopy to create "write-once" terabit-per-square-inch data storage*** ("like a CD, but capable of holding 5,000 times as much information in the same space"). • ***Nami, a decentralized, distributed network of orbs*** ("display a wave-like wash of color by communicating with each other [...] model for localized networks for everyday household use, where all your consumer products become "nodes" that integrate themselves into a single network"). • ***A new technology to mass produce super-cheap transistors*** ("by printing them directly onto a plastic substrate using a solution of cadmium selenide nanocrystals"). • ***Expressive Footwear*** ("sport a wireless suite of sensors, microcomputer, and data link that measure more than a dozen different parameters of motion and feed this information wirelessly into a PC, which uses a unique program to turn the movements into sound"). • ***New ways of joining the physical environment and cyberspace*** ("making "tangible bits" accessible through everyday physical surfaces like walls or desktops, and eventually through household surfaces like refrigerator doors").	• ***Periscope, a browsing device*** ("allows a user to explore the physical world by navigating its digital shadow—in this case, Web pages situated at the places they represent in the real world"). • ***A prototype for a hand-held, human-powered generator*** ("creates five watts of power by being twirled over a person's head by a string [...] has implications for providing affordable power for simple computers in the poorest and most remote areas of the globe"). • ***Autonomous agents capable of having a real-time, face-to-face conversation with a human.*** ("communicate using both verbal and non-verbal modalities"). • ***New techniques for information hiding*** ("Including [...] use of mid-level vision models and the placement of unique identifiers on physical objects") • ***A handheld digital mirror that serves as a simple, everyday diagnostic imaging tool*** ("for people to "photograph" health indicators, such as blood sugar levels or heart rate").

6 Technological Paths to the Future: Results of the First Delphi Round

This chapter presents the results of the second phase, that is, the first Delphi round. As mentioned earlier, the study has been completed through three empirical phases. The *first* phase was the preliminary phase where the technological paths of the future were defined through expert interviews and the literature. The *second* phase is the first Delphi round, where an Internet-based questionnaire was sent to various experts. The objective of the first round was to expert opinions on technological theses and phenomena constructed through the preliminary phase. Hence, it can be stated that the orientation of the first Delphi round was technological. Structured expert interviews were also made in the course of the second phase. The *third* phase was the second Delphi round. In this phase, the technological framework constructed in earlier phases was brought to the field of education and societal development. The second Internet and electronic questionnaire was sent to experts. Structured expert interviews were also made in the third phase. The experts interviewed in third phase were mainly societal.

The questionnaire for the first Delphi round was planned on the basis of the interviews and the formation of technology lists. It was constructed as an Internet-based questionnaire, which the chosen experts could complete. The experts were chosen from a special mailing list. The questionnaire was divided into three sections: estimation of the future importance of certain technological phenomena, estimation of the plausibility of theses related to technological development, and the timing of the theses. The volume of answered questionnaires from the first round is quite small (n = 32). However, it is big enough to fulfill the basic principles of the Delphi technique. The utilization of the Delphi technique does not require vast masses of answers, because it is not based on statistical significance or stochasticity, but on the notion of expertise as mentioned earlier in the theoretical part. The basic idea of the results is, therefore, *the presentation of the distributions of opinions of chosen experts*. Hence, the presented distributions have a kind of double function: they can be thought of as references for the experts in order to complete the second Delphi round, as well as the presented results of the first round.

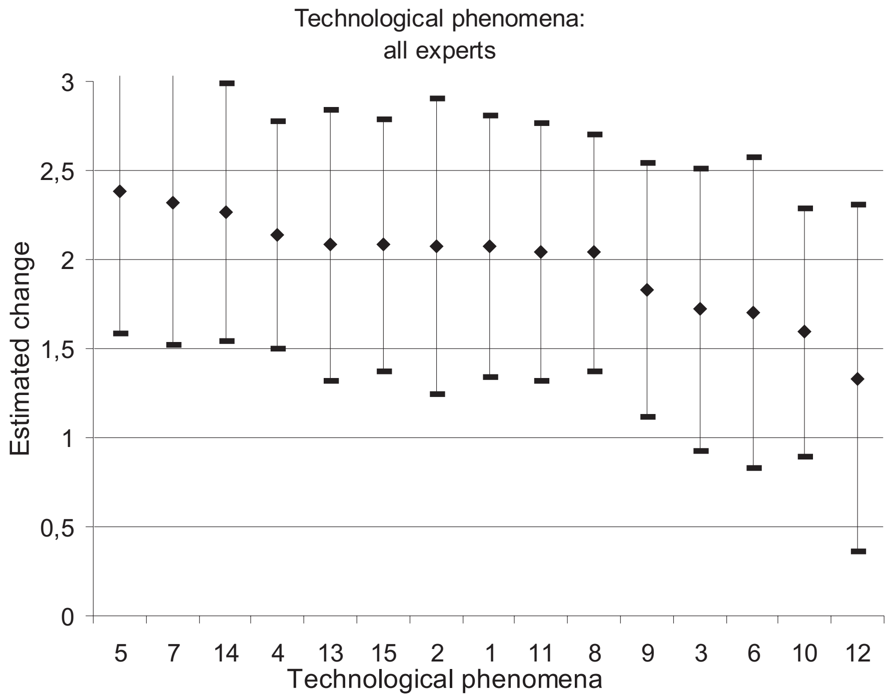
The questionnaire was completed through three basic steps: delivering the background information, defining expertise, and answering the questions. After delivering the background information, experts could define their area of expertise in information and communication technology, biotechnology, and material and nanotechnology. From the basis of the definitions the expert groups presented were decided. The time perspective in the presentation of results is very long-term, to 2015.

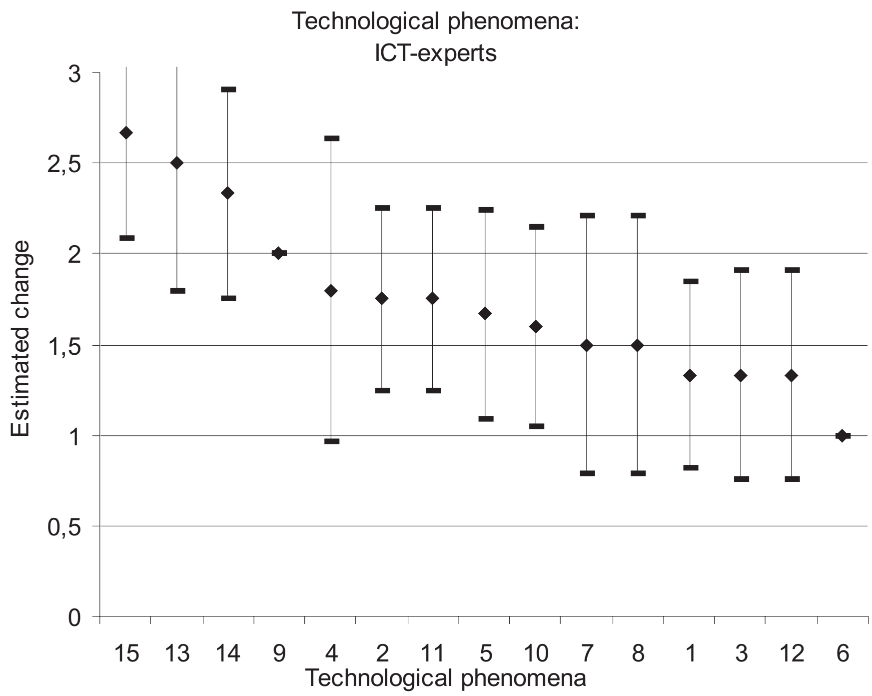
6.1 Importance of the technological phenomena

In the first question, the experts were asked to form their opinions on the importance of technological phenomena based on expert interviews and the literature. The technological phenomena were formulated on the basis of the key technological trajectories presented in the previous chapter. The answers are presented in four parts: all experts, ICT-experts, bioexperts, and material and nanoexperts. The scale was 0 = importance is insignificant or remains the same, 1 = importance increases somewhat, 2 = importance increases significantly, 3 = importance increases dramatically (Figure 3, page 63).

Ten most important technological phenomena according to the expert estimations were: (1.) the third generation in computing, when technology recedes into the background of our lives (ubiquitous computing), (2.) miniaturization, (3.) virtual reality, (4.) possibility generated by Green methods to reduce the amount of waste and hazards, (5.) Artificial Intelligence, (6.) a person simultaneously communicates with multiple devices in a fully interactive workspace (Human PC-Interface), (7.) artificial organs in a human, (8.) environmental scanning, (9.) cloning of human organs, and (10.) machine intelligence.

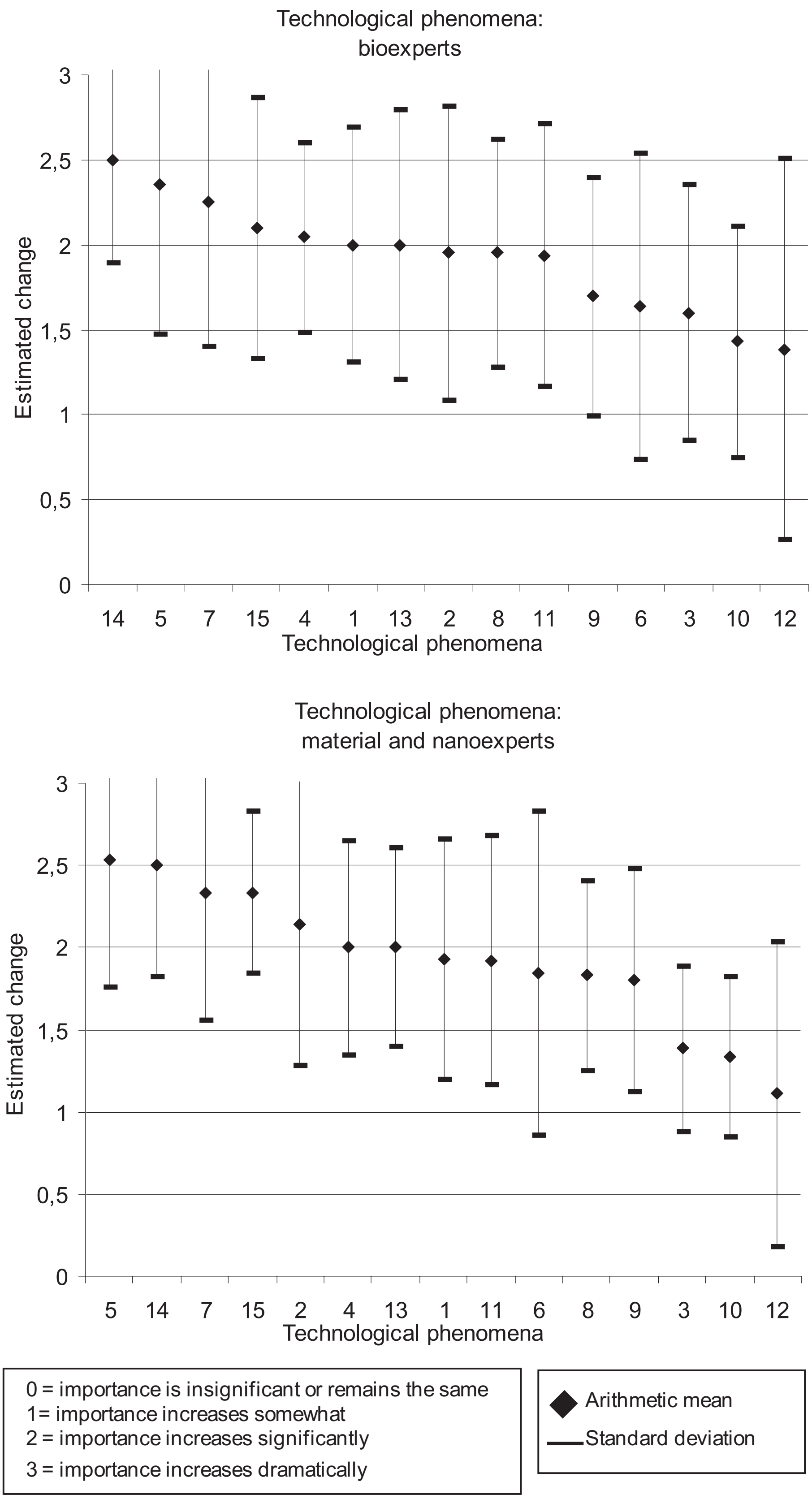
The answers were also divided into three expert groups: ICT-experts, bioexperts, and material and nanoexperts. The estimated top three technological phenomena are presented in the text. *ICT-experts* estimated the importance of technological phenomena as: (1.) A person simultaneously communicates with multiple devices in a fully interactive workspace (Human PC-Interface), (2.) Artificial Intelligence, and (3.) virtual reality. *Bioexperts* estimated the following three phenomena to be the most important: (1.) virtual reality, (2.) the third generation in computing, when technology recedes into the background of our lives (ubiquitous computing) and (3.) miniaturization. The material and nanoexperts' top three (or top-four in this occasion) are: (1.) the third generation in computing, when technology recedes into the background of our lives (ubiquitous computing), (2.) virtual reality. A split third place between (3.) miniaturization and (3.) a person simultaneously communicates with multiple devices in a fully interactive workspace (Human PC-Interface).





0 = importance is insignificant or remains the same
1= importance increases somewhat
2 = importance increases significantly
3 = importance increases dramatically

◆ Arithmetic mean
— Standard deviation


Technological phenomena:
bioexperts
Estimated change
3
2,5
2
1,5
1
0,5
0
14 5 7 15 4 1 13 2 8 11 9 6 3 10 12
Technological phenomena
Technological phenomena:
material and nanoexperts
Estimated change
3
2,5
2
1,5
1
0,5
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5 14 7 15 2 4 13 1 11 6 8 9 3 10 12
Technological phenomena
0 = importance is insignificant or remains the same
1= importance increases somewhat
2 = importance increases significantly
3 = importance increases dramatically
Arithmetic mean
Standard deviation

1. Environmental scanning
2. Artificial organs in human being
3. Materials to conduct electrical current with no resistance and extremely low losses (superconductivity)
4. Possibility generated with green methods to reduce the amount of waste and hazards
5. The third generation in computing, when technology recedes into the background of our lives (ubiquitous computing)
6. Biocompatible polymer surfaces
7. Miniaturization
8. Machine intelligence
9. Gene manipulation of plants
10. Gene manipulation of animals
11. Cloning of human organs
12. Cloning of human beings
13. Artificial Intelligence
14. Virtual reality
15. A person simultaneously communicates with multiple devices in a fully interactive workspace (Human PC-Interface)

Figure 3. The estimation of importance of technological phenomena

6.2 Societal impacts of technologies

The experts were asked to indicate the five most important technologies within the next 15 years from the point of view of their societal impacts. The basic idea of the question was qualitative: technologies could be chosen from existing lists in the questionnaire or experts could present their own views. After the formation of their views on the most important technologies, the experts were to indicate possible innovations which could spring from the adoption of these technologies. Comments could also be made that would expand the sketches.

Table 7 presents the intrinsic results. The Table is structured as follows: in the first column from the left the primary class is presented, in the middle column the secondary class and in the third column special characterizations. The primary class is based on the researchers' classification of all the answers into four technological groups. The second group presents the nominated technologies classified into these groups. The column of special characterizations presents the open comments and innovations linked to technological groups. For example, in the case of nanotechnology, there were four primary depictions, only one technology mentioned, and five open characterizations. The technological trajectories which got most references were chosen to be presented. It must be noted that some of the characterizations are quite utopist depictions, yet interesting as thoughts about the future. Also some of the characterizations might present a bit too technocratic and mechanistic view of people, but these are also worth considering as an alternative technological trajectories.

Table 7. The qualitative indications of future key technologies

Descriptive level of characterizations		
General		Special
Primary class (frequency)	Secondary class	Characterizations (open comments and direct quotes)
Nanotechnology (4)	• Miniaturization	• Monitoring human body and repairing as necessary • Bio-chips implemented in the human body/brain with three main functions: 1. ensure high consciousness and ethical behavior, 2. store and make available information / world encyclopedia, 3. continuously health scanning and warning when something's wrong **[!]** • Reducing resources and environmental impact per unit of economic growth • Drug delivery, special hybrid circuits, new materials, quantum computing
Information and communication technology (3)	• Adaptable human-machinery interface • Digital TV • Integration • Multimedia communication • Ubiquitous communication • Optical communication • Printable electronics [!] • Wideband networks	• Adaptable human-machinery interface a) Enhanced machine to machine communication, systems testing the human's state of mind b) checking prior knowledge and knowledge organization (mind maps, etc.) c) finding ways to represent new information with optimal redundancy and interaction (like good private teacher, mentor, tutor) • Integration > Device integrate via bluetooth and other technologies, so that you have only one personal device via which you communicate, get entertainment and news, photograph, compute, do work, get information, pay etc. Additional devices are waiting at work, home shop, car etc. • Multimedia communication > Wireless voice, video, text and other data can be transformed in real-time from any device to any device in non-expensive way. • Ubiquitous communication > Short-range radio technologies low-power circuits, ubisensing • Optical communication > Embossed structures, new optical semiconductor devices • Printable electronics > Cost-efficient simple circuits IT is still just beginning. Worldwide standards are needed (like roads and gas for cars) • *Wideband networks > Information will be available everywhere*

Computation (3)	• Artificial intelligence • Human centered technology • Human PC-Interface • Neural network • Speech recognition • Ubiquitous technology	• Artificial intelligence in broad sense (aid to human mind in knowledge management) > a) methods to use "soft" information in reasonable and repeatable ways b) effective methods to handle non-textual information • Intelligent environments • Human centered technology > Devices and systems based on human behavior instead of technology • Human PC-Interface > Make technology ubiquitous throughout our everyday lives • Machine intelligence > Embedding AI, voice recognition and synthesis in so many built things that the build environment seems alive • Neural network • Speech recognition • Ubiquitous technology > Intelligent environments with embedded computing power • Virtual reality
Environmental technology	• Solar technology • Fission, non-fossil, cheap energy sources • Space solar power • Waste management, climate control • New energy sources, deep sea systems	

The following Table 8 presents a list of weak signals collected from the open section. These weak signals were not included in the more general Table 7 (above) because of the particularly hypothetical and futuristic nature of these depictions. But again these formulations are interesting considering the contingent nature of technological development. The direction of innovation can never be totally prognosticated and sometimes development might take totally alien directions than forecasted. Therefore, it is very important to consider more "sci-fi" alternatives as weak signals for the long-term technological development. One particularly important presentation in this vein is Ray Kurzweil's *The age of spiritual machines: when computers exceed human intelligence.*

Table 8. The weak signals of qualitative indications

Weak signals bubbling under	
General characterization	Special characterization
Antigravitation technology	Re-usable space craft, high speed, and cheap launching technology to make space travel available to the general public.
Combined social, technical and biological means to improve quality of life	a) Intelligent buildings, b) real or artificial pets, c) real working service societies (houses, villages, etc.)
Conscious-Technology	Integration of the human body with technology and the built environment with human perception will make humanity seem more like a consciously created interlined species
New learning methods / education	Abstract thinking capability helps to survive and innovate in the information society
Understanding the final theory (quantum physics and relativity)	Teleportation, time travel

Open comments made by respondents:

- *"I suggest there is a 50/50 chance that political and societal unrest may result in very little change over the next 15 years. Resources may be diverted from science and product development to the extent that very little change may occur."*
- *"In order to exploit the possibilities of any new technologies a completely new kind of paradigm at the industrial and societal level is needed."*
- *"Conscious technology explained in Future mind."*
- *"Two very strong trends: ubicomp & optoelectronics. Nanotechnology later, still unclear what the impacts will be."*
- *"The general trend would be de-globalization, which means that local and global systems work in more harmony than today. The increased demand for food (eat, drink, live), energy, and communication services pressure all societies to operate with maximum efficiency."*

6.3 Plausibility of the technological theses

This section presents the results of the estimated plausibility of technological theses (Figure 4, page 71). Technological theses were constructed on the basis of the defined key technological trajectories. The aim of the theses was to present a somewhat short and tangible formulation of some basic notion combined with each key technology. The idea was to present a general class of key technology followed by a short illustration which further specifies the characterization. The estimation of plausibility was done on the following scale: 5 = highly plausible, 4 = plausible, 3 = difficult to say, 2 = implausible, 1 = highly implausible. The theses presented were (the bold emphasis depicts the general term of the key technology, the continuation presents an illustration of it):

1. Photonic materials
Materials that produce, perceive, and handle light will replace conductors made of copper in many devices, which affects, for example, information transference.

2. Intelligent materials
Materials that monitor and repair their own condition relieve humans of observation tasks.

3. Biomedical materials
Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and other surgical operations.

4. Unbreakable materials
Useful life of devices increases when certain parts of consumer goods can be replaced with flawless materials.

5. New polymers
New polymers are used in industry to conduct and store electricity, which makes production more effective.

6. Nanotechnology
Hard and elastic nanotubes are used in objects that get easily damaged, for example, in electronic utility goods to prevent damage and make them last longer.

7. Sensors
Sensors, that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in the environment.

8. Diagnostics
In health care, it is possible to install nanosized machines in human beings to diagnose diseases, dose medicines, and monitor vital functions.

9. Biomimetics
By imitating and adapting natural methods, for example, in paper production it is possible to prevent environmental hazards.

10. Gene manipulation
Hereditary diseases can be prevented and cured with gene manipulation .

11. Targeted medicines
In health care, there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.

12. Cell technology
Cloning can be used to treat infertility.

13. Bioproducts
Bioproducts are used to clean soil and water.

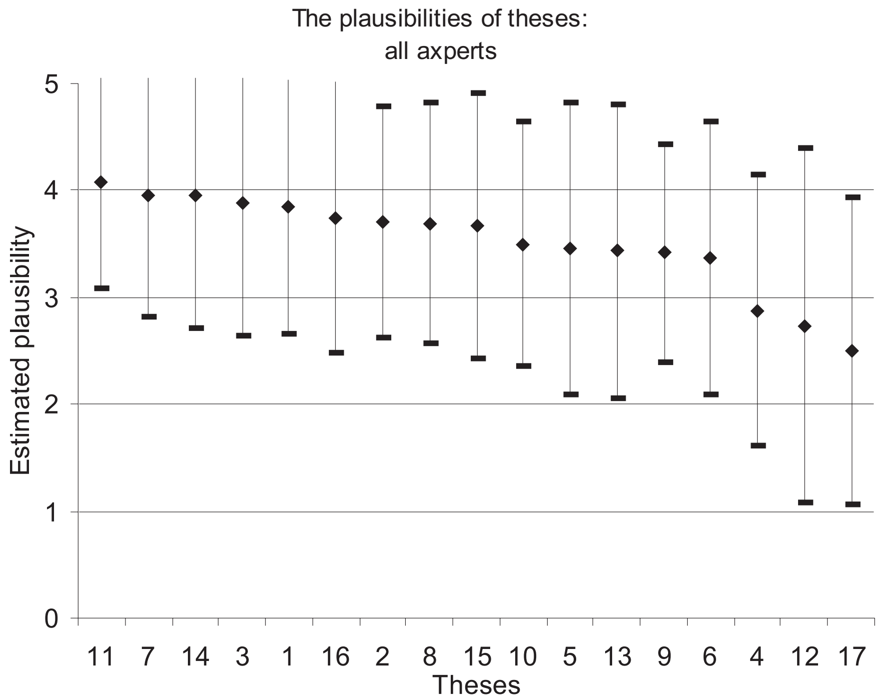
14. Integrated technology
Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.

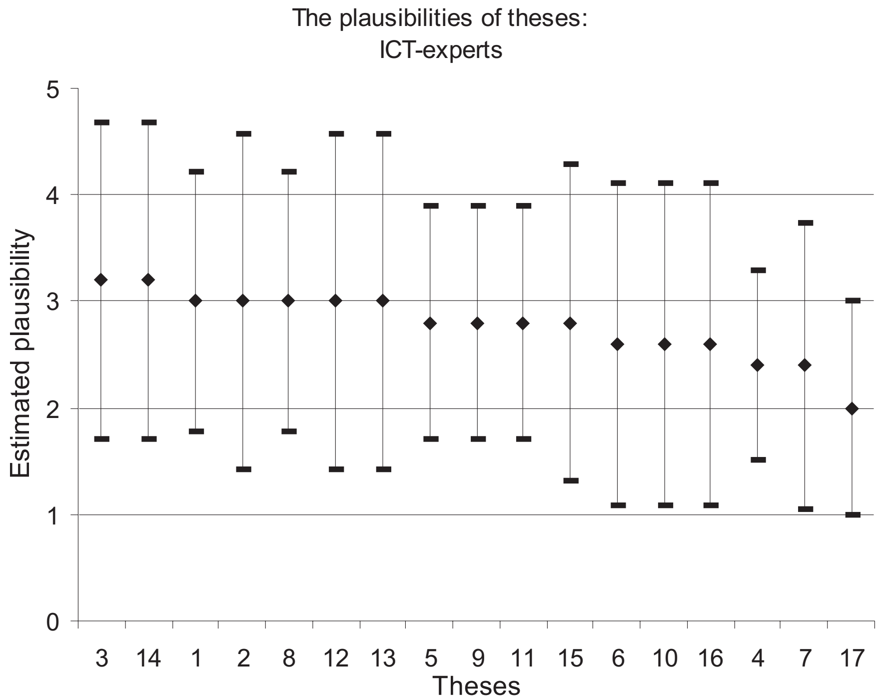
15. Virtual reality
Virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people.

16. 3-G Technologies
Opportunity to transfer text and picture fast increases a variety of different public services.

17. IT-technology
Highly developed IT-technology will replace paper in offices.

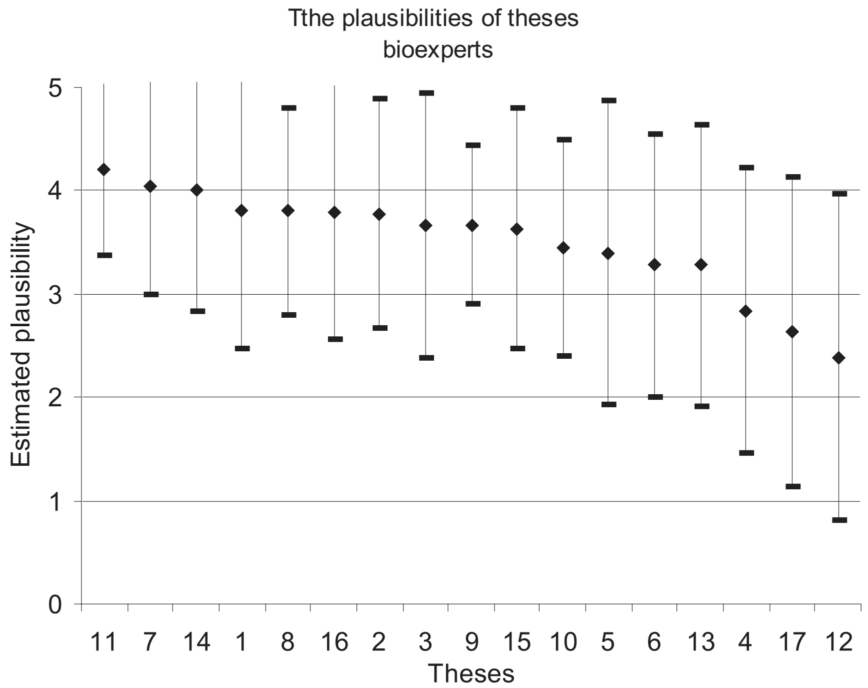
The most plausible theses according to all the experts were targeted medicines, sensors, integrated technology, biomedical materials, photonic materials, 3-G technologies, intelligent materials, diagnostics, and virtual reality. These nine theses were used as a basis for the second Delphi round. ICT experts estimated that the theses about biomedical materials and integrated technology were the most plausible. According to the bioexperts, the two most plausible theses were targeted medicines and sensors. Material and nanoexperts estimated theses about targeted medicines and integrated technology to be the most plausible.





5 = highly plausible 4 = plausible
3 = difficult to say 2 = implausible
1= highly implausible

Arithmetic mean
Standard deviation


Tthe plausibilities of theses
bioexperts
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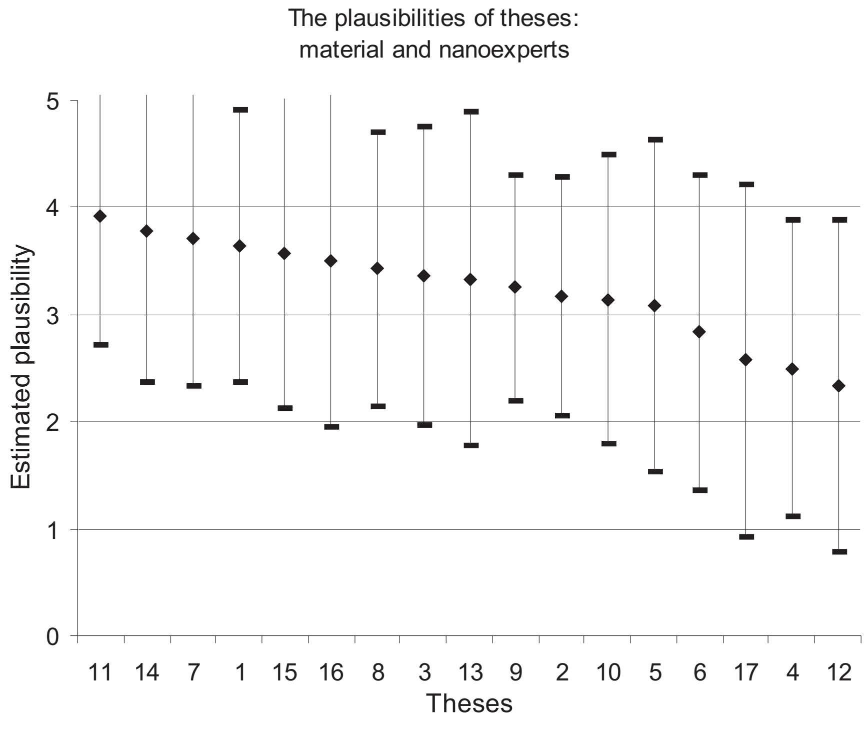
Theses


The plausibilities of theses:
material and nanoexperts
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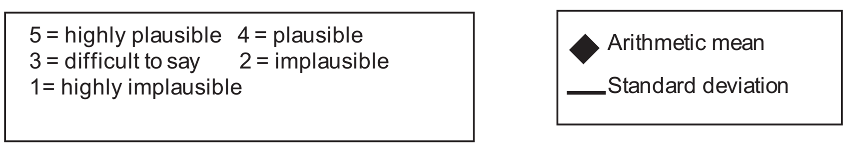
Theses


5 = highly plausible 4 = plausible
3 = difficult to say 2 = implausible
1= highly implausible
Arithmetic mean
Standard deviation

Technological theses:

1. Photonic materials
Materials that produce, perceive, and handle light will replace conductors made of copper in many devices, which affects, for example, information transference.
2. Intelligent materials
Materials that monitor and repair their own condition relieve humans of observation tasks.
3. Biomedical materials
Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and other surgical operations.
4. Unbreakable materials
Useful life of devices increases when certain parts of consumer goods can be replaced with flawless materials.
5. New polymers
New polymers are used in industry to conduct and store electricity, which makes production more effective.
6. Nanotechnology
Hard and elastic nanotubes are used in objects that get easily damaged, for example, in electronic utility goods to prevent damage and make them last longer.
7. Sensors
Sensors, that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in the environment.
8. Diagnostics
In health care, it is possible to install nanosized machines in human beings to diagnose diseases, dose medicines, and monitor vital functions.
9. Biomimetics
By imitating and adapting natural methods, for example, in paper production it is possible to prevent environmental hazards.
10. Gene manipulation
Hereditary diseases can be prevented and cured with gene manipulation.
11. Targeted medicines
In health care, there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.
12. Cell technology
Cloning can be used to treat infertility.
13. Bioproducts
Bioproducts are used to clean soil and water.
14. Integrated technology
Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.
15. Virtual reality
Virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people.
16. 3-G Technologies
Opportunity to transfer text and picture fast increases a variety of different public services.
17. IT-technology
Highly developed IT-technology will replace paper in offices.

Figure 4. The plausibilities of technological theses

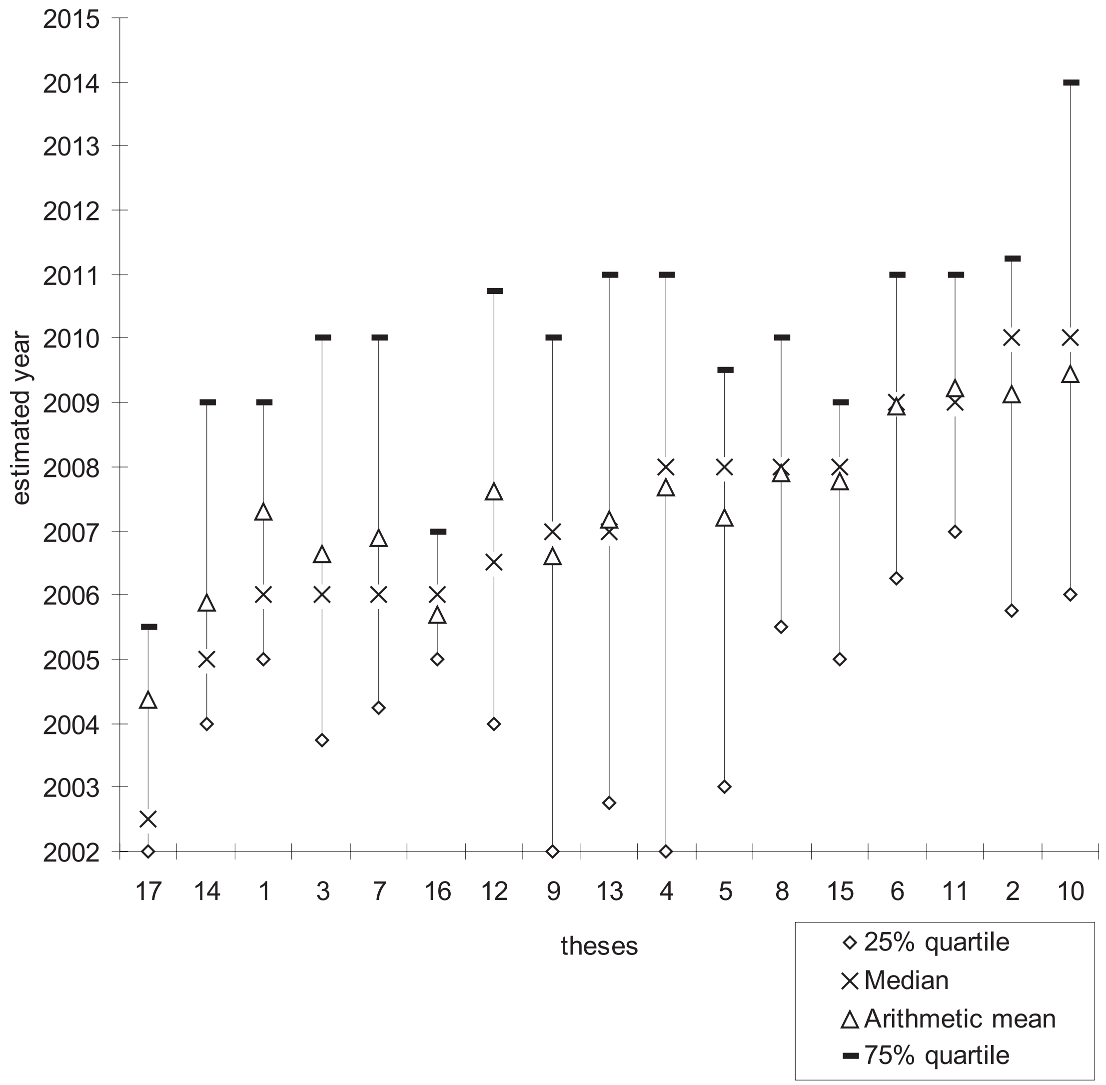
6.4 Timing of the technological theses

In the section timing of the theses, experts were to estimate a year when the above-mentioned theses will happen by at least 50 % probability. If the thesis seemed particularly implausible then there was a chance to mark “will not happen”. In the timing of the phenomena section, there were no expert group divisions. The results are presented in Figure 5.

The theses with the smallest median (meaning ”the quickest” theses to be realized) were *IT technology* (highly developed IT technology will replace paper in offices) and *integrated technology* (homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people). Theses with the highest median (referring to the ”the slowest” theses to be realized) were *intelligent materials* (materials that monitor and repair their own condition relieving people of the observation tasks), and *gene manipulation* (hereditary diseases can be prevented and cured with gene manipulation).

The theses with the highest probability (%) of not happening at all were *IT technology* (highly developed IT technology will replace paper in offices 35 %) and *cell technology* (cloning can be used to treat infertility 30 %). These results refer to the particularly ambivalent nature of the theses. The IT technology thesis was estimated to be the quickest one to be realized, yet it seems to be the most implausible, also. The paperless office seems to be a kind of utopia which is near, but hard to believe in. The result for the cell technology thesis reflects the general ethical dilemma with cloning: there are nowadays many actors who would wish be the first cloner of humans, but the legislative and ethical issues are still largely not discussed. The third and fourth most implausible thesis was *unbreakable materials* (useful life of devices increases, when certain parts of consumer goods can be replaced with flawless materials 20 %) and *virtual reality* (virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people 15 %).

Timing of the phenomena (estimated 50 % probabilities):
all experts



Thesis																
17	14	1	3	7	16	12	9	13	4	5	8	15	6	11	2	10
Will not happen %																
35	10	5	5	0	5	30	10	10	20	5	0	15	10	5	5	10

Technological theses:

1. Photonic materials
Materials that produce, perceive, and handle light will replace conductors made of copper in many devices, which affects, for example, information transference.
2. Intelligent materials
Materials that monitor and repair their own condition relieve humans of observation tasks.
3. Biomedical materials
Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and other surgical operations.
4. Unbreakable materials
Useful life of devices increases when certain parts of consumer goods can be replaced with flawless materials.
5. New polymers
New polymers are used in industry to conduct and store electricity, which makes production more effective.
6. Nanotechnology
Hard and elastic nanotubes are used in objects that get easily damaged, for example, in electronic utility goods to prevent damage and make them last longer.
7. Sensors
Sensors, that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in the environment.
8. Diagnostics
In health care, it is possible to install nanosized machines in human beings to diagnose diseases, dose medicines, and monitor vital functions.
9. Biomimetics
By imitating and adapting natural methods, for example, in paper production it is possible to prevent environmental hazards.
10. Gene manipulation
Hereditary diseases can be prevented and cured with gene manipulation.
11. Targeted medicines
In health care, there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.
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Cloning can be used to treat infertility.
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Bioproducts are used to clean soil and water.
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Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.
15. Virtual reality
Virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people.
16. 3-G Technologies
Opportunity to transfer text and picture fast increases a variety of different public services.
17. IT-technology
Highly developed IT-technology will replace paper in offices.

Figure 5. The timing of technological theses

7 Societal Impacts of the Technological Paths: Results of the Second Delphi Round

The key idea of the first Delphi round can be characterized as gaining expert insights into the technological trajectories and technological alternatives of the future. The key idea of the second round can be defined as follows: to gain expert insights into the impacts of these technological trajectories to the societal structures of education and work, with a special emphasis on the structure of professions which was reflected on the basis of the results of the first Delphi round. The nine of the most important technological theses which were the result of the first Delphi round were chosen to be the basis of the second round.

The second round was also completed as an Internet-based questionnaire. The experts in the second round were chosen from the special mailing lists from World Futures Studies Federation, World Futures Society, participants of the special Futukeys session in the annual conference of World Futures Society in Philadelphia, UNU Millennium list, FPI (Futures Professionals International) list, lists from the Finnish ministries, and other sources (for example, the list from the National Technology Agency). There were 40 answers in the second Delphi round.

The questionnaire was based on three types of questions: the estimation of the impact of the technological theses on the professions or educational branches, the estimation of the plausibility of the listed "new" future professions, and estimations when it is at least 50 % probability these professions will become a true new practice. The questionnaire was completed in two basic steps: delivering the background information and answering the questions. It must be noted that in the second Delphi round no special group division were made and all the answers were analyzed as a whole. This was because the questions in the Delphi round were more societal and applied by nature and it was considered that no divisions based on specific technological expertise were needed. Time perspective in all the questions was very long-term, to 2015.

7.1 Impact of technological theses on professions and educational branches

The first section of the second Delphi round was based on the technological theses that were estimated the most important in the first Delphi round. The theses are presented below in the order of the estimated plausibility:

- **Targeted medicines** In healthcare there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.
- **Sensors,** that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in the environment.
- **Integrated technology** Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.
- **Biomedical materials** Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and other surgical operations.
- **Photonic materials** Materials, that produce, perceive, and handle light, will replace conductors made of copper in many devices, which affects, for example, information transference.
- **3-G Technologies** Opportunity to transfer text and picture fast increases variety of different public services.
- **Intelligent materials** Materials that monitor and repair their own condition relieving people of the observation tasks.
- **Diagnostics** In healthcare it is possible to install nanosized machines in people to diagnose diseases, dose medicines, and monitor vital functions.
- **Virtual reality** Virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people.

The main task of the experts was to indicate the professions or educational branches most strongly influenced by each of the technological theses of the first Delphi round. The assumed time period was until 2015. The impact was to be measured as follows: 3 = the number of people in the profession or educational branch has increased enormously, 2 = the number of people in the profession or educational branch has increased, 1 = the number of people in the profession or educational branch has increased somewhat, 0 = the number of people in the profession or educational branch remains the same, -1 = the number of people in the profession or educational branch has decreased somewhat -2 = the number of people in the profession or educational branch has decreased and -3 = the number of people in the profession or educational branch has decreased enormously. The main idea of the scale was to get as nuanced results as possible yet still maintaining the readability of the questionnaire.

The list of professions or educational branches utilized was constructed as a combination based on the different classifications. The public classifications adapted generally, for example, by Statistical Centre of Finland or the Ministry of Labour were either much too detailed or too "static" considering the orientation of this study, and so it was decided that an alternative strategy was to be used. The list was formed as a result of an adapted combination of the educational branches and some general classes of professions. The key notion was to highlight those practices which would be important in a knowledge-technology intensive structure and, therefore, had the quality of "future-orientation". This list would certainly have looked quite different if this study would have had a more specialized perspective. After several thorough discussions, the list became the following:

- Architect / spatial expert
- Biochemist / biologist
- Business / economics expert
- Computer hardware expert
- Computer software expert
- Mathematician, statistician
- Medical doctor / pharmacologist
- Social and cultural researcher / psychologist
- Teacher, educational expert
- Office worker
- Service, sales, and nursing
- Manufacturing etc. (blue collar worker)

The idea of each of the professions / educational branches (PEBs) was to combine different elements that were assumed central in the knowledge-technology intensive structure on the basis of the literature and the first Delphi round. The following presents a short characterization of the each of the PEBs. The first, architect/spatial expert, connotes the increasing importance of the spatial dimension in the information society and biosociety. It refers not just to the growing need for regional and architectural planning in the age of hyper-accumulation of capital and congestion, but also to the growing need to understand and conceptualize spatiality in the context of technological development. For example, the rapidly emerging field of mobile geopositioning, mobile cartography, and geoinformatics all require specialists of spatiality in order to design and engineer the technical solutions and plan effective applications. Another example of the growing need for spatial experts is in the applications of virtual reality and 3D-environments, which could be used for multiple purposes such as the fields of planning, medicine and, of course, entertainment.

The second PEB refers to the more traditional notion of biochemist/biologist and the rising importance of the molecular and nanometrical information about life. The third option also refers to the "traditional" notion of expertise in economics and business management. Through the fourth and fifth categories, the double-sided notion of modern computer technologies is present and, hence, the hardware and software division. The sixth category emphasizes the increasing importance of mathematical and statistical knowledge in biosociety. Mathematical conceptualization is needed in the basic research in the sciences, as well as planning more effective computing systems. Vastly expanding fields are the professionals in applied mathematics working in multidisciplinary fields, like bioinformationists developing calculations to manage the rapidly growing mass of molecular information and also understand the complex system of life. Categories seven, eight, and nine refer again to the more traditional professional or educational branches, although it must be mentioned that a growing need for a more analytical and systematical understanding of social and cultural processes at a global level will probably place some emphasis on social and cultural experts. The categories ten to twelve refer to the more traditional professions of industry and service society. It should be emphasized that these professions are also present in the biosociety although informational development will continually change the procedures and contents of these professions. These more traditional branches were also chosen in order to test the knowledge-technology intensive change hypothesis connected to the notions of the information society and biosociety.

The results of the first section are presented in Figures 6 (page 81), 7 (page 85) and 8 (page 89). The data was organized primarily on the basis of frequencies and, secondly, on the basis of arithmetic means. In the Figure "frequency", the absolute frequencies of the PEBs are presented and in the Figure "the impact of technological theses", the estimated impact of technological theses on the PEBs are presented. It should be noted that the frequencies refer to the number of entries gained by each PEB. The entries can be positive, neutral, or negative. In this sense, the "high frequency" does not necessarily imply "high importance" because the effect can be positive or negative. *What "high frequency" implies is that many of the experts have estimated that the thesis in question will cause positive or negative changes to that particular profession or educational branch*. It means that theses with high frequencies (theses on the left side of the graphs) are most plausible statistically. Furthermore, it should be emphasized that the weak signals defined in this study are interpretations based on the combination of quite low frequency and a major change in the estimated impact. Therefore, these possibilities should be approached literally as *weak signals* (see Figure 10, page 106).

It is also very important to acknowledge that the connection between the theses and PEBs is based on the notion of *realizing alternatives*: the results presented can be thought of as scenarios for the future *considering* that the thesis in question will gain importance. This means that the results of the first section should be interpreted in the context of the alternative that the thesis in question will have a (societal) effect. For example, if the (unlikely) option, that researchers will completely stop (or at least minimize its societal effect) developing targeted medicines, occurs in the future then the results relating to the first thesis will not obviously form a feasible alternative.

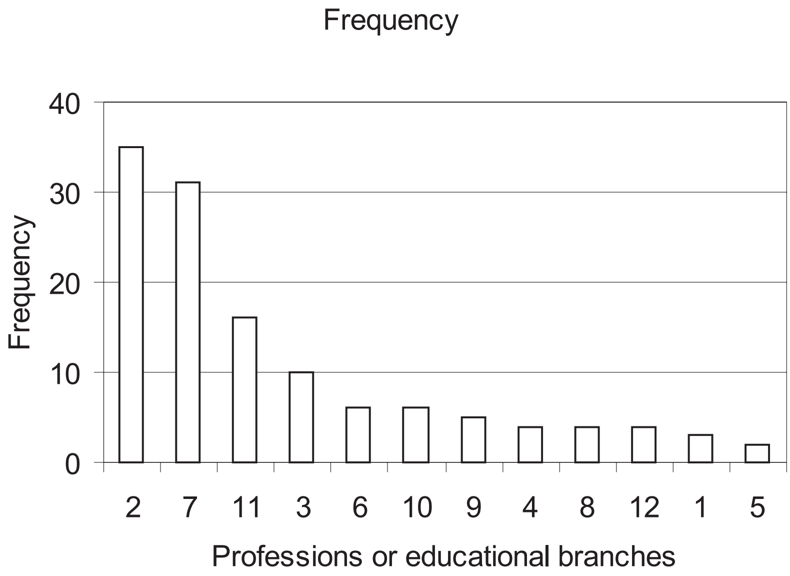
Figure 6 presents the results for three of the most plausible technological theses of the first round for all the experts. The most plausible thesis in the first round was *targeted medicines* (in healthcare there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer). Four of the most affected PEBs on the basis of the frequencies were biochemist/biologist, medical doctor/pharmacologist, service/sales/nursing, and business/economics expert. Considering the estimated changes in the structure of PEBs, the results were interesting: people in all of the PEBs were expected to increase except for architect/spatial expert, office worker, and, of course, blue collar worker. The professions mostly on the rise were biochemist/biologist, medical doctor/pharmacologist, and business/economics expert. Particularly interesting is the expected rise in the number of computer hardware experts. The *second* in plausibility was the thesis on *sensors* (that measure movement, transition, and change of form, and which will be used to observe such things as hazardous changes in environment). The highest frequencies were in the following PEBs: computer software expert, computer hardware expert, mathematician/statistician, and biochemist/biologist. The former four PEBs were also estimated to be the most important in the future. The PEBs rising in the future are: architect/spatial expert, business/economics expert, service/sales/nursing, and social and cultural researcher/psychologist. The most important "weak signals" (PEBs that are estimated to gain significance in the future) will be, according to the estimates: teacher/educational expert and medical doctor/pharmacologist. The *third* technological thesis according to plausibility was *integrated technology* (homes, offices, and other built environments will merge through information and communication technology and enable rapid communication between people). Considering this thesis, three PEBs with the highest frequencies were: computer software expert, computer hardware expert, and architect/spatial expert. The number of people working in these branches was expected to grow significantly, if this thesis would gain in importance. Important "weak signals" will also be business/economics expert, social and cultural researcher/psychologist, mathematician/statistician, and teacher/educational expert.

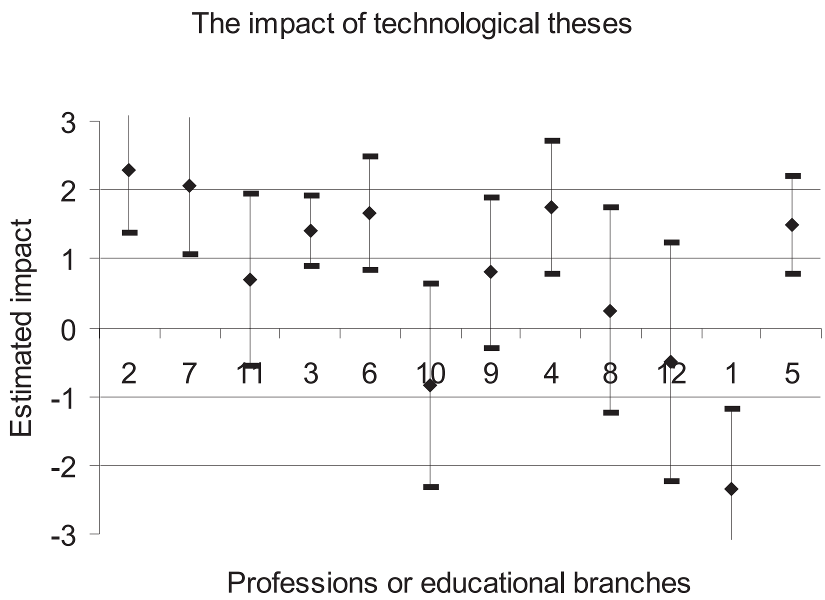
In Figure 7, the presentation results of the first section are continued. In this Figure, the future of the PEBs is estimated in the context of the fourth, fifth, and sixth most important theses of the first Delphi round. The *fourth* technological thesis from the first round was *biomedical materials* (implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and in other surgical operations). In this context the PEBs with the highest frequency were: biochemist/biologist, medical doctor/pharmacologist, and service/sales/nursing. These PEBs were also estimated to become more important. The most important "newcomers" are computer software expert and computer hardware expert. One of the most interesting "weak signals" in this sense would be the expected rise of "blue collar workers". Of course, this notion in this context should be approached with extreme caution, especially because of the low frequency and the possibility of "human error", but still we can speculate: can the production of biomedical materials or some other product characteristic of the biosociety (such as advanced materials, see footnote below) be a starter for new forms of mass production? The *fifth* technological thesis is *photonic materials* (that produce, perceive, and handle light, and will replace conductors made of copper in many devices, which affects, for example, information transference). The highest frequencies in the context of this thesis were in the following PEBs: computer hardware expert, computer software expert, and manufacturing (blue collar worker)[5]. The experts estimated a rise in the number of people in the computer sector in the future. A "weak signal" might be the estimated rise in the number of spatial experts. The *sixth* of the technological theses was *3-G technologies* (opportunity to transfer text and picture quickly increases variety of different public services). Logically, the number of computer software experts is of crucial importance, as well as computer hardware experts and business/economics experts, the latter probably due to the potential of the applications of 3-G technologies to the consumer markets. The most important newcomers might be the PEBs social and cultural researcher/psychologist and teacher/educational expert, prob-

5 The PEB "manufacturing" has the third highest number of entries. As can be noted from the "impact" -graph, the estimated impact is neutral (meaning that people working in that branch will remain the same as now), although the standard deviation is quite high. Anyway, this might add strength to the speculation about the "weak signal of mass production" in the context of material technologies.

ably characterizing the applicability of these technologies to social services and education.

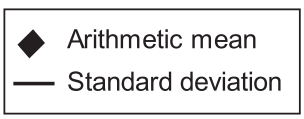
Figure 8 presents the third and final part of the results in the first section. The *seventh* most plausible thesis in the first round was *intelligent materials* (materials that monitor and repair their own condition relieving people of the observation work). The three most affected PEBs on the basis of the frequencies were manufacturing (estimations underlined a slight decrease in the future, contrary to the slight "weak signals" other "material" technologies), computer software expert, and service/sales/nursing. The estimated changes in the PEBs were also interesting: service/sales/nursing were estimated to rise slightly (although with high standard deviation), computer hardware experts, biochemists/biologists, and business/ economics experts were also estimated to increase. We can continue wild speculation about "weak signals": the result might indicate a commercial potential for the intelligent materials in many products. The *eighth* thesis in plausibility was *diagnostics* (in healthcare it is possible to install nanosized machines in human beings to diagnose diseases, dose medicines, and monitor vital functions). The following three PEBs had the highest frequencies: medical doctor/pharmacologist, service/sales/nursing, and biochemist/biologist. These three PEBs were also estimated to be the most important in the future. Newcomers with expected rises were: computer software expert, computer hardware expert, business/economics expert, and mathematician/statistician. The *ninth* and the last technological thesis in the first section was *virtual reality* (it enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people). Considering this thesis, the four PEBs with the highest frequencies were: computer software expert, computer hardware expert, social and cultural researcher/psychologist, and teacher/educational expert. The number of people working in these branches was expected to grow significantly, if this thesis were to gain in importance. Important "weak signals" will also be architect/spatial expert, mathematician/statistician, business/economics expert, and biochemist/biologist.



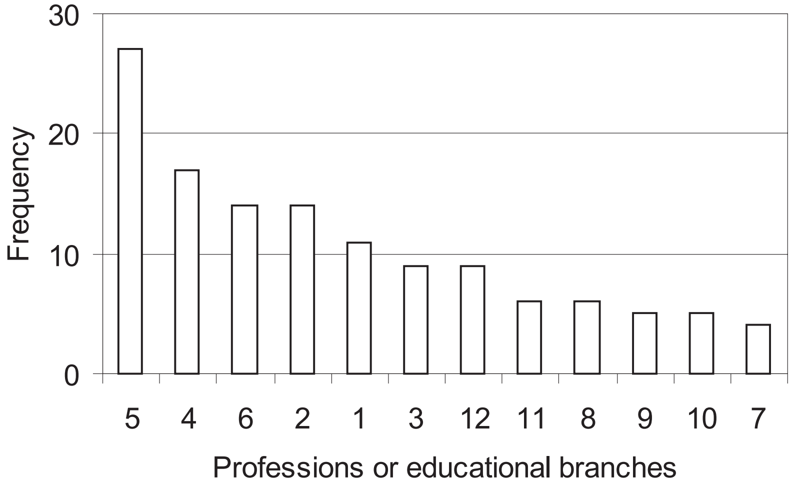


1. Targeted medicines

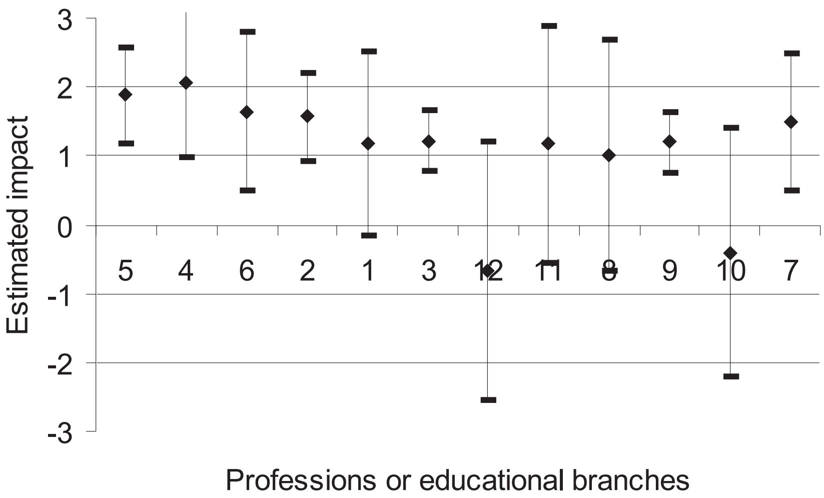
In health care, there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.



Frequency

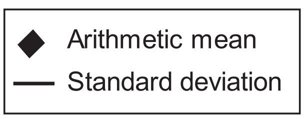


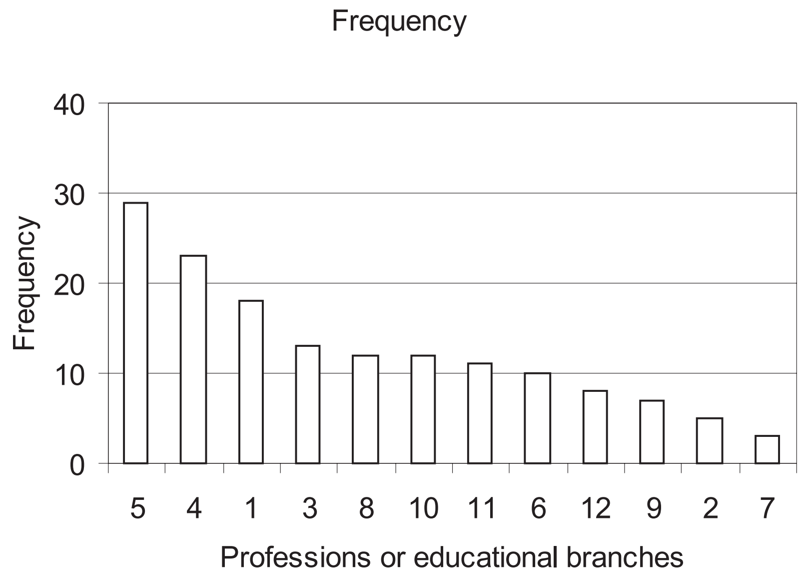
The impact of technological theses

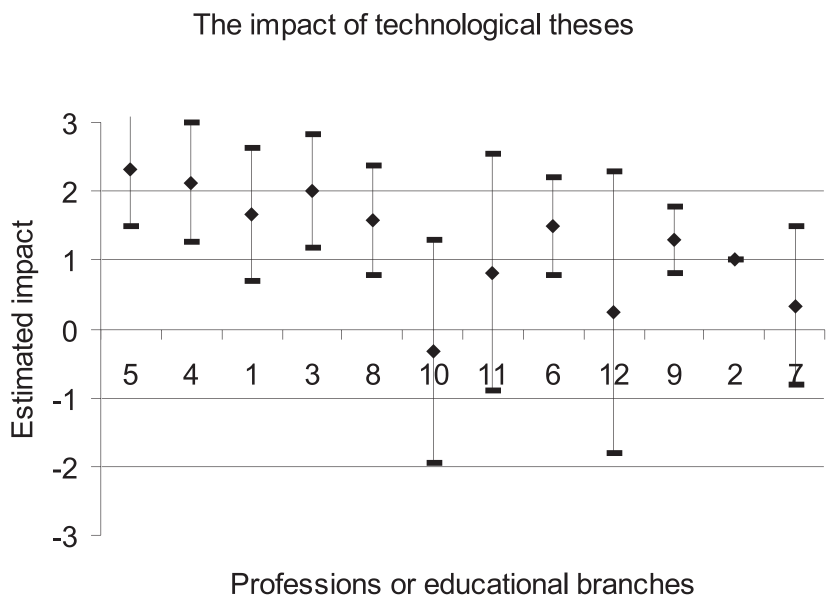


2. Sensors

Sensors, that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in the environment.

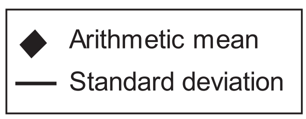






3. Integrated technology

Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.



The list of professions / educational branches:

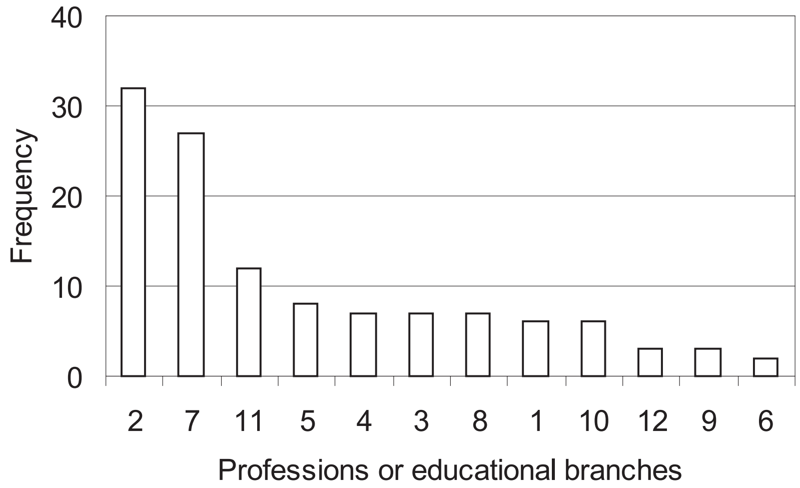
1. Architect / spatial expert
2. Biochemist / biologist
3. Business / economics expert
4. Computer hardware expert
5. Computer software expert
6. Mathematician, statistician
7. Medical doctor / pharmacologist
8. Social and cultural researcher / psychologist
9. Teacher, educational expert
10. Officeworker
11. Service, sales and nursing worker
12. Manufacturing etc. (blue collar worker)

Scale:

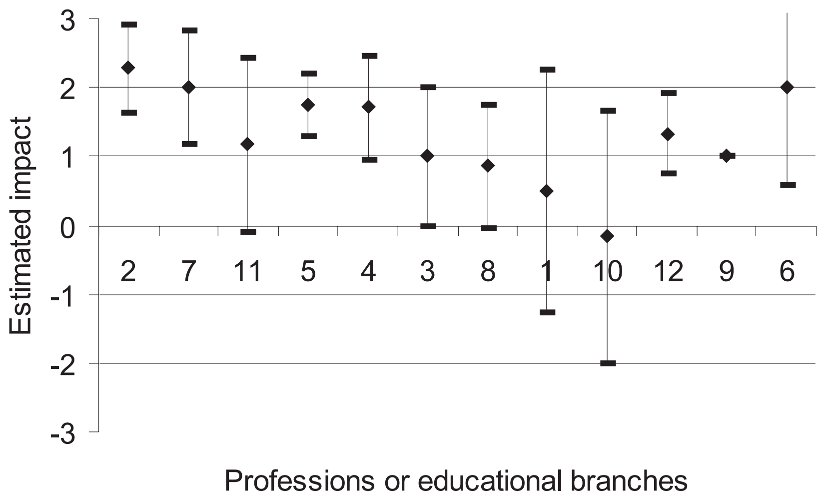
3 = the number of people in the profession or educational branch has increased enormously
2 = the number of people in the profession or educational branch has increased
1 = the number of people in the profession or educational branch has increased somewhat
0 = the number of people in the profession or educational branch remains the same
-1 = the number of people in the profession or educational branch has decreased somewhat
-2 = the number of people in the profession or educational branch has decreased
-3 = the number of people in the profession or educational branch has decreased enormously

Figure 6. The effect of theses on professional or educational branches I

Frequency



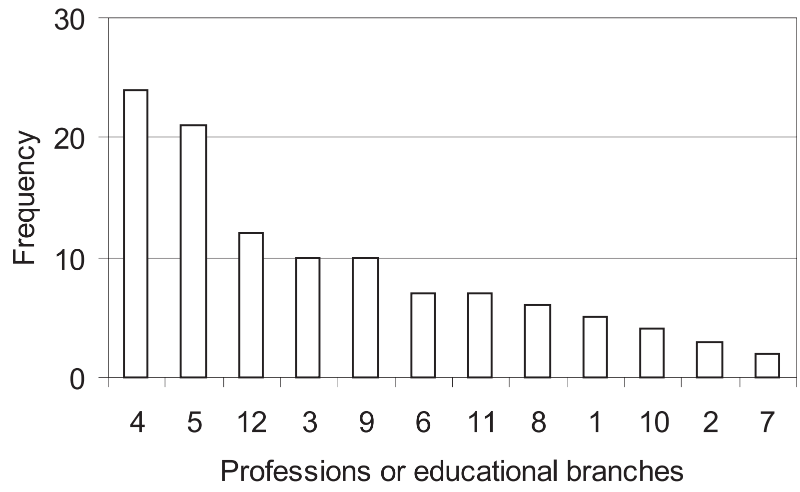
The impact of technological theses



4. Biomedical materials
Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and other surgical operations.

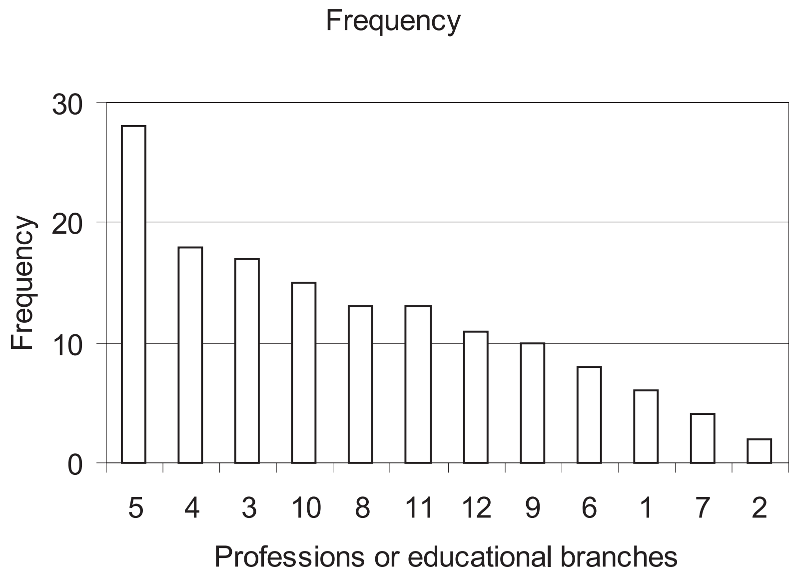
Arithmetic mean
Standard deviation

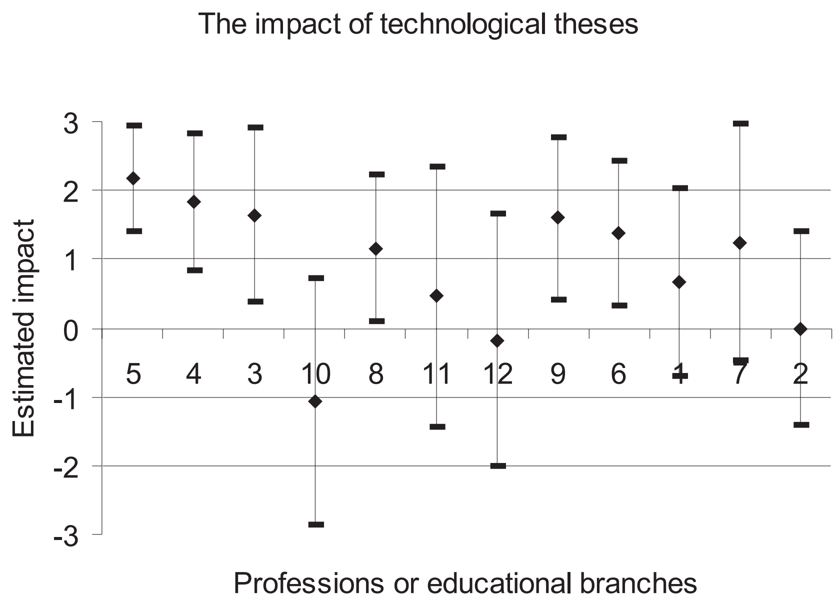
Frequency



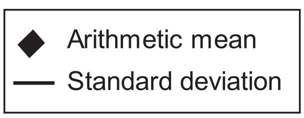
The impact of technological theses

5. Photonic materials
Materials that produce, perceive, and handle light will replace conductors made of copper in many devices, which affects, for example, information transference.





6. 3-G Technologies
Opportunity to transfer text and picture fast increases a variety of different public services.



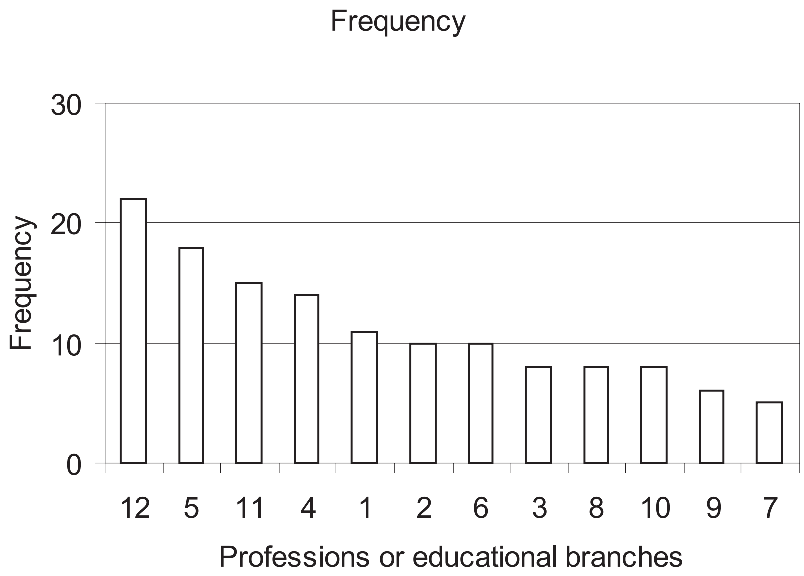
The list of professions / educational branches:

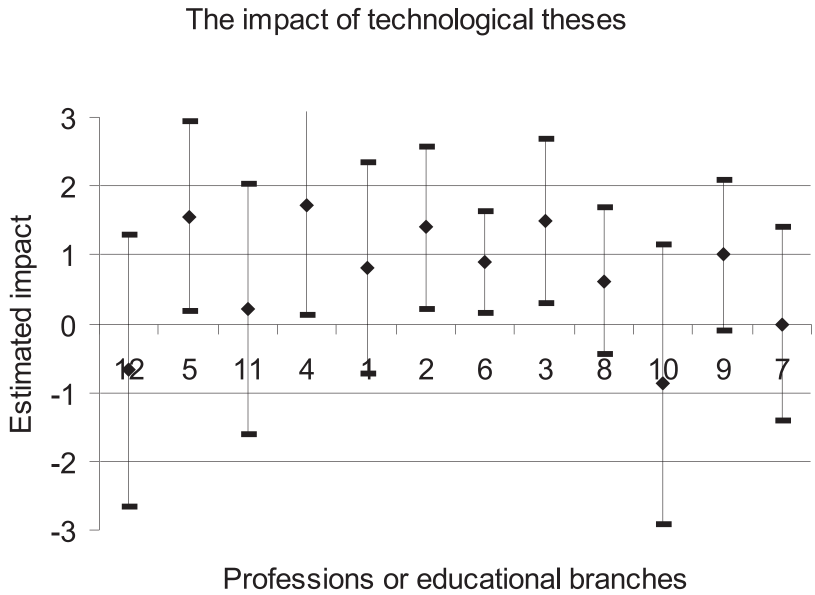
1. Architect / spatial expert
2. Biochemist / biologist
3. Business / economics expert
4. Computer hardware expert
5. Computer software expert
6. Mathematician, statistician
7. Medical doctor / pharmacologist
8. Social and cultural researcher / psychologist
9. Teacher, educational expert
10. Officeworker
11. Service, sales and nursing worker
12. Manufacturing etc. (blue collar worker)

Scale:

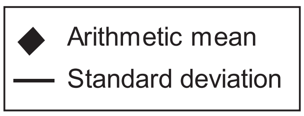
3 = the number of people in the profession or educational branch has increased enormously
2 = the number of people in the profession or educational branch has increased
1 = the number of people in the profession or educational branch has increased somewhat
0 = the number of people in the profession or educational branch remains the same
-1 = the number of people in the profession or educational branch has decreased somewhat
-2 = the number of people in the profession or educational branch has decreased
-3 = the number of people in the profession or educational branch has decreased enormously

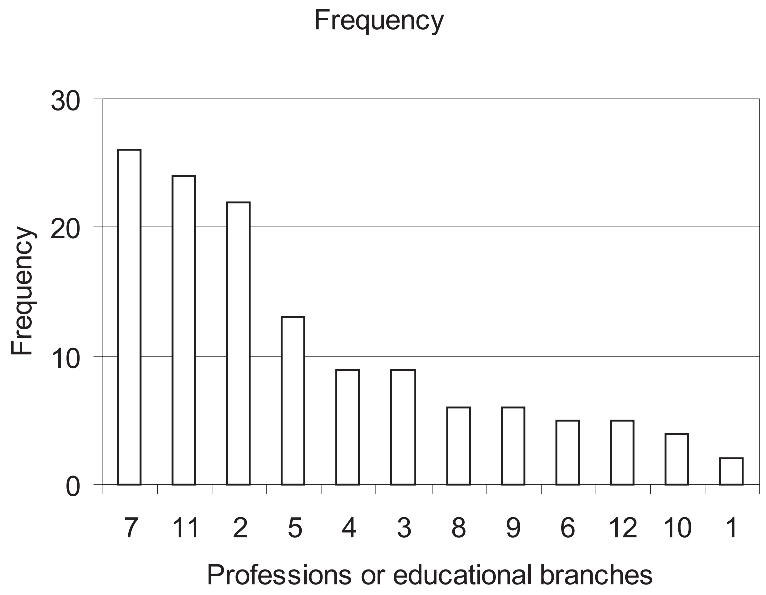
Figure 7. The effect of theses on professional or educational branches II

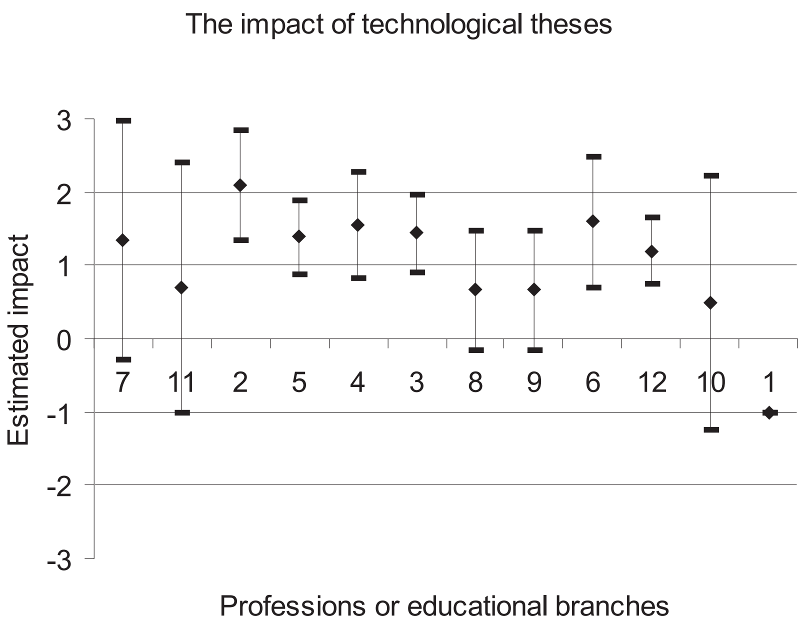




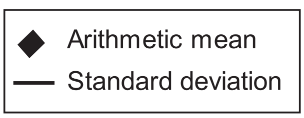
7. Intelligent materials
Materials that monitor and repair their own condition relieve humans of observation tasks.

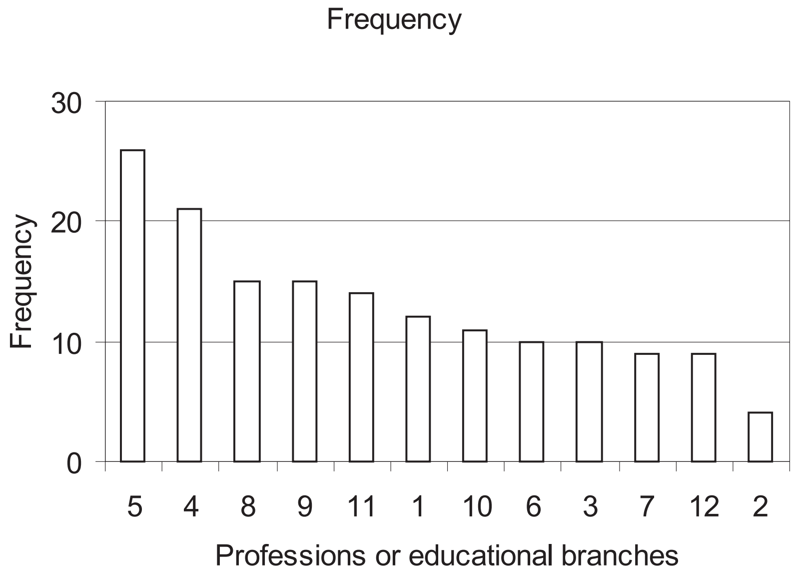


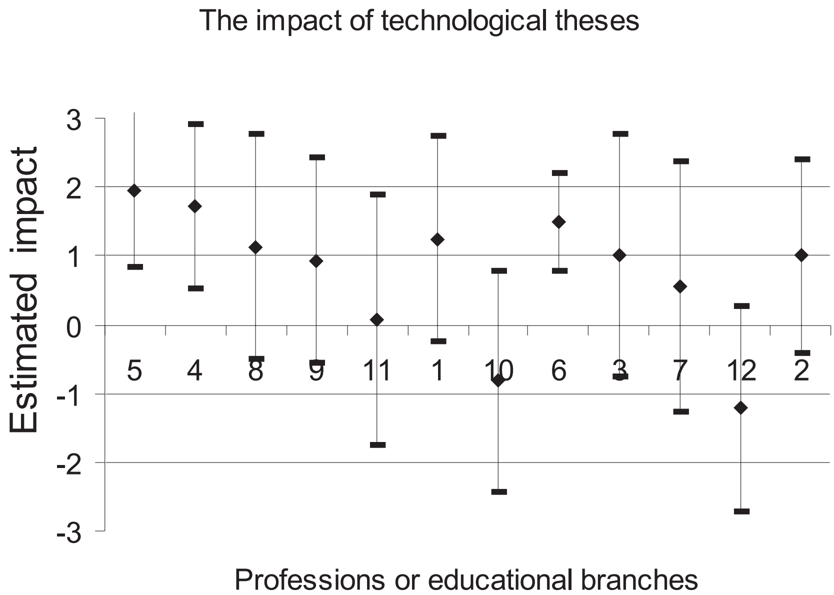




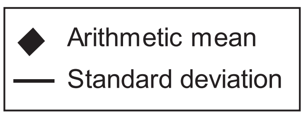
8. Diagnostics
In health care, it is possible to install nanosized machines in human beings to diagnose diseases, dose medicines, and monitor vital functions.







9. Virtual reality
Virtual reality enables distance working, distance healthcare, and other distance services making public services cheaper and more easily available for people.



The list of professions / educational branches:

1. Architect / spatial expert
2. Biochemist / biologist
3. Business / economics expert
4. Computer hardware expert
5. Computer software expert
6. Mathematician, statistician
7. Medical doctor / pharmacologist
8. Social and cultural researcher / psychologist
9. Teacher, educational expert
10. Officeworker
11. Service, sales and nursing worker
12. Manufacturing etc. (blue collar worker)

Scale:

3 = the number of people in the profession or educational branch has increased enormously
2 = the number of people in the profession or educational branch has increased
1 = the number of people in the profession or educational branch has increased somewhat
0 = the number of people in the profession or educational branch remains the same
-1 = the number of people in the profession or educational branch has decreased somewhat
-2 = the number of people in the profession or educational branch has decreased
-3 = the number of people in the profession or educational branch has decreased enormously

Figure 8. The effect of theses on professional or educational branches III

7.2 Future professions

In the second section of the second Delphi round, the experts were to test a more future-oriented approach to the changing professions in the biosociety. The original idea of future professions was primarily based on the short article in *Futurist* (Paterson 2002). A couple of the titles (cool consultant and cybrarian) are quoted directly from that article and others are elaborated on the basis of the literature. The idea was to create and test new professional categories, which could be as feasible as possible (the feasibility can be a double-edged sword considering truly "new" categories) and would reflect a cross-scientific and multidisciplinary view.

The new professions are:

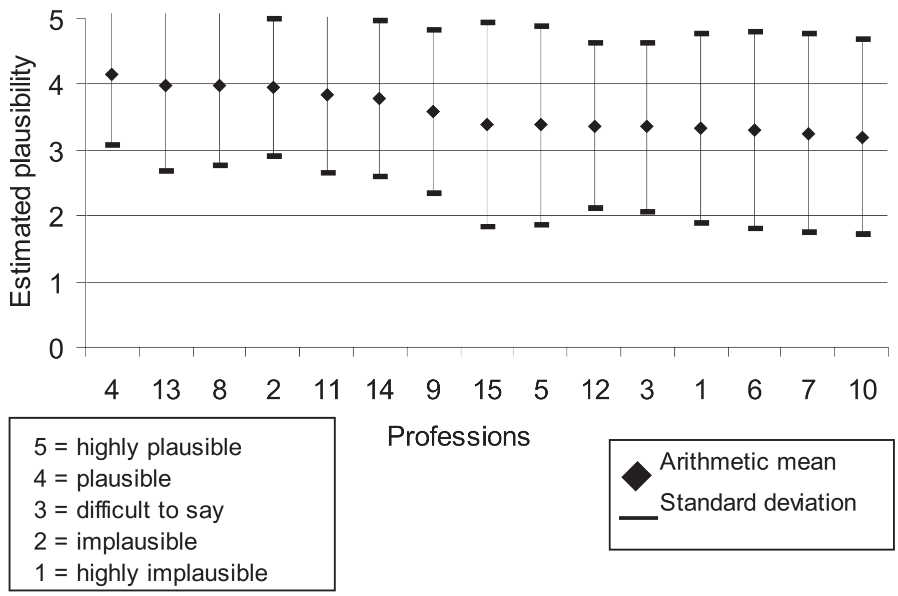
1. **Artifical organ designer** (plans bodily ”spare parts”, enhanced organs, etc.)

2. **Artificial intelligence consultant** (advises organizations and people in the utilization of advanced robotics and computing)
3. **Bioelectronics designer** (plans devices in the intersection of biotechnology and electronics)
4. **Bioinformationist** (works with the genetic information and serves as a bridge between the scientist and those developing drugs and clinical techniques)
5. **Cool consultant** (helps marketers or city planners determine what might become trendy)
6. **Cybrarian** (monitors the ever-growing Internet)
7. **Gene therapy consultant** (designs tailor-made gene therapy strategies and programs)
8. **Geoinformationist** (expert in digital applications of geographic information, such as positioning systems and cartography for mobile computing)
9. **Nanotechnology consultant** (advises organizations in the adaptation of nanotechnological devices)
10. **Simplicity expert** (simplifies and streamlines organization or corporation's technology)
11. **Smart home designer (**tailors technological solutions to future homes)
12. **Social network analyst** (studies the flow of power through an organization or company)
13. **Virtual doctor** (practices medicine through virtual reality, for example, from a distance)
14. **Visualization specialist** (specializes in the visualization of data and visual interfaces)
15. **Web gardener** (maintains and nourishes web-sites)

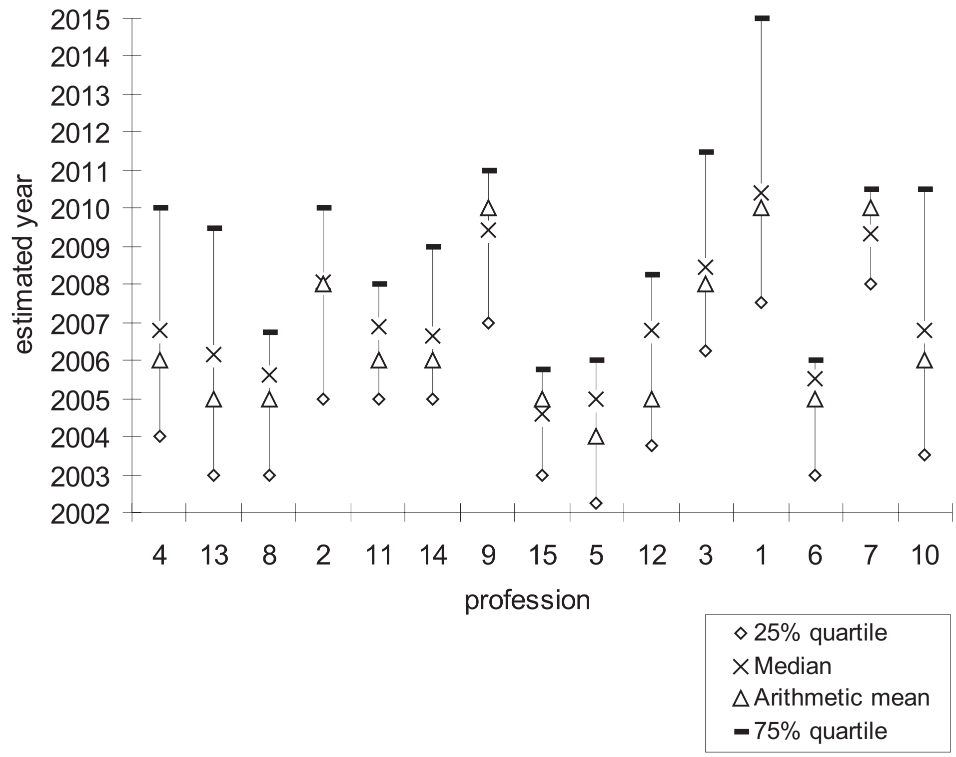
The second section started with the estimations of the plausibility of every profession according to the following scale 1 = highly implausible, 2 = implausible, 3 = difficult to say, 4 = plausible and 5 = highly plausible. The results are presented in Figure 9. As can be seen from the graph, the most plausible professions were: bioinformationist, virtual doctor, geoinformationist, artificial intelligence consultant, smart home designer, visualization specialist, and nanotechnology consultant. Generally, it can be mentioned that the formation of the future professions was quite successful in the sense that none of the professions were estimated to be particularly implausible. It should also be noted that all the collected estimations had quite high standard deviations reflecting a quite high variation in the estimations.

Figure 9 presents the results of the timing of the “realization” of the future professions. The experts were to estimate the year when the probability that the profession will become a truly new practice is at least 50 %. It was also possible to estimate that the profession in question will not become a true practice at all by choosing the option “will not happen”. An interesting feature was that generally the deviations were quite mild, that is, 50 % of the answers were inside a quite short time-span. Also the general trend seemed to be that all of the professions were estimated to be “realized” in the quite near future, within the next ten years. This might sound a bit too optimistic considering more exotic professions like artificial organ planner or gene therapy consultant. The “fastest” realizations were estimated to be cool consultant, web gardener, virtual doctor, geoinformationist, social network analyst, and cybrarian. The “slowest” professions to become true practices were artificial organ designer, gene therapy consultant, nanotechnology consultant, bioelectronics designer, and artificial intelligence consultant. Professions, with the highest “will not happen” percentages were: cybrarian (15 %) , artificial organ designer (12,5 %), cool consultant (12,5 %), gene therapy consultant (10 %), and web gardener (10 %). One general conclusion can be that the professions with a stronger current connotation (for example, connections with the Internet and currently emerging mobile technologies) were estimated to be realized faster than professions with more “distant” connotations (for example, the generally acknowledged slowness of the basic biological research, “fuzziness” of the current situation development, and ethics of genetic technologies, etc.).

The plausibilities of future professions:
all experts



Timing of the professions (estimated 50 % probabilities):
all experts



Thesis														
4	13	8	2	11	14	9	15	5	12	3	1	6	7	10
Will not happen %														
0	2.5	2.5	0	0	2.5	2.5	10	12.5	5	5	12.5	15	10	10

The list of future professions:

1. Artifical organ designer (plans bodily ”spare parts”, enhanced organs, etc.)
2. Artificial intelligence consultant (advises organisations and people in the utilization of advanced robotics and computing)
3. Bioelectronics designer (plans devices in the intersection of biotechnology and electronics)
4. Bioinformationist (works with genetic information and serves as a bridge between the scientist and those developing drugs and clinical techniques)
5. Cool consultant (helps marketers or city planners determine what might become trendy)
6. Cybrarian (monitors the ever-growing Internet)
7. Gene therapy consultant (designs personally tailored gene therapy strategies and programs)
8. Geoinformationist (expert on digital applications of geographic information, for example, positioning systems and cartography for mobile computing)
9. Nanotechnology consultant (advises organizations on adaptation of nanotechnological devices)
10. Simplicity expert (simplifies and streamlines an organization or corporation's technology)
11. Smart home designer (tailors technological solutions to future homes)
12. Social network analyst (studies the flow of power through an organization or company)
13. Virtual doctor (practices medicine through virtual reality, for example, from a distance)
14. Visualization specialist (specializes in the visualisation of data and visual interfaces)
15. Web gardener (maintains and nourishes web-sites)

Figure 9. The plausibilities and timing of the future professions

At the end of the second section, there was also a opportunity for open comments concerning the questionnaire in general or the new professions. The most important professions and comments are collected in Table 9. All the professions presented in the Table are quite interesting and can be considered complements to the original list. One expert made an intriguing comment that all of the future professions are being currently practiced in some way or another. From the basis of this experiment, it is interesting to see which of these professions will be realized in some way or another and which will not.

Table 9. The professions proposed in the open answers

Examples of the proposed professions
• *Intellectual capital consultant (advises organizations in measuring, enhancing, and managing their intellectual capital)*
• *Meta information analyst* (studies/simplifies fundamental information structures for organizations)
• *Reality consultant* (monitors future imagery against the most probable human behavior)
• *Risk minimizer* (specializes in identifying, forecasting, and counteracting likely future personal and corporate risk)
• *Strategic pathfinder* (helps the management of various organizations define their optimum role in the market and the elements of a functioning leadership)
• *Technology linker* (connecting different technologies for new innovations in cross scientific/cross technological/cross cultural communication)
• *Virtual futurist* (serves actual online forecasting on the basis of interconnected Internet information sources)
• *Virtual organization consultant* (considers organizational needs and provides support in establishing organizational structure to meet needs, taking advantage of information and communication technologies, personal work preferences, and the elimination of dedicated physical space for an organization).

8 Discussion, Conclusions and Recommendations

Intensifying and diversifying technological development poses challenges for educational and vocational structures. Technological breakthroughs and innovations can be so fundamental that the entire productive system should be transformed in order to correspond to their requirements. Technological breakthroughs and innovations that will be central in future are often extremely hard to anticipate realistically, as the case of the Internet suggests. However the preparation for the possible developments, characterization, and partial mapping of possible future paths is crucial, if one wishes the educational and vocational structures to respond and complement the technological and innovation structures constituting competitiveness in the future. Therefore, the functioning blueprint for actions is not just the famous *just-in-time*, where the creation process of products is distributed and outsourced to networks in order to ensure the maximum flexibility, shortest possible time of production, and smallest possible stocks. The functioning blueprint for the future should always include the component *before-its-time*, or at least the component *prepared-for-this-development*, so that when technological breakthroughs, as surprising as they might be, appear, the preparations for this alternative are at least theoretically considered.

The main goal of the study is to *characterize the most important developing technological trajectories (key technologies) of the future and analyze and form conclusions about the societal, educational, and professional impacts of these trajectories*. The starting-point of the study has been the *construction of synthesis concerning the societal impacts of key technologies*. The study has covered a vast field and so it is clear that quite strict emphases and limitations have been unavoidable. The technological division utilized in the study sought to cover the central implications of the most important technologies in the future, although striving for societal synthesis has obliged the emphasis of the study to stick to a somewhat general level considering the massive amount of detail modern technologies comprise.

Results. The study was completed in three different phases, which had somewhat differing emphases. Each of the phases includes partial results that form the aggregate chain of results in the study. The phases were the preliminary phase, first Delphi round, and second Delphi round. The general results are presented in the next part.

Preliminary phase. The preliminary phase in this study has two parts: the elaboration of general technological paradigms (expert interviews, literature) and formation of a systematized picture of key technologies (expert interviews). The results of the preliminary phase structured the completion of the subsequent Delphi rounds. A short summary of the key results of the interviews is presented at the end of this chapter. The systematized key technologies are presented in Table 10 below.

Table 10. Result of the preliminary phase: the key technological trajectories of the future systematized.

Information and communication technology	Biotechnology	Material and nanotechnology
• Advanced data storage	• Artificial organs	• Biocompatible polymer surfaces
• Artificial intelligence	• Biochips	• Fuel cells
• Computerized healthcare	• Biomimetics	• Functional polymers
• Distance learning	• Cloning	• Intelligent materials
• Electronic paper	• Genetic engineering	• Miniaturization
• Human computer interface	• Genetic therapy	• Sensors
• Modular software	• Targeted pharma-ceuticals	• Superconducting materials
• Neural networks		
• Optical computers		
• Intelligent agents		
• Ubiquitous computing – UbiComp		
• Applications of virtual reality		

First Delphi round. The results of the first Delphi round were collected through an Internet-based questionnaire. The orientation of the first Delphi round was *technological*: the main objective was to gain expert opinions of technological theses and phenomena constructed through the preliminary phase. The questionnaire was divided into three sections: estimation of the future importance of certain technological phenomena, estimation of the plausibility of theses related to technological development, and the timing of the theses. For further details see the actual report.

According to the results of the first Delphi round, the following technological phenomena are most important in the future:

- third generation in computing, when technology recedes into the background of our lives (ubiquitous computing)
- miniaturization
- virtual reality
- opportunity generated by Green methods to reduce the amount of waste and hazards
- artificial intelligence

- a person simultaneously communicates with multiple devices in a fully interactive workspace (Human PC-Interface)
- artificial organs in people
- environmental scanning
- cloning of human organs
- machine intelligence

The second part considered the plausibility of the technological theses presented. The most plausible theses were also utilized in the formation of the second Delphi round:

- **Targeted medicines** In healthcare there will be more effective medicines well targeted to cure, for example, certain parts of the body affected by cancer.

- **Sensors,** that measure movement, transition, and change of form, will be used to observe, for example, hazardous changes in environment.

- **Integrated technology** Homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people.

- **Biomedical materials** Implants and human spare parts made of biomedical materials will be used in skin and organ transplantation and in other surgical operations.

- **Photonic materials** Materials, that produce, perceive, and handle light, will replace conductors made of copper in many devices, which affects, for example, information transference.

- **3-G Technologies** Opportunity to transfer text and picture fast increases variety of different public services.

- **Intelligent materials** Materials that monitor and repair their own condition relieve humans of observation tasks.

- **Diagnostics** In healthcare it is possible to install nanosized machines in people to diagnose diseases, dose medicines, and monitor vital functions.

- **Virtual reality** Virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people.

Another estimation connected to the theses was the timing of the theses. In the timing of theses, experts were to estimate the year when the above-mentioned theses will happen by at least a 50 % probability. The timing concerned 2002–2015 (the project started in 2001). If the thesis seemed particularly implausible then there was a chance to mark the option “will not happen”. The most central results can mentioned as follows:

Theses with the smallest median (meaning ”the quickest” theses to realize)

- *IT technology* (highly developed IT technology will replace paper in offices)
- *Integrated technology* (homes, offices, and other built environments will merge through information and communication technology and enable fast communication between people).

Theses with the highest median (referring to the ”the slowest” theses to realize)

- *Intelligent materials* (that monitor and repair their own condition relieve humans of observation tasks)
- *Gene manipulation* (hereditary diseases can be prevented and cured with gene manipulation).

Theses with the highest probability (%) of not happening at all

- *IT technology* (highly developed IT technology will replace paper in offices 35 %)
- *Cell technology* (cloning can be used to treat infertility 30 %)
- *Unbreakable materials* (useful life of devices increases, when certain parts of consumer goods can be replaced with flawless materials 20 %)
- *Virtual reality* (virtual reality enables distance working, distance healthcare, and other distance services, making public services cheaper and more easily available for people 15 %).

Second Delphi round. The results of the second Delphi round were also collected through an Internet-based questionnaire. This time the orientation was *societal*: the main objective was to gain expert opinions on the changes in vocational and educational structures brought up by the emerging key technological trajectories systematized in the preliminary phase and the first Delphi round. The questionnaire was divided into two sections: estimation of the vocational and educational impacts of the most important technologies and estimation of the plausibility and timing of the realization of the future professions. For further details see the actual report.

The main task of the experts was to indicate the *professions or educational branches* (PEBs) most strongly influenced by each of the technological theses of the first Delphi round. Nine of the most important technological theses were chosen to form the guideline defining the possible future paths.

The list of professions or educational branches utilized was constructed as a combination based on the different classifications. The public classifications adapted generally, for example, by Statistical Centre of Finland or the Ministry of Labour were either much too detailed or too "static" considering the orientation of this study. The list was formed as a result of an adapted combination of the educational branches and some general classes of professions. The key notion was to highlight those practices which would be important in a knowledge-technology intensive structure and, therefore, had the quality of "future-orientation". Also the characterization of professional or educational branches was emphasizing the ”fluidity" of the future by not sticking to traditional professions or educational branches, but by presenting an alternative and synthetic approach. The PEBs are:

- Architect / spatial expert
- Biochemist / biologist
- Business / economics expert
- Computer hardware expert
- Computer software expert
- Mathematician / statistician
- Medical doctor / pharmacologist
- Social and cultural researcher / psychologist
- Teacher / educational expert
- Office worker
- Service, sales and nursing
- Manufacturing etc. (blue collar worker)

Figure 10 presents an interpretation of the results of the first part of the second Delphi round. The general idea of this presentation is to provide an illustration of the effects of the theses on professional or educational branches, if the theses are realized. Key technologies are connected to the *professions or educational branches* (PEBs) through four steps: 1) PEBs with high frequency and rising (most important and rising) 2) PEBs without such high frequency, but rising (rising) 3) PEBs without high frequency and declining, and 4) PEBs with quite low frequency, yet very high expected rise in the future (weak signals or possibilities).

Targeted medicines

Most important and rising:	**Rising**:	**Declining**:	**Weak signals (possibilities)**:
biochemist / biologist medical doctor / pharmacologist service, sales and nursing business / economics expert	mathematician / statistician teacher / educational expert computer hardware expert	office worker manufacturing (blue collar) architect / spatial expert	computer software expert

Sensors

Most important and rising:	**Rising**:	**Declining**:	**Weak signals (possibilities)**:
computer software expert computer hardware expert mathematician / statistician biochemist / biologist	architect / spatial expert business / economics expert service, sales and nursing S & C researcher / psychologist	manufacturing (blue collar) office worker	teacher / educational expert medical doctor / pharmacologist

Integrated technology

Most important and rising:	**Rising**:	**Declining**:	**Weak signals (possibilities)**:
computer software expert computer hardware expert architect / spatial expert	business / economics expert S & C researcher / psychologist service, sales and nursing mathematician / statistician	manufacturing (blue collar)	teacher / educational expert medical doctor / pharmacologist

Biomedical materials

Most important and rising:	**Rising**:	**Declining**:	**Weak signals (possibilities)**:
biochemist / biologist medical doctor / pharmacologist service, sales and nursing	computer software expert computer hardware expert business / economics expert S & C researcher / psychologist	office worker	manufacturing (blue collar) **[!]** teacher / educational expert mathematician / statistician

	Most important and rising	Rising	Declining	Weak signals (possibilities)
Photonic materials	computer hardware expert computer software expert	business / economics expert teacher / educational expert mathematician / statistician service, sales and nursing	S & C researcher/psychologist	architect / spatial expert medical doctor / pharmacologist
3-G Technologies	computer software expert computer hardware expert business / economics expert	S & C researcher / psychologist service, sales and nursing	office worker manufacturing (blue collar)	teacher / educational expert mathematician/statistician architect / spatial expert medical doctor / pharmacologist
Intelligent materials	computer software expert computer hardware expert	service, sales and nursing architect / spatial expert biochemist / biologist mathematician / statistician business / economics expert	*manufacturing (blue collar)* office worker	teacher / educational expert
Diagnostics	medical doctor / pharmacologist service, sales and nursing biochemist / biologist	computer software expert computer hardware expert business / economics expert	architect / spatial expert	teacher / educational expert manufacturing (blue collar) **[!]**
Virtual reality	computer software expert computer hardware expert S & C researcher / psychologist teacher / educational expert	architect / spatial expert biochemist / biologist mathematician/statistician business / economics expert	office worker manufacturing (blue collar)	medical doctor / pharmacologist biochemist / biologist

Figure 10. The combined interpretation of the results in the second Delphi round: the effects of technological theses on professional or educational branches

In the second section of the second Delphi round, the experts were to test a more future-oriented approach to the changing professions in the biosociety. The new professions were

1. **Artifical organ designer** (plans bodily ”spare parts”, enhanced organs etc.)
2. **Artificial intelligence consultant** (advises organizations and people in the utilization of advanced robotics and computing)
3. **Bioelectronics designer** (plans devices in the intersection of biotechnology and electronics)
4. **Bioinformationist** (works with the genetic information and serves as a bridge between the scientist and those developing drugs and clinical techniques)
5. **Cool consultant** (helps marketers or city planners determine what might become trendy)
6. **Cybrarian** (monitors the ever-growing Internet)
7. **Gene therapy consultant** (designs tailor-made gene therapy strategies and programs)
8. **Geoinformationist** (expert in digital applications of geographic information, for example, positioning systems and cartography for mobile computing)
9. **Nanotechnology consultant** (advises organizations in adaptation of nanotechnological devices)
10. **Simplicity expert** (simplifies and streamlines organization or corporation’s technology)
11. **Smart home designer (**tailors technological solutions to future homes)
12. **Social network analyst** (studies the flow of power through an organization or company)
13. **Virtual doctor** (practices medicine through virtual reality, for example, from a distance)
14. **Visualization specialist** (specializes in the visualization of data and visual interfaces)
15. **Web gardener** (maintains and nourishes web-sites)

The second section started with the estimations of the plausibility of every profession. The most plausible future professions were:

- **bioinformationist**
- **virtual doctor**
- **geoinformationist**
- **artificial intelligence consultant**
- **smart home designer**
- **visualization specialist**
- **nanotechnology consultant**

The second part of the second section dealt with the timing of the “realization” of the future professions. The experts were to estimate a year when the probability that the profession will become a truly new practice is at least 50 %. It was also possible to estimate that the profession in question does not become a true practice at all by choosing the option ‘will not happen’. The interpreted results were:

The “fastest”
- cool consultant
- web gardener
- virtual doctor
- geoinformationist
- social network analyst
- cybrarian

The “slowest”
- artificial organ designer
- gene therapy consultant
- nanotechnology consultant
- bioelectronics designer
- artificial intelligence consultant

Professions with highest “will not happen” percentages were: cybrarian (15 %) , artificial organ designer (12,5 %), cool consultant (12,5 %), gene therapy consultant (10 %), and web gardener (10 %).

Summary of the interviews. According to the results of interviews, the following four trends will be important in the development of information and communication technology: continuing informationalization of work, developments in the information management, intensification of entertainability, and a kind of leveling down or “democratization” of information. The continuing informationalization of work refers to the rising needs for ICT skills, but it also means more competitive nature of work and more short-term vacancies. Developments in information management is the second trend emphasizing the developments in interfaces and “new” kind of combinations of information. The intensification of entertainability is the third trend that appeared in the interviews. Intensifying entertainability is a trend penetrating the whole genre of ICT, from the professional solutions to creation of games. The fourth trend is the democratization leading to pluralization and the strengthened significance of direct marketing.

Among the interviewees, there were difference of opinion concerning biotechnology as the next big boom after ICT. The greatest reservation sprung from the issue that making products in the field of biotechnology is very “slow”. The actualization of products will take about ten years of research, development, and testing on average. It must be noted that product development of the biotech industry might not replicate the highs and lows of information and communication technology. On the contrary, the biotech industry might be successful *because* its slow product cycle will generate a more wavelike form of development instead of incremental steps and hypes.

The industrialization of modern biotechnology got its momentum in the United States. The current situation is that the general scientific level comparable with the USA already exists in Europe, but many North American companies are much more advanced in the development of products and commercialization. In Europe, the number of firms in biotechnological research and production has risen dramatically at the end of the 20th century and the start of the 21st. Currently, the number of firms in the field is higher in Europe than in the United States, but the European firms are considerably smaller comparing the turnover rates. This is because biotechnology as an entrepreneurial business is still quite young in Europe and the actual ”selection of the fittest” firms is still largely unexecuted. The European Union (EU) has started to play a very important role in the field of technology. One of the most significant impacts the EU has had is the increase in the cooperation between research groups across Europe. For many of the interviewees, Japan is a kind of interesting enigma. Firstly, some interviewees see that Japan has very good chances in some special sectors of biotechnology. Secondly, some still portray Japan as an industrial copyist and license buyer instead of an original inventor of technologies and procedures. Interviewees saw that the most crucial shortcoming in the structure of Japanese biotechnology is that the relations of industry and the academic world do not work properly.

A very interesting theme discussed during the interviews was the emerging possibility of “bio-induced commodities”, biotechnology consumer products. The nature of these commodities is still rather vague seen from the contemporary perspective. However, if these bio-induced commodities would be as applicable and generalizable as, for example, mobile phones, they could have huge market potential. This notion of "biocommodity production" is also present as a weak signal in the interpretation of the central results of the second Delphi round. Scrutinizing the weak signals of the possible vocational changes in the case of biomedical materials and diagnostics, one can find an intriguing aspect: the hypothesized rise in the number of blue collar workers (see Figure 10). Although this result does not have the "statistically significant" quality of a large sample, it might provide a much more significant glimpse into the future than mere statistical likelihood. Could it be possible that new kinds of mass consumer products will emerge, for example, in the fields of biomedical materials or diagnostics? Are these commodities produced in factories of the future by blue collar workers of the biosociety?

General recommendations. This section shortly discusses five general recommendations formed on the basis of the results. The recommendations are presented as paths where to channel the focus of interest in the future.

I) *The concept of education should be widened.* According to the interviews, the information about the contemporary world should brought alongside the classical education. The basic level of education does not emphasize information about current events and socio-technical developments. One way to widen it would be to provide up-to-date information on developments in social and natural sciences, technologies, environment, and research in the elementary level at schools.

II) *There is an increasing need to combine societal viewpoints on the development of technology, to bring societal experts to discuss the development of technology along with technical experts*. This recommendation has connections with the strategy of the Ministry of Education, which emphasizes the birth of the "third culture", in which the development of technology and content is intertwined and where the "strict divide between technism and humanism" is dissolved (Ministry of Education 2002: 34). Societal viewpoints should be accentuated in technical education thus bringing more emphasis on the application-oriented approaches. Furthermore, there is a growing need for research focusing on the relations between technology and society. Research could be realized by creating special Master's and Doctoral programs focusing on the problems of technology and society.

III) *There should be critical cross-checking between the contemporary educational and vocational structure and the results of this study.* In Finland, there is much discussion about the number of engineers and technical professionals. More important than the mere number is the following question: Does the current technical education (vocational, university level) correspond to the emerging technological trajectories?

IV) *There is a strong necessity for research focusing especially on the changing vocational and educational situation bred by the fusion of technologies.* According to the results of this study, the fusion of biotechnology, nanotechnology, and information technology will give rise to new demands for qualified professionals, and hence, new demands on education.

V) *To prepare for the emergence of completely new professions.* The transformation and fusion of societal and technological spheres might result in completely new professional structures that combine and divide the economic structure in new ways.

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Information and communication technology

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Biotechnology

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Material and nanotechnology

Biocompatible polymer surfaces

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Interviews

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Appendix

Article Section

Toni Ahlqvist, editor

Osmo Kuusi

Use of human genetic information in the biosociety – three scenarios

Background of the article

The scientific revolution in the area of molecular biology started in the 1950s. The main background of this article is an assessment project of the future prospects and challenges of this revolution. The assessment was made by the Parliament of Finland in 2002. The assessment evaluated the latest scientific achievements in molecular biology. It was focused, in particular, on the prospects and challenges of human genome and stem cell research.

In the Parliament of Finland, technology assessment (TA) activities are closely connected with the Committee for the Future, which was established for the first time in 1993 and received permanent status in 1999. The Committee's main task is to look for a "whole map" of future challenges for Finland. In practice, this "parliamentary futures policy" is realized first of all in the Committee's answer to the government's account on the future. The government is required to give the account in every electoral period. If we compare the parliamentary TA activities in different countries, a special Finnish feature of assessment projects – including the human genome and stem cells project – is a broad approach comparable to the general orientation of the Committee for the Future. Another special Finnish feature, which has also had some impacts on the results of the projects, is that TA projects are carried out not only for the MPs, but by the MPs who have taken an active part in the scopeing, management, and dissemination of TA studies as members of Steering Groups.

The basic report of the assessment project will be published in Finnish in spring 2003. The scenarios discussed in this paper were, however, not presented during the assessment process or in its basic report. All the basic elements of the scenarios were, however, discussed during the assessment process. In particular, the "regulatory approach" , "the narrow innovation oriented approach", and "the broad innovation oriented approach" were extensively discussed both during the assessment process and in its basic report.

Three phases in the revolutionary process of biosciences

Fotis Kafatos (2002) distinguishes three phases in the revolutionary process of molecular biology since the 1950s. At the start of the period, genetics identified that genes are based on a double-helical molecule, DNA. The essence of life can ultimately be ascribed to the inherited existence and expression of DNA (or RNA) information. The linear sequence of bases or “letters” in DNA can be copied, transcribed into RNA, translated into protein, and interpreted in shaping the protein into a three-dimensional tool. Proteins are key “designers and builders” of structures and functions of any organism. In this first stage of the revolution, the reductionist approach prevailed. The focus was on the most fundamental questions and the simplest organisms. It was, for example, found that the expression (or “reading”) of specific genes is regulated according to an intrinsic program or in response to changes in the environment. For example, it was found that viruses of bacteria (bacteriophages) could remain quiescent, with their DNA replicating along with the replication of bacterial DNA, as a part of it. Viruses can, however, switch into an active “lytic” cycle, in which renewed expression of some viral genes leads to rapid proliferation and release of the viruses, accompanied by the destruction of the host bacterial cell. For example, ultraviolet light has such an effect on some passive bacteriophage DNA sequences.

According to Kafatos (2002), the second phase of the revolution happened in the period between the early 1970s and early 1990. It come about by development of new technologies giving the ability to “read” the DNA of any organism, and to isolate, experimentally alter, and reintroduce variant genes in vivo. It made possible the molecular description of genes irrespective of origin. It introduced reverse genetics. The first phase genetics began with an observed function of an organism and tried to discover the underlying gene sequence. Reverse genetics begins with a gene sequence and tries to infer its function by introducing it to a cell or organism from which it was absent. New techniques promoted a big shift from the simplest and most general to the more complex and specific. On the other hand, the striking evolutionary unity of life at the molecular level came into focus, greatly facilitating the use of convenient lower organisms as models for the study of species that previously seemed intractable, including humans. It was learned that the same pathway (codified by similar genes) could function in seemingly unrelated processes, such as development, immune responses, or cancer. In parallel, biology spread from the domain of pure science to its applications. Suddenly, the distance between laboratory, factory, hospital bed, and cultivated field began to shrink.

The third phase of the revolution started in the 1980s and is still ongoing. According to Kafatos (2002) it represents a fundamental shift in research strategy: from piece to piece to global analysis and from hypothesis driven research to discovery based formulation and subsequent testing of hypotheses. The starting points are comparisons of full descriptions of all genes of organisms (genomes). The first full descriptions were made concerning viral, bacterial, and simple eucaryotic genomes (the first was the genome of brewer's yeast). Beside the first full description of the human genome in 2001, complete physical maps and genome sequences are now available concerning the most important model organisms: the bacterium E Coli, the worm C.elegans, and the fruitfly Drosophila melanogaster. December 2002 will be remembered in the history of biology: the whole genome of a mouse was published for the first time. In the development activities of, for example, drugs, the mouse has been closest to a human being.

Kafatos also calls the third stage the Functional Genomics revolution. He prefers this term to "Post-Genomics". The term emphasizes that full description is a tool to understanding function. Global description is powerful in formulating hypotheses, but the hypotheses then have to be tested. It can only be realized with experimental biology. This necessity for integration reinforces a key feature of Functional Genomics, its interdisciplinarity. Kafatos mentions Bioinformatics, Comparative Genomics, Expression Genomics, Proteomics, Structural Genomics (or Structural Proteomics), and Genome Engineering as constituent parts of Functional Genomics.

Public reactions to the revolutionary process in the biosciences

The three stages mentioned by Kafatos also describe rather well the changing public concern regarding molecular biology. In the first stage, only insiders used to be interested in the topic. As Halldor Stefansson (2002) has remarked, nobody expected stories about what molecular biologists uncovered in lowlife yeast, tiny fruit flies, or microscopic worms to make the headlines of newspapers or to become topics of TV talk-shows. During the second phase, a dramatic change occurred in public perception and in the extent of public interest. With the applications to the fields of food production, pharmaceuticals, and biomedicine, molecular biology overflowed well beyond academic boundaries. In the third stage of the revolution, the reach of molecular biology is also extending into realms once thought only the province of law or religion, such as mental health, drug abuse, or the use of tissues originated from embryonic stem cells. The possible cloning of people and gradual but fundamental "re-building" of the human genome have challenged the prevailing value systems. Besides Wall Street investors, consumer associations, ecologists, and religious bodies with their particular "value based knowledge systems" are interested.

The new interest has resulted not just in regulatory restrictions and moral blame, but also in a lot of invested money from venture capitalists . The first reaction concerning the fears of the general public was, according to Stefansson (2002), the "deficit model" of public understanding of science. This perspective sees the principal problem of the relationship between science and society as growing out of public ignorance or misunderstanding of the facts or processes of science. According to Stefansson, if employed unilaterally the "deficit model" is bound to underestimate the expertise of "lay people" and provoke the lack of trust. It inadequately recognizes legitimate differences in the values and preferences of people.

In the third stage of the biotechnical revolution, the unfeasibility of the "deficit model" has been generally recognized and new ways to handle the problems have been developed. During the last ten years, the social impacts of biosciences have been favorite themes in many parliamentary technology assessment units e.g. TAB (www.tab.fzk.de) in Germany, POST (www.parliament.uk/post/home.htm) in the United Kingdom, and Teknologirådet (www.tekno.dk) in Denmark. The technology assessment institutes in Switzerland (www.ta-swiss.ch) and Austria (www.oeaw.ac.at/ita) have also been active in this area. In Finland, the first parliamentary technology assessment project concerned plant gene technology (Salo et al. 1998). Some new methods have been developed which are especially suitable for the dialog of politicians, researchers, other experts and citizens. Consensus conferences, in particular, where lay people make "consensus statements" based on the briefings of experts have proved to be a rather good way of handling complicated problems.

Finnish perspective to the challenges of the Post-Genome Era

The recent main challenge of the Post-Genome Era. concerning the use of human genetic information, seems to be how to make progress with diseases depending on the activities (or expression) of many genes. Such diseases include various kinds of cancer, diabetes, heart diseases, Alzheimer's, and Parkinson's disease. Though the best future promises of progress seem to be in such common dangerous diseases, the increasing human genetic information also opens up the new controversial area related to special features of any individual, such as the size of a person, abilities to learn, mental health, ability to manage stress, and inclination to substance abuse.

Many European countries, for example, Germany, Switzerland, and Austria have limited the accepted applications of genetic testing to those with positive health impacts with few exemptions, for example, genetic fingerprints used to identify criminals. In the previously mentioned assessment project, the unanimous view of the Finnish panel was, however, that an individual should not be punished for obtaining information about his or her genetic characteristics. There seems to be a kind of gray area in genetic testing. The testing in public laboratories used to focus on genes directly related to health. On the other hand, Finnish experts at least seem not to be eager to punish someone who uses his or her own money to study all types of his or her genetic features in a private laboratory, perhaps aboard to begin with. The same seems to concern his/her child though some panelists suggested sanctions if a child's genes related to intelligence, near sight, poor hearing. and growth in height were tested. Though most Finnish experts did not accept that insurance companies or firms are permitted to use genetic information in their selection of customers or employees, some considered that it would be very reasonable to use genetic information when a person is planning for his or her future occupation.

In order to promote the research related to diseases depending on the expression of many genes, many countries has recently started to collect extensive blood sample banks and related genetic information banks. Alongside the Icelandic and Estonian projects, the Biobank project, which began in the UK in February 2002, is an important initiative. Blood samples of at least 500,000 people with relevant phenotype date will be included in the UK Biobank.

In Finland, blood samples feasible for genetic testing have been collected from around 100,000 people. This has been done with public funding for public health purposes or with the donors' informed consent for the study of certain diseases. It used to be possible to combine the blood material with rather rich phenotype data. The problem is that the material is scattered in the Institute for National Health of Finland and different universities. A key question in the assessment project has been how to use this material in a phase of rapid technological development. How to use the material in the discovery of causes of widespread diseases such as cancer, diabetes, asthma, heart and vascular diseases, and cerebral diseases?

The rapid technological development was rather extensively discussed in the assessment (e.g. the future role of biochips). In the second round of the Delphi study, a main theme was a possible Gene Information Centre of Finland (GICF). This hypothetical institution would be similar to Statistics Finland and the NCBI (National Center of Biotechnology Information) in the USA.

As a national resource for molecular biology information, NCBI's mission since 1988 has been to develop new information technologies to aid in the understanding of fundamental molecular and genetic processes controlling health and disease. More specifically, the NCBI has been charged with creating automated systems for storing and analyzing knowledge about molecular biology, biochemistry, and genetics; facilitating the use of such databases and software by the research and medical community; coordinating efforts to gather biotechnology information both nationally and internationally; and performing research into advanced methods of computer-based information processing for analyzing the structure and function of biologically important molecules.

The main task of the Gene Information Centre of Finland (GICF) would be the collection and distribution of anonymous genetic information concerning the Finnish population. In the first stage, the Centre would only be a register of genetic information concerning the Finnish population. Later, perhaps rather soon even, this institution would handle the administration of the abovementioned genetic information and blood samples at least after they are no longer very valuable to their collectors. It is also possible that it is a kind of archive of blood samples. It would have a "copy sample" of all collected samples. It would also accumulate further blood samples andgenetic information on Finns. In the long run, the Gene Information Centre would also collect stem cell related information and material. Like the NCBI, it would also be the national center for biochip information.

For the use of already collected material in the GICF, the key ethical, legal, and administrative issue is the need to widen the specific informed consent given by the sample donors for some specific uses, for example, for the research of some type of diabetes. The same problem of "wide informed consent" has also been met in the UK Biobank project. This issue was discussed extensively during the assessment project. The discussion was focused on the following questions: Is it acceptable to broaden the informed consent from the research of some specific disease to the research of all diseases important for national health? Especially, if the further research is based on the anonymous material, which will be held in the GICF, what kind of further acceptance is needed?

Finland has specific strengths and weaknesses in the collection and use of genetic information. They were extensively discussed during the assessment process. Experts felt that Finland's most important strengths in this field are an internationally unique founder populations, long tradition of extensive sample studies of the Finnish population made by the Institute for National Health of Finland and universities, the registration of population data since the 1750s, and well-organized public health services. The experts thought that recently the most important weakness is the recent administrational and financial crisis of the Finnish health care system related to the unclear role of municipalities, the central government, and the private sector. Though the experts did not mention it explicitly, another difficult barrier would be "in practice property rights" of researchers concerning the research material they have collected.

Scenarios of the use of human genetic information in the Post-Genome Era

The experts in the study were asked whether the "regulatory approach", "the narrow innovation oriented approach", or "the broad innovation oriented approach", concerning the future of the use of the genetic and stem cell information, was close to their own approach.

The regulatory approach was described as similar to the recent practice in most EU countries. In the EU, the security of the applications of biosciences has been the focal point. Any application of genetic engineering needs the approval of some public regulatory body. For example, the European Commission has criticised this current practice because the result seems to be that new initiatives the new biotechnology increasingly come outside Europe.

In innovation-oriented approaches, the focus is in the promotion of innovation. It is accepted that risks are always present when new innovations are launched. But good results cannot be achieved without taking some risks. In the narrow innovation oriented approach, both the innovations and management of risks are interpreted as belonging basically to the relationships between firms and customers. As in the USA, the role of government is to finance basic research and provide just frameworks for interaction between firms and their customers. In the broad innovation oriented approach, the role of the government is more active. It is considered that the activity of the government in the areas of education, infrastructure investments, promotion of institutional renewal, and launching of national heath focused programs is a good way to promote national wellbeing targets (e.g. good general health).

The majority of the experts heard were ready to accept the broad innovation-oriented approach. There were, however, also considerable minorities in favor of the regulatory approach and the narrow innovation oriented approach. In particular, there were many experts who said that their approach has aspects of two or three approaches.

What would be alternative scenarios of the use of human genetic information in the Post-Genome Era? Three scenarios are presented below. They are the first outlines of possible futures based on the above three approaches.

Scenario 1 The feelings of safety first of all (regulatory approach)

In this scenario, people who are not experts in biosciences ("lay people") used to feel that - as in the case of nuclear power – there would be terrible risks in the use of human genetic information. Even if the recent applications of the human genetic information – e.g. genetic testing; genetic engineering of other human cells than germ cells; or production of human proteins in animals or plants – have not yet caused considerable damage, it is considered that the promotion of gene technology can be compared to a "slippery slope" or an inclined plane leading to eugenics and/or considerable health or other types of damage in wellbeing. The risks of the use of genetic information are compared, for example, with the risks of the greenhouse effect. It is suggested that though the evidence concerning possible wide damage of the extensive use of human gene information is not convincing, strict caution is the reasonable choice.

In this scenario, most citizens and political decision makers prefer to put strict limits on human genetic testing and other (e.g. food) applications of human genetic information. Molecular biologists at least passively accept this policy. Gene tests related to, for example, near sight, poor hearing, intelligence, and growth in height are forbidden. In general, the approved applications of human genetic testing and other uses of human genetic information are in the area of serious health damage. For other purposes, there are few approved uses though there is considerable pressure from other countries to apply a more permissive strategy.

Even in this type of scenario, there are, however, reasons to assume that the majority of experts in the applications of human molecular biology think that the probabilities of serious risks in the use of human genetic information are so low that extensive uses are reasonable. Experts seem to be, however, against this position. This seemly inconsistent behavior might be possible if, besides the minority of true believers of the "slippery slope argument", there is a considerable number of experts who passively approve the fears of people.

I discern four types of potential passive approvers of people's fears. A common feature of all these types is that they are "democrats" in the sense that they use the fears of lay people as arguments for their position.

The first group of such experts we could call "bad intuition oriented democrats". Though these experts see few if any rational reasons for the slippery slope argument, they have bad intuitive feelings concerning the use of human genetic information. The reason might be the religious values of the experts. They might intuitively consider that applications of human genetic information hurt the sanctity of human life, or more generally human dignity. Intuitively, they can accept the violation of this sanctity if it is done to save lives but not for other "more profane" reasons.

The second group I call "half-informed democrats". This group includes experts who understand the basic facts of molecular biology, for example, the protein synthesis. Though they consider, based on their scientific understanding, that lay people exaggerate the extensive use of human genetic information, they do not, however, fully trust their own competence. These experts often have crucial roles in the developer communities of applications of biosciences – lawyers, advisers to politicians, ethical experts, for example, philosophers or theologians, and social scientists, so it seems reasonable to accept "the democratic opinion of the people" especially because there are many real scientific experts who seem to have the same opinion.

The third group I call "opportunistic democrats". In Finland, you might find these among researchers who co-operate with foreign experts, but are less eager to co-operate in Finland. Because it is perceived that research resources in Finland are limited, many research groups prefer to have contacts with foreign groups, which have much more resources. They might see too intensive a co-operation in Finland as a threat for their international activities. The interest of these groups is to keep the genetic material collected by them – both the blood samples and genetic information – in their private use. For example, the idea that there would be an organization like the above-mentioned Gene Information Centre of Finland is not very promising for them. The reason mentioned for the lack of co-operation might, however, be ethical: it is suggested that the information regarding those involved in the experiment is not safe if the genetic material is collected in a common Finnish data/blood bank. In this way, the timid attitudes of the public are reinforced.

The fourth group of experts, which is inclined to passively approve of people's fears , are experts in regulatory bodies. They have to face the reactions of suspicious citizens. The narrow interest of the regulatory administration is to avoid any realized risks as far as possible. Besides that, any critical news in the media, that would provoke feelings of fear in the public, is seen troublesome. To avoid such trouble, it is reasonable to also be restrictive in cases where it is, from a scientific point of view, hard to find any sensible reason for the fear. In 2001, a much-discussed case of this type happened in Finland. The case concerned genetically engineered cows producing lactoferrin, a common component of mother's milk. Because of patent problems, the firm producing lactoferrin had to stop and most of the cows had to be slaughtered. The regulatory bodies and slaughter-houses insisted that these cows had to be killed and burned in a special institute for handling of dangerous material. It was not even allowed to feed them to mink. In the press, the lactoferrin cows were compared to BSE cows.

Scenario 2 Many new well-paid jobs in profitable biofirms (narrow innovation-oriented approach)

A favorable precondition of this scenario is the strong orientation of society towards basic economic matters and the promotion of entrepreneurship. In the scenario, public discussion is more focused on economic growth, new well-paid jobs, international competitiveness of domestic companies, and successful entrepreneurs than in the other scenarios. The recent international competitiveness and success of bioindustry would also be a good precondition. In Finland, for example, the recent expensive failure of the Orion Co., in the development of a drug for the treatment of anxiety, is not a very good starting point for such a scenario. Orion is the leading firm in Finland, which uses commercially human genome information. Its research and development activities based on the deramsiclane molecule were stopped in February 2003 resulting in a loss of about 50 million euros.

The suspicious attitude concerning the activities of the government would promote the scenario. As well as in the USA, such lack of trust on the part of the government seems to now prevail in many earlier socialist countries but less here in Finland. If people do not trust the government and its regulating or innovation promoting bodies, they prefer to solve ethical problems directly with the companies. It is reasonable to assume that legal institutions will in this case replace the government's direct prohibition or promotion . The direct activities of the government are accepted only if the activity is seen to be necessary and private firms are not interested in doing it. In this scenario, such activity is the basic research based on human gene information.

The third precondition of the scenario is the permissiveness of society. In a society where people have various cultural, religious, and other value related backgrounds, and these differences accepted, it is reasonable that prevailing norms are agreed inside different groupings. As in the USA, some might have very strict personal norms related to the use of human genetic information, but they accept that others have different norms.

This scenario does not depend very much on the attitudes of lay people concerning the use of human genetic information. Most lay people might or might not believe in some kind of slippery slope argument, but it is, however, possible that firms are developing applications of human genetic information which most people personally do not accept. For example in the USA, the general attitude of lay people seems to be against the applications of human embryonic stem cells. At least this seems to be a reasonable assumption based on the decision of President Bush not to allow the use of public money for applications based on the use of new embryonic stem cell lines. But it is possible to carry out these applications in firms using private money.

What about the behavior of those expert groups which actively or passively accepted the fears of lay people in the first scenario? In general, the attitudes of lay people seem to have less impact on the behavior of experts than in the first scenario. Because different opinions are accepted, experts can select those partners who have similar opinions. Experts believing in the slippery slope argument or having bad conscience concerning the sanctity of life would work in those projects which they consider to be ethical. "Half-informed democrats" might trust more to their own reason though they might also take into account the opinions of scientific experts and lay people. "Opportunistic democrats" might promote their private interests more freely, and they need to use less rationalizing ethical arguments. Finally, "regulative experts" have less to regulate.

A basic conflict in this scenario concerns the roles of private and public domains of information. As with bioinformation, the earlier practice of most universities in the USA was to keep the basic research results as open source information. During the last 15 years or so, universities have increasingly taken patents for their basic research-related inventions, though some important databases like the NIH (National Institute for Health) genetic sequence database and the NCBI Database of Single Nucleotide Polymorphisms (dbSNP) are open. The many minor patents ("patent mines") are hindering the development of the basic research, especially practical applications based on the main inventions of the basic research.

Scenario 3 National health and innovations for all (broad innovation-oriented approach)

The most important precondition of this scenario is the trust of lay people in public institutions. A feeling of solidarity amongst people in a country is also a precondition. "We Finns (or Americans, or EU citizens) might do important things together when we co-operate and trust each other". The trust in scientists means that lay people believe in the honesty of scientists. In the scenario, people believe that scientists and other experts are inclined to say what they know. It is generally supposed that even if somebody is not ready to tell business secrets, for example, he or she will not lie - at least to other Finns – but will prefer to honestly tell that he or she is not able to answer the question to the best of his or her ability.

As in scenario 2, the policy concerning the use of human genetic information is more focused on innovations than on regulation. In the second scenario, this focus is the result of the general permissive and promoting attitude concerning companies' innovation activities. In this scenario, the most important source of innovations is the co-operative activities of universities, public administration, and firms. Though lay people might have fears concerning the future applications of the human genetic information, they believe in the responsibilities of the national (or e.g. EU-wide) coalitions. They consider that these coalitions are able to take risks that are reasonable in comparison with the anticipated wellbeing benefits. It is considered that this type of co-operation will produce innovations, which better promote general wellbeing targets than the innovations of firms without such coalitions. The innovations are expected to have positive impacts primarily on national health.

The Gene Information Centre of Finland (or of the Nordic countries or of the EU) would be a natural part of such a scenario. There might also be, for example, large national or international projects for the more extensive use of biochips in the national health care systems.

What about the behavior of those expert groups which actively or passively accepted the fears of lay people in the first scenario? How would they behave in this scenario? Because the lay people used to believe in the evaluations of experts even if these evaluations are in contradiction with their fears, attitudes of lay people seem to have less impact on the behavior of experts than in the first scenario. Inside the group of experts, there might be, however, difficult problems. It might be difficult to get experts, truly believing in the slippery slope argument or having a bad conscience concerning the sanctity of life, to co-operate with other experts. They might be tempted to promote the prejudices and mistrust of lay people. "Half-informed democrats" might trust their own reason more though they might have problems if there are severe disputes between scientific experts. "Opportunistic democrats" might have feelings of uneasiness, because it might be more difficult for them to promote their private interests in such a scenario. They might also be tempted to promote the prejudices and mistrust of lay people.

As in the second scenario "regulative experts" would have less to regulate. Instead the "bioadministration" might have a very important role in the promotion of the truthfulness of the distributed bioinformation. The perception of the honesty of experts seems to be the most important single precondition for the scenario. In order to make it difficult for experts to be dishonest, a good general education in biosciences and the critical media reactions to any perceived dishonesty are important. First of all regulatory bodies or the "bioadministration" should be exemplary in its own honesty. It should never make a decision like that made concerning the lactoferrin cows discussed earlier.

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The role of ICT technology in societal change

Introduction

It is easy to notice that ever since we acquired our big brains, and perhaps even before that, human development has been based on our capability to pass information onto other members of our race (Wright 2000). At first, it may be that information was passed on by behavioral cues and imitation. Later, we learned to use signs and words to explain our ideas. Many of our ideas were also passed on in the form of constructed things and drawings, and later in the form of written documents. Essential to these written documents and constructs was that it was not necessary for the user to understand why the tools and instructions or other behavioral patterns work. Basically, current information and communication technology (ICT) is just a further development of these capabilities (Mann 1986). ICT allows us to accomplish various tasks without having to bother with the details or even understand them. Similarly, ICT allows us to get and transmit information across distances and store and combine information for later retrieval and analysis.

This sounds simple. But as we study history we notice that numerous socio-economic structures have evolved and collapsed due to changes in these capabilities. Stock markets and, thus, capital-intensive industrialization in market economies would not have been possible without advanced bookkeeping methods. Tax collection, citizenry, the intellectual property rights system, and various other systems would have been impossible to enforce without relatively advanced informa -tion handling methods. New technologies have not only assisted in building societal structures, but have also aided in dismantling many old constructs. Totalitarian systems have become harder to maintain as practically every place around the world can be connected to worldwide communication and synchronized mob movements against oppression have become easier than before (Friedman 1999). It may be that many current structures will equally be under pressure as technology makes further advances.

In 2020, computer applications will be smart enough to learn as they go. Emotional algorithms are under intensive study and it seems possible that computers both recognize and project emotions and even utilize emotions to enhance their own learning capabilities and simplify their goal-seeking algorithms. Satellite positioning systems, walking, talking robots, and wireless media applications will fundamentally change our lives and behavioral patterns long before that.

Genetic engineering is currently taking its first steps. Technologies will develop rapidly, and by 2020 a large body of useful, and less useful, properties of plants and living organisms will have been harnessed for human application. The organic world offers a myriad of opportunities: plants and creatures that can detect and produce electricity, change their skin color, breathe in water, shine in the dark, and produce an endless supply of chemicals and objects of hard and soft materials. Many of these capabilities will be harnessed and used as building tools, peripherals, and platforms for future ICT systems.

Materials sciences, nanotechnology, and many other branches will develop astounding new applications just as the biotech and information sciences, but the most mind-blowing changes will come out of cross-fertilization between the various disciplines. Technology will be developed above all to meet economic and societal needs. Hence, it is also important to understand that the greatest impact of technical advance is a catalytic one. The structures of the economy and society, even of our individual values, will alter as a consequence of technological change.

Historical perspective

During prehistoric and historic times man has not changed biologically. Basically we are still the same cavemen and women. The main difference might be that our mothers have taught us to be more polite and verbal. Human society has, however, changed and continues to change at a quickening pace. Most changes have been temporary, but a continuous development has been caused by information and knowledge. Mankind has harnessed them in the form of various layered technologies (Wright 2000, Mann 1986).

These technologies starting from hunting knives and fire to farming, and from storytelling or cave wall paintings to modern information systems, have affected our value systems, power structures, everyday routines, and environment. Within the next one hundred years, we will most probably leap as far forward as we have since we started storing information on cave walls. It may be that then we will no longer resemble cavemen even genetically.

It is important to try and understand what drives this development. There are various rules that seem to apply. There also seems to be random chance and even individual people may have been able to affect major parts of the outcome. George

Orwell is one example whose "Big Brother" vision has still today a tremendous impact especially on European information system development. Jules Verne has also inspired several generations and driven them to technological leaps in directions he shown. We can avoid mistakes if we understand where we are going. We can also often succeed in affecting the outcome when we understand the optional futures and driving forces.

It seems that hunger for power and the need to acquire wealth are very important factors driving technological development, even though they would seem to stand very low on Maslow's hierarchy (Maslow 1943). Development very often requires someone to use lots of resources to achieve goals, which most often are very selfish. However, this is not always the case as the invention of zero and the decimal system seems to prove. This invention and its acceptance all over the world did not require investments. The decimal system made calculations much easier than earlier methods. Even laymen could perform calculus and this lead to a widespread utilization of rational explanations instead of witchcraft. Earlier belief systems were replaced by scientific beliefs. The Pope had made the use of zero illegal – those in power often resist change – but some things cannot be controlled.

The recent theory of memes, memory genes, ideas and concepts, which have the strength to spread seemingly by themselves, explains the mechanisms of these phenomena (Blackmore 1999). Memes may spread even though spreading them produces no apparent benefit. Memes are basically non-hierarchical and self-organizing and have been used to fight strong social hierarchies.

Francis Fukuyama showed in his recent book *"The Great Disruption"* that humans have an inbred tendency to self organize. They also seem to have positive and even an unselfish need to create generalized rules for all to follow. Any group of humans will in the long run create and sustain rules and laws, which help them to collaborate relatively peacefully if left undisturbed (Fukuyama 1999).

When society stabilized enough to limit the use of violence, the best way to acquire great wealth was trade. The information flow was slow and erratic, and trading empires actually controlled the information flow, as well as most of the transport, making vast profits. Investments concentrated in these activities from the time of Caesar to Napoleon. The rules changed only after public communication routes were opened and public transport became available. One hundred years after Napoleon, trains raced all across Europe at over one hundred kilometers an hour and telegrams were becoming popular. The time of trade empires was over. Manufacturing gained in importance and became a better means of making a profit than trade. People turned their attention to studying better manufacturing methods and products, and power shifted to cultures whose customs and communications methods were better suited to investments in industrialization than trade

Now again our communication system has evolved far beyond any expectations. Corporations are valued for their expected future earnings, and wealth is acquired by interpreting early warning signals and changes in those future expectations. Globalization, standardization, increasing co-operation between networked companies, and fierce competition have decreased profits in manufacturing.

After Berlin, walls are crumbling everywhere – and without protective walls you have to be more efficient. Otherwise, you lose your customers, citizens, or employees and finally your investors and your job. Ideas now have almost a free market. This used to be different. I used to fight against invisible walls only a dozen years ago – it was possible to get ample funding for your ideas from big corporations only and they did not wish to compete with themselves. We had no option economy and no real independent risk funding. The big corporations held economic power within their fields and they wanted to keep that power and also as much of the money for themselves as possible. The free market economy is a frightening thing, but it does not just create inequality, it also removes old problems and empowers those who have good ideas. Money is no longer associated only with power. It is equally often associated with productivity, creativity, and vision.

Technological pressures

Decreasing transaction costs

One of the most fundamental trends is that costs related to all sorts of market transactions continue to decrease. Communication, manufacturing, and transportation costs have all steadily come down due to increased automation and various other inventions. One recent innovation, the mobile phone, is still causing turmoil in countries that have suppressed the information flow. There used to be science fiction books written on the subject of telepathy. If people could transmit their thoughts across distances to other people without knowing their whereabouts, this would greatly increase their group competitiveness. Mobile phones fulfill this dream and we see similar behavior patterns appearing that science fiction prophesized.

As ideas now move freely across borders and automated logistic channels move material things with almost equal ease, there is increasing pressure to harmonize various socioeconomic rules across the globe. Another aspect comes from the theory of chaos. One of the initial developers of the chaos theory, David Ruelle, has compared a developing society to a liquid that is heated (Ruelle 1991). Currently, we are increasing dynamics by lessening friction to re-organize and, along with new productivity increases, we are increasing the energy in society, thus, doubly accumulating potential for turbulent behavior.

Collaboration, information retrieval, and computer intelligence

The Internet and mobile phones have enabled easy collaboration between people around the world. There are laboratories with waldoes, and other remotely operated machinery, allowing telework even in such delicate jobs as surgery. Robots are being developed, which handle simple situations autonomously, but allow human remote intervention in case of complicated situations. Combined with virtual reality, these robots allow their operators to be present in dozens of places almost simultaneously.

As mobile communication has become commonplace it is not longer difficult to set up sensors and other monitoring devices on self-moving platforms. We can gather information from almost anywhere and every field of life. The latest mobile phones have enough memory capacity to store several days' worth of speech and a few minutes' of video information. Every year, these will almost double. Craig Venter has promised to produce in the near future commercially individual genetic charts from samples provided by customers (Williams 2003). Simpler chemical analysis from fragrances and other samples is already today almost cheap enough for individual usage and everyday practice in forensic laboratories. Every one of us has become a potential detective or spy and we can publish our findings anonymously through the Internet. Information is abundant and it is easier to acquire than ever before. People check the backgrounds of each other before meetings. Most of us have been mentioned on some web pages. And if we have not, that is also suspicious.

Information does not only flow between people and their machines. Machines are also increasingly connected to each other. It may require less than 15 years to see the kind of building automation that automatically sends maintenance alarms to robots that autonomously take care of simple maintenance jobs.

We used to think highly of our own mental capabilities. Chess computers, Websom and other neural networks, genetic algorithms, and their applications in various fields have made it apparent that computers are capable of both deductive and inductive reasoning, experimental learning, pattern recognition, and goal seeking functions. Google's new experiment, computer-edited real time news, could fool almost any reader into believing that a professional news editor has selected the news and edited the front page. We continually see new areas where computers do the analysis and reasoning that used to be done by highly esteemed and experienced individuals. Tacit knowledge for human interaction might seem the best last resort candidate for human wisdom. But that may not be the case. We will, within the next decade or two, see computers that recognize people and their emotions and react more appropriately to their needs and emotions than most people do.

Virtual reality, addictive behavior

Virtual reality is very soon becoming as important to us as our physical reality. Virtual reality can be completely imaginary, so that it allows us to sense or project something that actually does not exist. It can also imitate closely the structure of physical reality to enable us to sense or project into an environment, which is far from us in metrics of time or space. The Star Trek TV-series *Holodeck* is an example of the perfected virtual reality where one cannot sense any difference between virtual and physical reality. This level of perfection is not required, however. Virtual reality will have a profound effect on us long before the techniques are perfected.

Virtual reality might also mean that we will be enhanced, so that we can sense and remember things that exceed our physical limitations. If our mobile phones get holographic devices that project our image around them, and wheels or legs under them, we might as well let our phones travel by themselves and remain at home to view the virtual image they transmit to our virtual helmets. We might have virtual clothes, virtual makeup, and a virtual voice that would give the impression we wish to give. Soon we will also have new tools for renewing our physical appearance. Artificial skin will change color when we wish. With nano crystals, we get digital tattooing to enable tattooed wristwatches, pulse meters, or compasses. A tattooed snake, which starts to wiggle when one gets exited, might also be very popular.

Some enhancements will enable us to recall everything we ever heard and very soon everything that ever was spoken on the radio or television. With future speech recognition and mass storage, this will be almost as easy as searching web pages or email for indexed key words. We will also be able to see and hear things that do not exist. There will be no need for street signs when they can be shown on our virtual glasses or on the windshield. Translation devices allow us to listen in French or Greek if someone speaks Portuguese. This will also allow us to listen to rude arguments translated into sophisticated polite language. And if we do not like how people look – we can get lenses that modify them to suit our wishes. Augmented reality will become much more pleasing than real reality – for you, it could always be spring and sunshine!

Robots, cyborgs, and lengthened life

When the movie *Artificial Intelligence* was first screened, many people were very dubious about the emotional characteristics of the robot. AI was not realistic. Not because the main character had feelings, but actually because it was projected to be the first robot to embody emotions. We have feelings; many animals clearly have deep feelings – even signs of culture and concepts of right and wrong. One of the pioneers of artificial intelligence and robotics, Marvin Minsky says that feelings are a very efficient way of thinking (Minsky 1994). They are also necessary for efficient learning and motivation (Damasio 1994). It is likely that our robots and virtual bots will have sentiments long before they properly pass the Turing test for intelligence – before they can discuss with us in a natural manner.

Bill Joy is afraid that machines could make us useless. This could only happen if we started loving our machines more than our children and if there was nothing useful that we could do for other people better than their machines. There are signs that this is happening. Many people seem to like machines so much that they do not need children. Perhaps with pleasant bots in virtual reality they will not need friends. If this happens, perhaps we no longer deserve to live.

I believe, however, that our genetic machinery is wise enough to favor genes that enjoy children. Somehow, I also agree with Professor Stephen Hawking who said that we must develop our capabilities technologically to compete with our bots (Kurzweil 2001). He was talking about connecting computers directly to our minds.

Another issue that fosters great expectations and great fear is genetic technology. Milton Friedman recently said that technology has generally helped the poor. Emperors never had a need for running water because they had running slaves (Kane 2000). Genetic technologies will most probably help to produce cheaper food and medicine. Starvation would not kill as many. Technology might also produce seeds for trees that emit light and electricity or retroviruses for eyes that let us see in the dark. These and many other inventions would presumably benefit countries with a low production capacity if they could be mass-distributed.

Milton Friedman may well be right in almost every case, but the most fundamental question may prove his assumption wrong. If, as it now seems, even our nerve cells can be re-grown and we could practically live forever, this would pose grave problems for the concepts of equality. Not everyone, because of scarceness of resources and population pressures, can enjoy a longer life. Inequality will inevitably follow.

Socioeconomic influences

The impact on creativity and empathy

All these networks and information appliances have made it easy to acquire information and employ experts. More and more of the value of products has also turned out to be bits. The manufacturing and distribution costs of these bits approaches zero. According to Porter's theories on competition, this means that only the best-featured ones get profit (Porter 1998). Creativity will become one of the key success factors – creativity and sensitivity to the needs of others. This also increases the pressure for and against intellectual property rights as they maintain an artificial division of wealth in favor of the first inventors and their associates.

The change towards the increasing importance of creativity has already started. Just look at how the movie industry has been restructured, look at Lucas who gave his movie distributor a lousy 15 % - earlier he used to get only 15 % himself. Distribution is becoming a commodity handled by courier services and the postal service or simply the Internet. Look at Nokia; it is basically a design house, not an industrial giant. Nokia buys much of its manufacturing and distribution very cheap from subcontractors and makes huge profits. All this flexible production with programmable robots removed the risk from production and, at the same time, it removed profit.

Power has shifted to those who create. Information has started to lose its competitive value alongside ownership of the distribution channel and manufacturing. Organizational creativity and sensitivity seem to rule. Cultures with rigid symbol structures and communication hierarchies, as well as hierarchical initiative patterns, have to face this change and give way to more creative behavior patterns. Otherwise they must wither and lose their competitive positions. Many of the changes will be social innovations and strong hierarchies will fight against change because change very seldom favors those individuals in power.

Nokia was the first major company to follow Alvin Toffler's advice and allow its customers to individually take part in product design by deciding what ringing tone and what cover art and even what features they would prefer. You can even compose your own tunes. Nokia phones almost resemble the other famous Finnish phenomenon, Linux, which allows you to design your own operating system features to be included in the next global release for everyone to share. This is a very different culture to the previous careful product designs where nobody was allowed to tamper with the grand designs. In this new culture, everyone's creativity and individual identity is appreciated.

Hierarchical vs. self organizing networks

Think about those cultures where bosses do not give out their mobile phone numbers. Many bosses still considered it degrading, for example, in the US to answer their mobile phone without knowing in advance who is calling. However, there is very little added value from a mobile phone if you merely use it for calling. The real value of mobile phones comes from everybody being available when decisions have to be made and it works if people understand not to bother you when you would not appreciate it. In Finland, it seems to work and subordinates frequently inform and ask for advice in critical situations – often with discreet text messages. Organizational intelligence maximizes when all brains are almost telepathically connected.

When you think about the Internet – it is basically symmetrical. Or it could be. With efficient routers and multicast protocols and fast access, anyone could, instead of watching movies on demand, send their own content for others to view. Some of these structures and wants are already apparent in the Internet.

I can believe that someone would want to put a camera in front of her goldfish bowl. There might be more than ten people who would like it much better than what is on TV. Someone else might send an email to all members of the MG club to say that he will change his carburetor at 6 pm. Anyone who wants to see and learn can look through his garage camera linked to his home page and listen to his explanations.

There are so many who would say that producing good quality TV programs is difficult. It is really difficult to get the advertisers interested if you want to get enough people interested in something that actually does not interest them. It is not so difficult to get grandparents interested in kids' birthday parties or fans of a specific dog breed to get interested in their specific dog show. But the crucial question is: is it really more valuable emotionally to view a program than to participate in creating it? I know that it is valuable to at least give people the opportunity to express themselves if they have the need. According to Maslow, it is important for us to express ourselves to get recognition. Watching TV does not fulfill our basic needs but sending text messages does. Perhaps that is a reason why we have paid more for sending one text message than receiving the daily business paper.

Security through logging versus security through spying

Alvin Toffler started his visionary book *The Third Wave*: "A new civilization is emerging in our lives and blind men everywhere are trying to suppress it!" But this is not just a question of being blind to change. Very often those in power are afraid that they would lose their positions if things change. However, as walls are now falling everywhere, it is very hard to resist this turmoil. If you do not run fast enough you will be conquered. Blind men do not run fast.

It seems that we are drifting towards a world state as will be further discussed in 4.5. Currently, the networked bit realm resembles a strange mixture of the Wild West and feudal structures with virtual Disney worlds on every corner. In this Wild West, criminals enjoy great freedom because the dominant "Big Brother" metaphor requires that networks at least provide the illusion of supporting complete anonymity for everybody. Similar requirements in the real world would mean "no license plates", "no numbers on money" and "no finger prints".

Facing the increasing risks, this non-traceability leads to spy agencies requiring authority to listen in to everything. It seems that we get a Big Brother because we are so much afraid of one. This trend is especially strong in the US because corporations abuse consumer information in a way that is illegal in the EU.

Future versions of the Internet protocol, Ipv6 may include mechanisms for tracing messages to individual machines. This would mean license plates and this should mean full support for strong encryption and worldwide legislation to ban corporations from collecting consumer information in their databases without their approval. This would create a balance where networks would be safe and everybody would equally get information on each other – no big brother but small brothers peeking from every possible hole. Just as in small villages. Currently, it seems that people appreciate their privacy for hedonistic reasons, and this causes contradictory pressures and may lead to continuing conflicts and increasing risks.

Societal and hedonistic values, transparent society

It is almost tautological to claim that information storage and retrieval tools combined with networks speed up all development. Networks naturally favor individual and community traits that take advantage from these new tools. Let us now study the concepts of trust, honor, and openness in this sense. Toffler showed how the industrial society required a change in values (Toffler 1987). People had to easily immerse in new communities. Previous concepts of responsibility and loyalty to your old community had to be transferred to concepts of privacy and lawful responsibility to the state, which then would take care of your previous responsibilities like the elders and punishment for debts and crime.

Internet is often referred to as a global village. It is easy to find new business acquaintances and start co-operating with them. This fast-paced networked business model seems to be extremely efficient, but it requires a similar model of non-hierarchical trust that existed before the Industrial Revolution. If you are a bully, I will easily find out from others on the Internet. If you are a good guy, I can trust you and do business with you without long contractual negotiations with international lawyers.

It seems that there was not enough positive feedback for trust and honor in the Western industrial society, and for that reason we shifted towards hedonistic values and selfish behavior patterns. This suited the industrial society, but it does not match the needs of the networked era. There was a clear connection to privacy, also. It is questionable whether honor has any meaning if you cannot lose it in the eyes of your fellow beings. Not in the system theoretical sense, anyway, as the positive and negative feedback controls are not sustainable over generations. Francis Fukuyama has collected statistics which show that crime has increased more than tenfold during the last decades and in the US even fifty-fold (Fukuyama 1999). Also other societal norms have been crumbling at breath-taking speed.

I claim, like the author of *Transparent Society*, David Brin, that future technology might cure us (Brin 1999). I do not believe Fukuyama's conclusion that we just get to practice more religion even though we would not actually believe in God and just want to be selfish. I think that we will not be saved with this typical US hypocrisy. I believe instead that the future transparent society may bring us back to many of the values of the earlier small villages. We will respect others and know how they behave and they will know how we behave if we just yield to change. The Internet is a very fast channel for all sorts of rumors.

As Fukuyama pointed out rumors make it much easier for society to self organize and for people to have direct contact with others who have first-hand experience of the same issues we need to evaluate. In this transparent society, we might leave the doors unlocked and again trust people to keep their word. Various cultures will naturally try different paths, but as the Internet is global it will basically be a global change and a global challenge. Some will actually cope better with this change and some will fail.

But I am afraid we will resist this change if corporations and the state will not open up and if they collect our information and abuse it to maintain hierarchies. Luckily for us, the current approach of the EU is very much better than that of the US and we might get on with this transparent society much faster than they can. The EU bureaucracy is not nearly open enough, but corporations in the EU are not allowed to abuse our information in the way it is possible in the US.

Transparency and openness do not suffice as the only tools in a world where capabilities for mass manipulation and individualized destruction will be enhanced. We are gullible as individuals and some new forms of manipulation may prove dangerous enough to be penalized. When computers can create artificial persons that see how you react, they can also start manipulating you by rewarding you with a smile – when you react in an expected way. We might use these behavioral machines to shape us in suitable skills, but these could as well be used to get us hooked into buying patterns that we did not originally wish. These and other virtual "delights" may start spreading around the networks in the form of viruses listening to our Internet telephone discussions, reading our email and smiling to us while making suggestions about what we should buy or how we should use our time. Let us hope our electronic purses are safe from these viruses. Our minds most certainly are not.

Increasing utilization of virtual reality can lead to many different things. If we all start living in our own imaginary worlds, we will have less and less in common with others. Unfortunately, this is the way a networked society often tries to optimize itself. Everybody specializes, there will be more and more diversity. We still should favor things that enable us to communicate with each other and increasingly respect such common values that help us successfully network with each other. Alienation will make its advances whatever we do. There will be many who will get addicted to virtual reality. Tamagotchi was a very crude device compared to what is to come. This is just one of the many reasons why we should favor social cohesion, openness, interaction with other people, and why we should be afraid of mass entertainment, which deprives so many of us of meaningful relationships and leaves us feeling depressed and unnecessary. Our behavior, even our existence, is meaningless to the centrally distributed new soap opera extension of our family.

The concepts of state and virtual state

The Internet enables us to do many things in a new way. Simultaneously, it threatens a multitude of old structures and concepts. Just think about the two most important concepts in politics: the state and democracy. A state is a power structure inside a geographically limited area. The power is financed by collecting taxes from events inside the state borders.

But more and more of our wealth and activity has transformed into bits and bits know no borders. Bits move freely in virtual reality and nobody knows where they go or come from. Individual freedom is growing – I might work, I might spend or earn money – nobody knows. Local governments control less and less of the activities of their citizens and collect less and less taxes from what happens inside their borders because bits are not local and will easily find tax havens.

Naturally, we solve part of this problem by joining forces with all other states and enforcing taxes and legislation with international agreements. We might actually form a world state for virtual reality. But what then happens to democracy and individual freedom – what is individual freedom and democracy when a world state creates rules and the so-called free market handles all executive tasks in the non-local virtual realm. Democracy works best in small communities where people feel that there really are common problems to be addressed.

I have wondered if there could be such a thing as a democratic virtual community with its own set of responsibilities and rights similar to physical communities inside every larger state. It would be an intriguing thought as more and more of our common problems and activities are common with people outside our physical city. Currently, the citizens in virtual reality feel pretty much like they lived in someone's backyard where their landlords set all the rules and limitations. Currently, the Internet resembles some strange mixture of free market, feudal age, and Wild West. Current requirements from many media companies to get permission from the US legislators to allow them to attack such Internet hosts that carry copyrighted material just emphasize the point. Only in the Wild West would you seek justice by being aggressive yourself.

Immaterial rights and the digital divide

It seems popular nowadays to claim that information technology will enhance the gap between the rich and the poor. Some talk about rich and poor countries, others about individuals and families. Basically, I tend to agree with Milton Friedman. Generally throughout history most technological advances have favored the poor more than the rich.

All around us we see people and countries, which are falling behind while others seem to get more and more ahead. This would prove something if it were not a false vision. Perhaps we tend to forget that while this world becomes unjust to some, it simultaneously becomes fairer to many others. There are statistical signs showing that developing countries are showing stronger growth than industrialized coun -tries. One can also see many signs of old power structures falling and a more egalitarian society emerging.

There are few important principles guiding major changes in today's economic structures. A greater portion of the value of goods and services consists of bits than ever before. This part of the value chain can exist practically anywhere increasing the value of skilled labor in developing countries. This can be seen already in the statistics of many developing economies. A large portion of the exports, for example, from India is bits.

The law of increasing return plays an ever-increasing role in the digital economy as production and distribution costs approach zero. You can think about one fax or one Internet browser. By themselves they are worthless. They only become useful when enough people start using them. Therefore, many companies give away a great deal of their products practically for free to get enough users for a healthy user community.

A few other trends are also noteworthy when thinking about the digital divide. All sorts of transaction costs are decreasing because of information technology. This leads to outsourcing because big corporate hierarchies no longer offer advantages and their inherent slow reaction times are more harmful than ever. Governmental elements also move to open market outside old hierarchical structures. Pension funds, individuals, and venture companies search continuously for good ideas all over the world in order to invest in them. To get working capital, companies need to be open and reliable and much of the same also goes for states.

There are many confusing signs as several socioeconomic structures change. However, it seems clear that every government who seriously thinks about productivity in the global marketplace should make an effort to create opportunities for all citizens to get a useful education. There used to be a time when citizens were kept in ignorance in order for those in power to stay there. In today's society, most rulers realize that this path leads to a weakening economy. Outside totalitarian regimes, a weakened economy usually leads to a change in government.

As distances lose their significance and information delivery becomes much cheaper through the networks than through physical means, and as this new technology starts empowering people all over the world, it seems inevitable that many developing countries will be able take part in global affairs.

If we think about this from the individual's point of view, we will see some people get rich from very poor surroundings and spreading those riches around. Differences between various areas will lessen, but differences within any particular area might stay high and even increase.

Conclusions

Transaction costs continue to decrease – empowering people both in good and bad ways. Faceless people hide behind anonymity. Distances reduce and cultures get mixed leading to a growing complexity with chaotically different outcomes.

Governments try to control the turbulence by surveillance and limitations. This adds tensions, strengthens hierarchies, and chances to abuse this power. Trust be -tween citizens and their various organizations is necessary for any complex networked economy. Lower transaction costs require a lower per item cost of trust.

People are globally afraid of big corporations and even their own governments. Anonymity is appreciated. In Scandinavia, where governance is more transparent and corporations cannot abuse personal information, anonymity is not so highly valued. We allow nobody to spy on us, but we do allow logging information as a precaution.

Perhaps the only way to retain both our societal trust and freedom may be a transparent society where we would have to give up much of our privacy. The Greek word for private is *idiotiko* as opposed to democracy – perhaps this is wisdom. Perhaps privacy is a hedonistic value and hiding not necessary either for economic success or societal stability. Sadly the Internet helps both concealment and openness.

A crucial issue here is the potential rise of electronic cash. If someone can send me a blackmail letter anonymously on the Internet, and also anonymously collect the money over the Internet, this could not be controlled without massive global NSA-type organizations, if the Net does not support tracing and logging. With societal transparency, spying is not necessary and civil rights remain strong, and society free.

When Georg Soros' teacher, the philosopher Karl Popper, wrote his grand opus -"*Open Society*", there were very few really global networks. Still he maintained that no one should have hierarchical power over all issues (Popper 1945).. As more and more issues become global, most citizens feel too detached from the centers of power. Perhaps the world should not just be divided geographically. Perhaps we could be citizens of several states simultaneously – one physical and several virtual – based on our interests. Currently, the physical state has all the responsibilities and global matters are governed by organizations getting their mandate from local governments, the Internet ICANN being one of the few exceptions. If we want people to feel they really can affect global issues within their interest, we should perhaps consider virtual localities and some sort of semi-independent democracy within these.

Another issue is our growing capability through networks and automated production lines to manufacture copies of just about anything. Value is in bits and the one who gets them copyrighted or patented first gets all the profit. One could claim that the first person has created the added value, but this is mostly not true. Increasingly often this leads only to greater profits for economically developed countries and poverty for the countries that could have invented the same things later.

If all the positive benefits of networking could be harnessed, developing nations could prosper and sustainable growth could be reached because much of the material production can be replaced by virtual systems with decreasing energy consumption.

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Knowledge work and human competence

There is a broad consensus among information society researchers today that knowledge and information are increasingly important, not only for the competitiveness of national economies, but also for specific processes in the workplace. During the last half of the 20th century, knowledge work has indeed emerged as an important new watershed in the occupational structure of modern society, a key factor that distinguishes globally competitive economies from their weaker rivals. It is justifiable to generalize that innovative and creative potential ultimately determines the success of individual actors, as well as organizations surrounding them.

In recent years, Finland has often been projected as a model example of this “new economy.” It is suggested that this remote country in the north of Europe, with a population of no more than 5.2 million, has made excellent use of its innovative R&D and intellectual capital. In more concrete terms, the Finnish industrial structure has been rapidly moving from traditional manufacturing towards “high-tech” industries and, as a consequence, Finland has become an internationalized, innovation-based economy (Hernesmiemi et al. 1996; Kuusi Ed. 1996; Steinbock 1998). Indeed, recent statistics indicate that Finland has one of the most competitive economies worldwide (Rouvinen 2001).

For employees, this has meant ever-higher formal qualification requirements, constant and growing pressure to upgrade existing skills, as well as an increase in job tasks that involve independent decision-making and non-routine problem solving. International comparisons also suggest that the technological infrastructure in Finland is exceptionally “advanced.” Finland is one of the world’s leading mobile phone and Internet users and ranks among the top nations in many other economic, technical, and educational areas as well. For example, according to a recent survey project in which I participated, every other Finnish wage (and/or salary) earner used e-mail (57 %) and the Internet (45 %) as a working tool in 2000 (Blom et al. 2001; 2002). It is not incomprehensible to envision that in the foreseeable future even ordinary janitors will be equipped to communicate with their customers via e-mail (for different perspectives on the characteristics of the Finnish information society see, e.g., Kopomaa 2000; Steinbock 2001; Statistics Finland 2001; Viherä & Nurmela 2001).

Without in any way disputing the dramatic changes that the ongoing technological development has implied for individuals and for Finnish society as a whole, I do want to call into question the view which portrays the information society or knowledge work only in a positive or progressive light. Knowledge work seems to involve some deep-seated contradictions. In contemporary capitalism, the price of being a successful individual is the psychological pressure and emotional trauma of growing competitiveness.

The rise of knowledge work

A precise and unambiguous definition of knowledge work is hard to come by. It can be argued that the information age is still too young to fully define the role of the new knowledge work force (Elliott & Jacobson 2002, 74). However, two main arguments can be extracted from the existing literature. The first is exemplified by Marc Porat (1977, 2), who approached his empirical operationalization of the information(al) work process as a heterogeneous entity that includes such diverse activities as research and development, managerial decision-making, writing letters, filing invoices, data processing, telephone communication, and producing a host of memos, forms, reports, and control mechanisms. The starting point of his analysis was the following broad definition:

"Information is data that have been organized and communicated. The information activity includes all the resources consumed in producing, processing and distributing information goods and services." (Porat 1977, 2; italics added.)

Another important argument is centered on the notion of the symbolic content of work activities. For example, C. Wright Mills (1951) observed already fifty years ago a trend in which "fewer individuals manipulate things, more handle people and symbols" (p. 65). More recently, Robert Reich (1991) sketched a portrait of an elite of workers he calls symbolic analysts, explaining that this category refers to design tasks and expert jobs that require creativity and innovativeness par excellence. From this point of view, the routine communication of information, as understood by Porat, is not yet considered a type of work distinctive of the new information economy.

In addition to Reich, another well-known critic of the information society is Jeremy Rifkin, who in his scientifically controversial yet certainly thought-provoking book, The End of Work, states explicitly that it is unlikely that any of the most important occupational groups of the future will be very large:

"The few good jobs that are becoming available in the new high-tech global economy are in the knowledge sector. It is naive to believe that large numbers of unskilled and skilled blue collar and white collar workers will be retrained to be physicists, computer scientists, high-level technicians, molecular biologists, business consultants, lawyers, accountants, and the like." (Rifkin 1995, 36.)

According to the above views, which emphasize the symbolic aspects of knowledge work, the key to the new work processes lies not in the homogenous social collective, but in the cooperative and flexible individual, as well as in the ability of that individual to act as an interface between new technology and human interaction. Another common baseline assumption is that a measure of expertise is required from informational labor. For example, according to Paul Thompson et al. (2000) "the implicit model of the traditional knowledge worker is someone who has access to, learns, and is qualified to practice a body of knowledge that is formal, complex, and abstract" (p. 126). In other words, the most important criteria for knowledge work emerging from the current theoretical literature are centered on the symbolic content of task structures that, according to the authors cited above, allow for creative application, manipulation, or extension of knowledge.

Of course, these and any other sets of criteria are problematic and highly controversial. Just to give a few examples, the job of a writer, a freelance journalist or a university lecturer does not necessarily require the use of information technology, but in practice the typewriter has been replaced by the PC and the telephone has been all but replaced by e-mail as a means of communication among people whose job involves producing and manipulating symbols. Accordingly, the role of technology is recurrent in both empirical and theoretical literature on knowledge work. Although problematic this presumption is justified because the number of cases that fit in with the general idea of knowledge work but involve no use of information technology is so small that it is impossible to draw any relevant generalizations even with extensive statistical material.

However, if knowledge work is approached as an integrated process, then we might be able to identify a number of stages not directly bound up with the use of technology. If it is thought that creativity is emphasized in knowledge work at the expense of routines, then the most decisive and knowledge-intensive part of the job description may refer to cognitive processes that are independent of time, place, and the tools used. An innovative idea may emerge during leisure time as well as on the job. Furthermore, a major technical innovation that starts out as a simple abstract idea or theoretical model may well be finalized using paper and pencil just as well as sophisticated soft-ware. On the other hand, in some jobs a PC, computer terminal or a programmable machining tool may be comparable to the conveyor belt, serving as tools with which the operator can repeat routines or control the production process, without any creative input whatsoever. In other words, IT use does not serve as a sufficient criterion for knowledge work, even though in practice they are often connected.

It is clear, then, that we need more specific determinants for a useful definition of knowledge work. In addition to the use of information technology, a second criterion applied here is education, which is characteristic of all advanced information societies. In much the same way as IT use, this is a somewhat problematic criterion in that completion of a certain academic degree is neither an absolute condition for, nor an obstacle to, employment in a job that requires designing key aspects of the job itself. For example, the reality that many individuals without extensive formal education are employed in IT professions reflects the importance of an often-neglected route to skill development by informal learning on the job (Hilton 2001, 42). In practice, however, it is more and more difficult to get a job without formal qualifications.

Finally, the symbolic and abstract nature of the work should be considered. This allows us to distinguish knowledge workers from IT users and other wage earners on the basis of the design component involved in the job. This additional criterion avoids the problem of excessive technological determinism and also underlines the cognitive side of knowledge work.

Knowledge workers, then, are defined here as wage earners whose jobs meet the following three criteria: (1) the use of information technology, (2) independent design of important aspects of the job, and (3) at least upper intermediate vocational training (a college degree). IT users are defined as wage earners whose jobs do not meet either or both of the latter two criteria, while traditional workers (or, for brevity, others) are those who do not use information technology in their jobs at all.

This relatively simple classification allows us to draw a more realistic picture of the category of knowledge workers in Finland than is possible on the basis of the criteria employed, for example, by the OECD or Statistics Finland, both influenced by Porat's work. However, the overall picture is roughly the same regardless of the criteria applied: the share of knowledge work in Finland has significantly increased from the 1980s up to the present day.

Table 11. Number of Knowledge Workers, IT Users, and Traditional Workers in 1988–2000 (% of Finnish wage labor)

	1988	1994	2000
Knowledge workers	12	25	39
IT users	15	22	30
Others	72	53	31
Total	100	100	100
n	1 512	702	1 775

Table 11 shows that the share of knowledge workers has more than tripled and the number of IT users doubled from 1988 to 2000. At the same time, the number of traditional workers, who do not use information technology, has declined very sharply. In other words, there has been a clear shift in the division of labor towards jobs, which require IT skills: already over two-thirds of all wage earners are in such jobs.

Figures released by Statistics Finland give a somewhat different picture of the development of the information sector. According to these figures up to one third of wage earners were engaged in information occupations (a term taken straight from Porat) in 1980; by 1995, the share had increased to 44 percent but then leveled off. (Table 12.) Why this sudden slowdown in the growth of informational labor? The most probable explanation lies in the recession that swept across Finland in the first half of the 1990s, and particularly in the negative employment trends in the public sector, which are still reflected in the figures for 1995 and 1996. Unfortunately, due to revisions of statistical criteria in 1997, subsequent comparisons are not completely reliable. However, it may be projected that the most rapid transitional period is over. It is likely that the growth of knowledge work has approached its natural saturation point after which further growth slows down considerably.

Table 12. Trends in the Proportions of Persons Employed in Information Occupations in 1980–1998 According to Statistics Finland

1000's	1980	1985	1995	1996	1997	1998
I Information producers	224	282	334	348	345	373
II Information distributors	100	117	137	137	142	153
III Information users	109	132	151	156	160	182
IV Information processors	215	229	213	208	209	219
V Use and maintenance of IT equipment	109	108	75	71	64	67
Total	757	868	910	919	920	993
All employed persons	2328	2437	2068	2096	2170	2222
Information occupations (% of all employed persons)	33	36	44	44	42	45

Source: Statistics Finland 1999, 134. Figures from 1997 and 1988 are not fully comparable with those for the earlier years.

The most important observation in the figures presented in Table 12 is that both the relative share and, especially, the absolute number of workers classified as information producers has experienced the most significant growth. This group includes all scientists, as well as the producers of consultative services and market information (e.g., health care specialists, legal and financial advisers, and technical experts). Another important observation is that the share of information distributors and users has also increased. The former category comprises mainly teachers and communication and cultural workers, the latter category includes administrative and supervisory workers. Finally, occupations related to information processing (e.g., office clerks) have remained quite stable while the use and maintenance of IT equipment has somewhat surprisingly declined. Whereas office automation has made certain occupations such as word processing or telephone exchange jobs redundant, modern computer hardware requires relatively little maintenance compared to increasingly complex software.

Similar trends indicating the growing importance of the professional and technical workforce have also been reported elsewhere, in accordance with Daniel Bell's (1973) wellknown thesis on postindustrialization. To name a few examples, in countries as different as Ireland (Trauth 2000), New Zealand (Engelbrecht 2000), Singapore (Kuo & Low 2001), and the United States (Martin 1998) the increase in the proportion of informational labor has mostly been due to the growth in the number of information producers. Conversely, the occupations related to routine information handling have declined fastest. Since the production of information is fundamental to the growth and strength of an information society, this development can be interpreted as a healthy sign (Kuo & Low 2001, 286).

Statistics Finland's analysis is interesting because it is based almost directly on the ISCO–88-standard, that is, the International Standard Classification of Occupations by the International Labor Organization (ILO), and as such is heavily influenced by the examples set by Porat and his precursor, Fritz Machlup. As is well known, Porat's classification was intended to update and ultimately replace the classic categorization introduced in 1962 by Machlup in The Production and Distribution of Knowledge in the United States, in which Machlup "first introduced the notion of a knowledge economy as a result of his analysis of the contribution of information activities to the 1958 U.S. Gross National Product" (Schement 1989, 30; see also OECD 1981; Machlup 1980; Rubin 1983; Rubin & Huber 1986; Schement & Curtis 1995). At the same time, Porat wanted to draw attention to occupations that were important to the information sector, but that were less prominent in Machlup's classification. In 1959, Machlup estimated that the information sector accounted for 32 percent of the US work force; a decade later Porat's calculations indicated that the figure had in-creased to 40 percent.

The view advocated here, however, is that occupational classifications tend to be misleading in that they are poorly suited to comparisons over time. The occupational structure in Finland and other postindustrial economies is very different today from what it was in Porat's days, and an outdated occupational classification certainly does not provide the most viable basis for analysis. Accordingly, occupational sociologists generally agree that the formal occupational categories are outdated (Barley & Kunda 2001, 83).

Instead, the main strength of the classification suggested here is that the criteria applied are less dependent on time. IT use, the design element, and education emphasize not only the use of information technology, but also point to the nature and content of the job, regardless of the title. For this reason, a classification that takes into account the qualifications required is more in line with the theoretical idea of knowledge work than Porat's scheme – although, of course, no determinants are either suprahistorical or exhaustive.

After discussing the conceptual framework behind the idea of knowledge work at some length, we are now ready to take a closer look at how the transformation towards the information society has changed the Finnish occupational structure during the past decade or so. The focus is on the nature of knowledge work compared to IT users and traditional workers.

The nature of knowledge work

It can be argued that knowledge workers represent the hard core of the current working population. In many important respects, knowledge workers are the most advantaged social group. However, knowledge work has its grim downside. Although it offers a high degree of autonomy and consider-able monetary rewards, on the reverse side of the coin it also involves high levels of stress and high expectations to meet the demands of the transient labor market that characterizes the current phase of capitalist development in Finland and other advanced economies.

Knowledge work is at once rewarding and extremely demanding. The environment in which such work is done is often more creative and autonomous than is true for other types of work, but at worst it stretches the tolerance of the individual worker to its absolute limits. Contrary to the most optimistic visions of the information society, the diffusion of information and communication technologies (ICTs) is far from being our benign liberator from mundane realities a nd conflicts of working life. For some, ICTs are the new way of liberating labor from the constraints of tedious work, for others, ICTs will generate new forms of control, spreading outside the workplace into the domestic and personal spheres of people's lives (Rubery & Grimshaw 2001, 165). Even if the global transition from industrial towards information societies has certainly meant a more humane work environment for workers from all walks of life, the rise of knowledge work has also brought with it new problems and challenges, as I will elaborate below.

The first point I want to address is the contradictory role of education. It is often said that brain, not brawn, is the most valuable asset a worker possesses. For example, Frank Webster, echoing the views expressed also by Reich and many others, has argued that informational labor shares two special characteristics:

"The first is a capacity to change itself, and to adapt to change, as a matter of routine. Informational labour is always on the alert for novelty and new learning, constantly up-dating its skills – traits essential for prosperity in today's highly competitive global economy. A constant refrain here is the need for "flexibility", and symbolic analysts have this quality in abundance. The second characteristic informational labour shares is a crucial contributor to this adaptability – high-level education, not in a specific skill, but in a capacity to "self-programme" (or, in language popular in British policy circles, in having "learned to learn" and thereby become equipped for “lifelong learning”). Attendance at higher education institutions cultivates the “transferable skills” so essential to symbolic analysts, because these are what are required by the global market economy that is intensively dynamic. Indeed, no learning, at however high a level, is nowadays likely to last more than a decade or so – except for the capacity to re-educate oneself in readiness for meeting the challenges of constant change.” (Webster 2001, 267.)

As we have seen, the typology of knowledge work used in this study is based on education and the nature of the work. This also explains the high level of education in knowledge work: all knowledge workers have at least an upper intermediate education (a college degree). Half of them have an academic degree. Among IT users, the majority have a lower intermediate education, or they have completed a vocational training course. The training of traditional workers is very similar to that of IT users. (Table 13)

Table 13. Vocational Education of Knowledge Workers, IT Users, and Others in 2000 (% of Finnish wage labor)

	Knowledge workers	IT users	Others	Total
No vocational training	–	18	21	12
Vocational training course	–	27	32	18
Lower intermediate	–	38	34	22
Upper intermediate	53	14	8	28
Lower tertiary	15	2	3	7
Upper tertiary	32	1	2	14
Total	100	100	100	100
n	696	527	525	1 749

The data also indicates that knowledge workers have very often an occupation in line with their qualifications. Among all wage earners, 72 percent indicated they were in jobs matching their qualifications. The corresponding figure for knowledge workers is 84 percent, but much lower among both IT users (64 %) and others (62 %). The difference between knowledge workers and other worker groups is wide enough to raise the question of misuse of human potential. Especially from the point of individuals, having a job that does not match one’s qualifications is certainly frustrating. However, this is not the case with knowledge workers. Knowledge workers feel they need additional training to cope with the requirements of their jobs more often than other groups do: over one-fifth (21 %) indicate that they need much or very much additional training. Among IT users, the corresponding figure is 11 percent, and among traditional workers only six percent. Indeed, as Webster suggests in the quotation cited above, knowledge workers are under constant pressure to learn something new: only one in ten say they need no additional training at all. Among IT users, one in five needs no additional training, whilst among others the proportion is almost one in three.

However, the downside of the current emphasis on flexibility and lifelong learning is that work may also involve high levels of stress resulting from tight schedules, constant expectations to keep work related skills up-to-date, and fast paced decision-making needed to meet the deadlines. As a consequence, temporal and spatial boundaries between paid work and personal life have become increasingly blurred (Lewis 2001, 64). In the case of Finland, a clear indicator of this is that concerns of mental fatigue apply to the entire wage-earning population, but particularly to knowledge workers. Not surprisingly, mental strain and time and performance pressures are highest among knowledge workers. (Table 14) In all groups, the trend has been towards a more stressful work environment from 1988 to 2000.

Table 14. Concerns of Mental and Physical Fatigue among Knowledge Workers, IT Users, and Others in 2000 (% of Finnish wage labor)

	Knowledge workers	IT users	Others	Total
Work is often or almost always:				
– Physically strenuous	12	29	61	32
– Mentally strenuous	74	59	47	61
There is often or almost always:				
– A fast pace at work	74	66	67	70
– More work than time to do it	70	55	54	61

The following alternatives were given to the respondents: 1. Never, 2. Seldom, 3. Sometimes, 4. Often, 5. Almost always.

Working overtime and taking work home is also clearly more pronounced in the knowledge workers' group than in the IT users or traditional workers' groups. In 1994, 34 percent of knowledge workers regularly worked overtime. In 2000, the figure had already increased to 42 percent. Within the group of IT users, the corre-sponding figure was 15 percent in 1994 and 19 percent in 2000. Interestingly, there has been no change concerning the group of traditional workers of whom 14 per cent worked overtime both in 1994 and 2000. In addition to working overtime, knowledge workers also quite often take work home. In the survey conducted in 2000, 59 percent reported taking work home sometimes or partially. The corresponding figure for IT users was only 19 percent and for others 15 percent.

On the positive side of the coin, knowledge work offers a relatively high degree of autonomy, chance of flexible working hours, and, hardly surprisingly, better than average monetary rewards. Every other knowledge worker also occupies a managerial position. In these respects, knowledge workers differ very clearly from the two other groups. In short, knowledge workers have some strong advantages in developing and maintaining a positive work identity. According to Mats Alvesson (2001), education, status, high pay, and interesting work tasks facilitate positive identity constructions of knowledge workers. However, Alvesson is quick to add that people in knowledge-intensive companies are vulnerable to frustrations contingent upon ambiguity of performance and confirmation: "despite the comparatively high status of knowledge workers, their self-esteem can-not be taken for granted and must be secured in an ambiguous and fluid world" (p. 877).

Yet, there are also more concrete problems facing knowledge workers than the "elusiveness" of secure professional identities. For example, working overtime and, especially, taking work home may indicate that knowledge workers are unable to use the opportunity to control their working times very much to their own advantage. If you regularly exceed "normal" working hours, it does not really matter whether or not you have a theoretical chance to clock in and out of the office at any time of the day. (Table 15)

Table 15. Some Aspects of Authority and Autonomy among Knowledge Workers, IT Users, and Others in 2000 (% of Finnish wage labor)

	Knowledge workers	IT users	Others	Total
Occupies managerial position	50	22	15	31
Income index (all Finnish wage earners = 100)	123	91	78	100
Managerial responsibilities:				
– Assignment of job tasks to subordinates	45	17	13	27
– Deciding on methods used by subordinates	38	14	12	23
– Deciding on pace and amount of work	33	11	7	19
There is a chance:				
– To freely decide when to clock in and out of work	35	14	13	22
– To take a day off without losing pay or having to claim vacation time	35	21	12	24
– To work for a day at a considerably slower pace than normal without a loss of wages	68	59	42	58
– To decide yourself what to do and which assignments to take	64	43	27	47

Except for the income indices, the Table includes those respondents who replied "Yes."

Somewhat surprisingly, the work performed by knowledge workers is under very close scrutiny. Four knowledge workers in five reported that the volume and also the quality of output of their work are under surveillance. The same holds true for both IT users and others. (Table 16) This is paradoxical because surveillance is in many respects the antithesis of autonomy, which is required especially from knowledge workers who, more than average, should be involved in creative problem solving. In this sense, the work situation of knowledge workers can be described as contradictory. However, the time spent on tasks is far less controlled among knowledge workers than in other groups.

Table 16. Surveillance of Work Performed by Knowledge Workers, IT Users, and Others in 2000 (% of Finnish wage labor)

	Knowledge workers	IT users	Others	Total
The employer controls:				
– Volume of output	82	78	78	79
– Quality of output	79	81	81	80
– Time spent on tasks	17	32	44	29

The table includes those respondents who replied "Yes."

Based on the above figures, it may be argued that knowledge workers are being adapted to rapidly changing efficiency and productivity norms. This is understandable because in terms of their vocational training knowledge workers represent the best-educated and arguably the most productive population segment in Finland.

There is every reason to believe that a similar picture would also emerge from other highly developed information societies than that of Finland. The picture I have drawn here of knowledge work is pretty much in line with the research literature, which suggests that there is a simultaneous tendency in the workplace today towards increased flexibility, towards strengthening staff commitment, and controlling work (Robins & Webster 1999; Sennett 1998; Thompson & Warhurst Eds. 1998). Global competition, indeed, has its grim downside as G.M. Kelly, a former ILO official, has aptly argued in International Labour Review:

"Latter-day capitalism has disturbingly recidivist features, even in Europe. While great numbers are condemned to contingent and precarious employment, ordinary workers in "good" jobs and apparently most higher cadres typically endure long hours and an unrelenting sense of urgency. … To an extent not known since the worst decades of the European industrial revolution, the labour force everywhere is exposed to a work fatigue that is deeper than and different from mere physical or nervous exhaustion. Notions of work as fulfilment, as the expansion of individuality, as an enjoyable alternative to idleness, are retreating before the remorseless instrumentalism of global competition and rationalist ideology." (Kelly 2000, 16–17.)

The future of knowledge work

The classification of knowledge work applied in this study is just one among many different options. The aim has not been to provide an exhaustive account of all the changes that are going on in the modern workplace, but rather to give the reader some highlights of a simple yet analytic tool in use. The choice of criteria was based on the qualitative transformation of work. In particular, I have wanted to take into account the symbolic and educational skills that characterize the evolution to-wards the information society at the level of work processes. In my analysis, the claims according to which innovation-based societies are in essence "learning economies" are justified (Schienstock & Kuusi Eds. 1999).

The Finnish case points to the importance of a solid educational base for a nation's adaptability to large-scale social changes. Finland urbanized only about 40 years ago but since then started quickly to specialize in technology-centered industries. At the same time, Finland also began to follow other Nordic countries in their aim of building universal and democratically governed welfare states. Equal elementary education and increasing opportunities to acquire training at vocational and university levels were an essential part of this process, without which today's situation would not be conceivable. This is the social background that should be kept in mind when evaluating the recent success of the Finnish economy.

In light of my analysis, however, the argument I submit here with respect to the rise of knowledge work is that the Finnish information society is perhaps unique in character, but not quite as progressive as one is often given to understand (cf. Castells & Himanen 2002). The basic structures of the Finnish economy are still strong (in spite of the recent turbulences in global markets), Finland's technological infrastructure is very modern, and accordingly most occupations and jobs, where feasible, have been computerized; and yet the depth of the real change has been exaggerated. As much as I would like to argue as such, Finland is not a "high-tech wonderland" where social problems, unemployment, and problems at the level of the workplace are nonexistent.

It is clear that the glamorous success stories that have come out of the ICT sector are just the tip of the iceberg – though admittedly an invaluable part of the national economy. Nokia, for instance, which has become one of the most desired brands in the world, is certainly not the whole story of Finland (see especially Häikiö 2002). In reality, the hard core of the Finnish information society lies in teaching, research, as well as in various jobs in the public sector, which employs every other knowledge worker. In the case of Finland, this is consistent with the general theory of postindustrialization exemplified by Bell (1973, 15), who considered the growth of health, education, research, and government services as decisive for a postindustrial society.

In this respect one of the lessons to be learned from the Finnish experience is that a relatively large public sector is not necessarily an antithesis to thriving businesses.

On the contrary, it can be argued that it is the symbiosis of the basic social infra-structure and entrepreneurship that has made it possible for companies like Nokia to succeed in global markets. For example, without close collaboration with local technical universities and their research and teaching capabilities some of Nokia's main innovations would never have seen the light of day. Without a doubt Nokia and the ICT sector as a whole have been a tremendous boost to the economy. In the beginning of the 1990s, Finland was one of the least ICT specialized industrial countries; now it is amongst the most ICT intensive countries in the world (Koski et al. 2002, 155).

What conclusions, then, can we draw concerning the present state of knowledge work and its future? There are two points I would like to emphasize. First, the risk of polarizing employees into "core" and "disposable" segments of the labor force, to borrow Manuel Castells' (1996, 272) concepts, is a threat to be taken seriously, although currently a definitive conclusion remains a task to be left for future research. The second important aspect worth considering is that knowledge work itself involves some deep-seated contradictions. As my analysis indicates, knowledge work offers high autonomy and better than average monetary rewards, but on the reverse side of the coin it also involves high levels of stress and high expectations to meet the demands of the transient labor market situation that characterizes the current phase of capitalist development in Finland and other advanced economies.

All in all, knowledge work is at once rewarding and extremely demanding. Indeed, as, for example, A.R. Hochschild (1997) or Richard Sennett (1998) have recently suggested, many individuals on the fast track of career advancement have seen the demands of the job ruin their family life and made nonsense of the meaning of leisure. This is also a potential risk in the Finnish case although, for the sake of comparison, it might be added that hardly any European country is considered as competitive in spirit as the United States. However, in this respect the future may indeed turn out to be very American.

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Wellbeing technology – usagecontexts and know-how

Disciplines and definitions of wellbeing technology

Wellbeing technology is a multidisciplinary and multi-operator field of technology. In wellbeing technology research, medicine, as well as social and behavioral sciences, join with technology research, such as information technology, electronics, teletechnology, telematics, nanotechnology, biotechnology, smart materials, robotics, and mechatronics. The innovations in wellbeing technology come about in a modular fashion when experts in different disciplines simultaneously combine their know-how. Lasting innovations meet people's health or wellbeing needs, as well as those of social welfare and healthcare professionals, and/or the equipment and information needs of some service establishments.

Wellbeing technology is just now in the process of establishing its terminological content. The concepts include several subterms. Wellbeing technology can be divided into two main groups. The development trend of the first one deals with the technology used by the individual or consumer. The term 'independent living technology' suggests all the devices that help a person compensate for his or her movement and activity impairment. 'Self-care technology' means equipment and methods, with which a person can follow his or her own health and vital bodily functions, and use the technology to sustain his or her health. The term 'home care technology' comprises the telemedical health care equipment and systems used in the home. This electronic equipment is connected to some service organization like a health center or hospital. 'Smart home technology' means, in a broad sense, all the smart functions and household appliances used in the living environment. The technology also includes computer-controlled heating, ventilation, and lighting, as well as smart household appliances and entertainment electronics. 'Fitness and sport technology' includes the electronics and biomechanics connected to it.

The second development trend concerns technology used by service organizations and their staff, in other words 'business-to-business technology'. 'Hospital technology' means all the equipment, instruments, and fixtures. The technology in question is used in diagnoses, care, laboratory technology, radiology, surgery, and other electronic equipment of the hospital. The more limited concept of 'health informatics' refers to the hospital information systems, as well as their connections to the diversified hospital technology equipment. Health informatics also includes all the health care data from patients' records to the data entry of laboratory analyses and x-rays, as well as data transfer as electronic referrals and consultations.

The general term 'wellbeing technology', which covers the development trends of all the earlier specified technologies, is used in this article. Wellbeing technology products include all the technology, service, and the business and service activities associated with them, which promote, support, or maintain a person's everyday life, health, social wellbeing, and contacts with their environment.

Method of approach and wellbeing technology know-how

Wellbeing technology know-how comprises three sectors, technology, engineering, and service, which are integrated with each other in a modular fashion. *Technology know-how* connects together the knowledge technology of different fields, such as electronics, teletechnology, and medical science, in wellbeing technology. In the final analysis, knowledge materializes as components, equipment, instruments, and devices. *Engineering know-how and management* means the internal construction of equipment, instruments, or devices and their operability, functionability, controllability, and communicability. The primary one from the perspective of wellbeing is the operability and communicability with the user and his or her health and wellbeing needs. In this way, know-how takes into consideration the user-oriented operability. Finally, *service know-how* makes technology part of other social welfare and health care and business service systems. It is a question of the usage contexts of wellbeing technology and the application of technology according to the context requirements. Simply put wellbeing technology acts and communicates together with other service production.

On the one hand, the future of wellbeing technology is difficult to predict from the development of technology. On the other, estimating the wellbeing status of different population groups does not in itself help the anticipation and determination of know-how needs. The know-how needs and development work of technology can be approached in a context-limited manner, from the demands of the usage environment of wellbeing technology. Service know-how is emphasized in inspecting the usage contexts. Service is the wellbeing technology link to the surrounding world. That is why in this article, wellbeing technology is looked at as part of the usage environment and concept. The article deals with the development trends of wellbein g technology in various usage environments. In addition, know-how sectors and qualifications have been derived from the development trends, the significance of which will be further emphasized in the near future.

The usage contexts and know-how of wellbeing technology

The production-based tradition in the *building industry* is beginning to give way. Mass customizing is taking its place, in which accommodations are built to suit everyone's way of life from industrially produced modules. The house package of the future contains scheduled maintenance, usage and upkeep package, financing alternatives, and individual, easy-living technology and service concept. Mass customized dwellings are built especially for families with young children, who move to roomier or moderately priced dwellings in the suburbs or areas with owner-occupied housing. At the same time, some elderly people move from owner-occupied housing to smaller apartments in the city center and closer to the services. Elderly people need special services in their immediate surroundings. These services can be classified as the maintenance of one's own wellbeing and home environment, home care and hospital care services, and other services in the immediate surroundings. Services for one's own wellbeing and the home environment, and their construction, are also linked to new construction projects in the city centers, in which particular attention is paid to easy access, additional equipment, and other service areas. Neighborhood services mean, for instance, that an elderly person can be a client of some outside service provider. For example, a construction company builds a service center in the area where neighborhood residents can network as its clients. The active population more often seeks new types of service communities, where various services are found quickly and easily on the Internet. One moves from the passive information transfer of the Web to the information supply processed by computers. From the perspective of the future, the development trends in question require, among other things, the following know-how.

Table 1. Know-how of the building and construction industry

The regional plan emphasizes service and business infrastructure, web services, and service business know-how.
The regional planning researches how people partly network the area shops, logistics, and wellbeing services, and what kind of service businesses can be arranged in the area.
Training in the construction field takes into account the demands of easy access, in addition to mass customizing, modifiability, maintenance services, and technology and service concepts that make life easier.
The construction industry generalizes industrial modules and standards, the know-how of which is the basis for modifiability, additional equipment, and production planning
The construction industry needs even more expertise in materials design, logistics solutions, modular construction, maintenance services, scheduled maintenance, additional equipment and technology.
The design and maintenance of community information platforms requires service and .NET architecture expertise and interactive content service.

The *smart home concept* brings together information technology, electronics, and the traditional interior elements of the home. The smart home uses at the same time microelectronics, robotics, sensors, detectors, and teletechnology. The innovations based on these technology platforms comprise a wide range from different simple automated detectors to control systems of the home computer. It is the equipment in a smart home that supports, in many cases, automation concerning, especially, air-conditioning, heating, and lighting, Another challenge for the smart concept is to take into consideration the residents' whole life cycle, and the special needs of each period of life. From the perspective of wellbeing technology, this means that dwellings must be modifiable and that equipment and electronics operate wirelessly. The third smart home outlook pays regard to people who have functional or health special needs. The smart home offers elderly people a secure life at home regardless of movement impairment or sickness. The dwelling can, if necessary, become a home hospital. Fourthly, the smart home can be seen in the home's movables, such as furniture, household appliances, and textiles, to which is connected ever more intelligence, mobility, and modifiability. These goods are called 'smartness integrated' products. The resident makes independent choices, however, regarding what kind of technology and automatics he or she wants in the home environment. The central know-how needs of the smart home of the future are:

Table 2. Know-how of the smart home concept

Systems expertise is needed in home construction, in such things as the design and maintenance of the air-conditioning, heating, and lighting systems.
In the training in the home construction and interiors field, attention is focused on telecommunications systems, detector-, sensor-, and optics technology, and home automation systems.
Smart home concept know-how is based on the life cycle thinking of both people and changing dwellings.
Smart furniture, household appliances, and textiles require the know-how of information technology, automatic, electronics, and mechatronics in the traditional artisan trades and in raising the extent of value-added in these products.
Smart home know-how needs the know-how of customizing and tailoring services, as well as building it into individual or household service systems.

The increasing integration of the communications media means a transition to the world of multimedia. A *multimedia environment*, which consists of s ounds and videos both on the phone and television, as well as texts and graphics on the computer, increase the opportunities of communications in learning, virtual reality, and in other social interactions. In a wireless world, these combine in 2.5 and 3G data terminal equipment. Social welfare and health care services just as educational, training, cultural, and sports services, open up on the Internet, wireless phones, and digital television through multimedia. When these services are connected to satellite positioning GPS or to the NET positioning of wireless phones, the need of content services, and the search opportunity based on location and occasion, information about services can be transmitted in real time wherever a person moves or stays. In addition, different navigational programs and maps lead a person to the nearest services. Apart from the services situated in the person's everyday environment, mobility and distance functioning is expected of them.

The multimedia environment, the joining of channels offered by communications technologies, increases the chances of telework. *Telework*, which takes place at a distance from the employer's organization, offers, especially for those who do mobile work, a flexible communications channel and flexibility independent of time and place. Telework applications include teleoperations, distance guidance and maintenance, off-site monitoring and diagnostics, telemeasurement, and long-distance care, as well as distance programming. The amount of telework is expected to grow significantly in the near future. This development is formed by organizational learning, traffic jams, environmental pressures, as well as trends in individual work habits, and flextime.

Table 3. Know-how of the multimedia communication

Multimedia communications is taught in every school and multimedia education is offered in the multidisciplinary communications teaching establishments and colleges.
A wireless connection makes work and services mobile. Communications between people, equipment, and machinery is a know-how area of its own in communications theory. Accurate and specified precise information can be transmitted to the employees, as well as to individual interested parties.
Wirelessness means a wide growth in content services, which means growth in the recruiting needs of companies and public organizations for content producers and contact personnel.
Digital multimedia increases the need for know-how in interactive applications such as distance learning.
phaTelework and its administration places new demands for many professional groups doing mobile work from office work to health care, care-giving services, forwarding, and logistics.
Telework needs new professional preparedness in distance guidance-, operating, and long distance care.
Intellimedia or 'smart content' makes it possible to handle complex multimedia information in the home 24 hours a day, in which the users collect, combine, change, and copy multimedia material, and participate in a creative, interactive process.
A new service culture is developing in the area between home and service establishment.

Service centers, one-stop-shops, call centers, help desks, and contact centers are the more visible manifestations of the new service culture. People are in direct contact with call center-type services by various communications devices, by telephone, email, and Internet services, and they agree with the service providers about individual service profiles. Security systems offer help in cases of illness or where the person is unable to move, in search services, automatic fire alarms, burglary alarms, and other needs. It is a question of the creation of a wireless secure environment and connection to the nearby social welfare and health care services and other services. Service center clients can as well live in a block of service apartments, service row houses, as in other neighboring housing associations. A wireless service environment is important security for elderly people in the home and in its vicinity.

Telemedicine technology and services are applied in various forms of therapy in home hospital care. Personal emergency response systems (PERS) is an automated dialing system ("base unit") which can transmit one or more coded messages to a remote monitoring station when activated by the user or by a sensor (e.g., alert wristband). Monitored Medication Dispensing Systems (MMDS) is a programmable device for scheduled dispensing of medications that alerts an off-site monitoring station of patient non-compliance by means of a coded telephone message. Therapy Tele-Management systems (TTMS) are a dedicated configuration involving the on-line real-time continuous monitoring of a single specific in home therapy administration which would automatically track the patients' signs and adjust volumes and flows as indicated. Patient Telemonitoring systems (PTMS) are the input of patient data at scheduled intervals to a device that either has telecommunications capability or attaches to a standard telephone. All these systems have in common that they are connected with the health center, hospital, or other service provider. Therefore, the functions of the health centers and hospitals will extend to the home in the future.

The difference between public and private services is beginning to become unclear; services are connected one with another in different customer groups. The demand for *door-to- door services* is growing as the functional ability of the elderly weakens and number of institutional places remains the same. Home care handles both home services and home hospital care. What can be offered to all as home care is a question of need and evaluation. Basic services are offered equally by public and private social welfare and health care. Paid door-to-door services can be broadened to cover private or organizational cleaning-, shopping-, food-, and personal services. In addition, certain other commercial services such as hairdressers, massage, and chiropody can be offered as a mobile service in the more densely populated areas.

Table 4. Know-how of the telemedicine and distance services

The appearance of the latest distance services and their know-how concern almost all the service fields from social welfare and health care to door-to-door services and e-services.
The administration of distance services, telecommunications, and information present new challenges to the personnel of shops, and the service industry, as well as social welfare and health care. Distance service, telemedicine, and telecommunications are the new subjects in social welfare and health care training.
The administration and quality of information are central productive resources in industry and services.
Patients' own nurses monitor the health of their clients, make service need assessments, and guide the customers.

Devices technology earlier dealt with products and services, such as prosthetics and rollators, that compensate for varying degrees of movement impairment. The current range of devices is widening with new products. The widest signs of development concern different kinds of devices for measuring and monitoring health. The best-known technological applications are pulse meters, blood pressure meters, body fat meters, and alcometers. The latest meters are ones that describe alertness and stress. The next to become general are devices and care systems that monitor various illnesses and their treatment. For example, people suffering from asthma, diabetes, epilepsy, and cardiovascular problems are using devices to care for and monitor their health in real-time, and with which they can regulate their medication and vital functions. A second development direction is in devices that compensate for limited/restricted hearing or sight/vision. The hearing-impaired are using personal amplification systems (for use in communal viewing situations), of which one significant area of development is text captions (sub-titles). Closed text captions are also widely used for learning foreign languages and with children with reading and writing difficulties. Vision impairment or damage can be compensated for by a "video or audio description" system, which uses a voice description of the visual sequences of the visual content of television or cinema programming.

Table 5. Know-how of the self-care and personal amplifications systems

People's responsibility and know-how in following their own health is stressed. People independently use monitoring devices and self-care systems developed for different illnesses.
Workplace health care uses data systems to follow employees' health, promote health, and support methods and the know-how connected with them.
Public and private health care monitor customers' illnesses electronically and use telemedicine cures. Their own personnel specializing in telemedicine maintain the system.
Personal amplification systems and audio descriptions and the special know-how connected with their use are applied in the care of the visually- and hearing impaired.
Adapted and customized services need the administration of the tailor-made know-how and systems.

Sports equipment- and fitness technology have been one of the fastest growing areas in wellbeing technology in recent years. The sports (equipment) industry is based on a movement concept that covers sports equipment in addition to movement and rehabilitation physiology, lifestyle information, as well as other travel and peripheral services. Equipment production is aimed, above all, at the active and professional sports markets. New materials bring lighter and more durable solutions than earlier to the market. In addition smart clothes are designed in the first stage as sports clothes, after which they spread to other clothing products. At the same time, it can be seen that the elderly and movement-impaired are adopting the same movement technology materials. The elderly and movement impaired are producing supportive solutions for their own mobility. Personal fitness programs, competitive sports programs, and the new type of sports centers also belong to the development of the movement concepts.

Travel, traffic, and logistics services are growing and linking with each other. Communal information platforms can be applied to each of these. An example of an information platform for travelers is the public transport application, which covers the whole country. Finnish public transport is moving to an electronic schedule and routing system that covers the whole country. Also every sport and hobby can build national and international communal information platforms, which offer to the participants full service from sports and free time activities equipment to social intercommunication and travel.

Table 6. Know-how of the sport and fitness technology

Designing and developing movement concepts needs both type and equipment know-how.
Designing movement concepts needs special support services, such as travel, accommodation, etc know-how.
The administration and know-how of different age groups' movement needs and movement technology is customized.
The designing and maintenance of general information platforms needs expert personnel, who have knowledge of both sports and free time activities, and information technology skills.
Personal television and its program production need expert producers of content services in sports and free time activity groups.

Institution and center environments offer growing *business-to-business markets* to wellbeing technology. B-to-b markets are divided into three segments, each of which partly has its own customers. The first segment covers the *equipment, instruments, and furnishings used in medicine and hospitals*, in which electronics, information technology, biotechnology, and mechanics are combined. The products in question are diagnostic, surgical, and other high technology products used in nursing. The second segment comprises pharmacological products, medicines and doctors ordering them. These medicines are seen as belonging to biochemistry and biotechnology, which is why they are not included in wellbeing technology. The third segment is *health informatics* applications.. Health informatics will be used more and more in organizational management, communications, as well as a tool for the laboratory and radiology. Laboratory tests and X-rays are transferred in electronic form to the doctor's desktop. In addition to this virtual segments are being created in which health informatics serves the cooperation needs between different organizations. Key areas are electronic patient information records and care multimedia, in which patient data, radiology imaging, laboratory test results, current care instructions, electronic referral and feedback system, and other information is seen on the doctor's desktop. Other developing health informatics application areas are virtual hospital concepts, e-health business, (video)consultation, and long-distance care and surgery, as well as other self-care support systems.

Table 7. Know-how of the hospital technology and health informatics

The significance of technical sciences in medical and health care education is growing.
Technology expertise is needed more than ever in the near future in hospitals.
Health informatiics know-how is needed in the designing, maintenance, and developing of virtual concepts.
Health informatics and distance medicine are central subjects in the training of doctors and nurses.
In certain specialist nursing fields like radiology, distance consultation and its know-how are a central approach.
Information management, the exploitation of evidence-based medicine and the use of medical data banks are in a key position in health care education.
Distance health services, virtual health centers, and health portals offer interactive health information and the field requires its own expertise.

Know-how general qualifications

Wellbeing technology is based on multidisciplinary know-how in which the technology basic research combines with the know-how of other branches of science and practical needs. Since the turn of the millennium, wellbeing technology education and research has started in many universities and vocational colleges in Finland. Each research institute has built its know-how in its own tradition of science.

In-depth special know-how and extensive customer knowledge, as well as general knowledge, cross over in wellbeing technology know-how. Extensive know-how concerns the basics of different generic technology areas, but also different contexts of the technological applications and the needs and possibilities of these. Generic wellbeing technology know-how is based on information technology, tele-technology and communications, automatics, electronics, biotechnology, optics, and material technology. Real new innovations are, however, being created in the areas of this special know-how of these disciplines, which are semantic Internet, health informatics, telemedicine, small robotics, microelectronics, biomechanics, special optics, as well as ultra light and smart materials. In promoting wellbeing technology, it is necessary to determine the areas of expertise, where multidisciplinary research groups can be founded. Ahead are specific development areas each of which contains its own areas of expertise. Of the 20 universities in Finland, 10 are multidisciplinary universities in which it is possible to develop basic research in wellbeing technology.

Table 8. The generic technologies of wellbeing know-how

Information Technology Broadband services and digiTV services, semantic Web Health Informatics	Tele Technology Wireless services and communities Tele-medicine Telematics	Automatics Small technology robots Household appliances electronics	Electronics Microelectronics Nano-technology Information technology and electronics integrated into products	Biotechnology Biomechanics	Optics	Material technology Ultra light materials Smart materials

Wellbeing techniques know-how is based on the utilization of basic research and combining and applying different technologies in different product groups and service environments. Cooperation between behavioral sciences and the humanities and technical sciences increases. Technologies like sensors, detectors, light and laser control systems, data systems, biosignal handling, electronic image transfer, smart connections, wireless communications, wireless connection, digital signal handling and positioning are successfully used in industry. The utilization of these technologies in the promotion of wellbeing is just taking its first steps.

Therefore, innovation education and innovation development has an important position in the promoting of wellbeing technology know-how. Innovation education gets through at its best all the education streams in the vocational colleges and also certain areas of the university education. It is characteristic of innovation know-how to feel the value added and innovation processes, direct innovation activities in organizations, communications with outside science and technology sources, utilize multi-professional teams and project models, design and refine value added services, as well as identify customer needs at first hand, and knowledge of the usage context and environment. Innovation education can be included in the teaching program in vocational colleges, because the basic task of a vocational college is to train professional experts in the tasks of work life and their development. Research and development work stresses the promotion of area development, as well as co-operation with small and medium-sized enterprises.

Table 9. The techniques of wellbeing know-how

Recognizing customer needs Significance of behaviorial sciences and the humanities. Knowledge of usage context and environment	Leading/managing innovation activities Multiprofessional teams and network cooperation Communications between different professional groups	Knowledge and design of value added and innovation processes	Utilization of project know-how and models Design and refinement of value added services

In service know-how service functions are planned for wellbeing technology products and/or products that will be integrated into other service systems. The role of service is emphasized in the so-called new service based business. Firstly, the products themselves fill some task associated with health, movement impairment, hobbies, or sports, which the user experiences as a technological service. Secondly, the significance of the services is emphasized as a separate value added service. These include usage education/training and data services, care, maintenance upkeep and updating, monitoring contacts, and user group socialization. The service know-how area concerns coupling products such as alert telephone, into part of other social and health care systems. Finally, electronic devices communicate with their usage and service environment, which is why the significance of system know-how will be stressed even more. Other service know-how qualifications are the administration of service chains, interface know-how, information quality and management in service chains, value added and life cycle thinking, as well as service business activities. Taken as a whole, the customer need, usage context, and adaptability to the surrounding systems create a foundation for wellbeing know-how and development.

Table 10. The customer, value added services and communication management know-how

Customer know-how	Value added services know-how	Communications management and knowledge of service environment
Upkeep of health, minimization of movement impairment, hobby or sports equipment business activity and content services know-how, consumeration, management, mass customizing knowledge	Maintenance- upkeep-, updating-, monitoring-, communication know-how, socialization of user groups, and free time activity groups, providing mutual services	Management of service chains, interface know-how, information quality and management, system know-how, service business activities, interoperability between net services, management of communal information platforms

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Tiivistelmä

Tutkimuksen tavoitteena oli määritellä ja rajata tulevaisuuden keskeisimmät teknologiset kehityslinjat (avainteknologiat) ja analysoida niiden yhteiskunnallisia, koulutuksellisia ja ammatillisia vaikutuksia. Avainteknologiat on rajattu informaatio- ja kommunikaatioteknologian, bioteknologian, sekä materiaali- ja nanoteknologian aloille. Lisäksi tarkastellaan näiden avainteknologiaryhmien yhdistelmiä, ns. fuusioteknologioita.

Tutkimuksen metodologia perustuu delfitekniikkaan ja se toteutettiin kolmessa vaiheessa. *Preliminäärisessä vaiheessa* tutkittiin teoreettis-empiirisesti teknologisen kehityksen oleellisia kehityslinjoja ja tehtiin systemaattinen jäsennys tulevaisuuden keskeisimmistä avainteknologioista. *Ensimmäisellä delfikierroksella* kerättiin ja analysoitiin asiantuntija-arvioihin perustuva aineisto koskien tutkimuksessa määriteltyjä tulevaisuuden avainteknologioita.

Päätuloksena ovat aineistoon perustuvat analyysit teknologisista ilmiöistä, teknologisista teeseistä ja teknologisten teesien toteutumisen ajoittumisesta tulevaisuudessa. Seuraavat teknologiat ja niihin kytketyt teesit arvioitiin keskeisimmiksi: kohdennetut lääkkeet, sensorit, integroitu teknologia, biolääketieteelliset materiaalit, fotoniset materiaalit, 3G-teknologia, älymateriaalit, diagnostiikka ja virtuaalitodellisuus. *Toisen delfikierroksen* päätavoitteena oli ensimmäisellä kierroksella keskeisiksi nousseiden teknologioiden yhteiskunnallisten vaikutusten analysointi asiantuntija-arvioihin perustuen. Ensimmäinen päätulos on keskeisiksi arvioitujen teknologisten teesien yhdistäminen tutkimuksessa muodostettuun luokitukseen ammatti- ja koulutusaloista siten, että ammatti- ja koulutusalojen muutosta voidaan teknologia- ja teesikohtaisesti tarkastella. Toinen päätulos on tutkimuksessa muodostettujen uusien tulevaisuusammattien uskottavuuden ja ajoittumisen analyysi.

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Titel
Nycklarna till framtiden: Sociala, utbildningsmässiga och yrkesmässiga konsekvenser av utvecklandet av nyckelteknologier

Referat

Syftet med undersökningen var att definiera och dra upp linjer för de viktigaste framtida utvecklingstrenderna inom teknologin (nyckelteknologier) och analysera deras sociala, utbildnings- och yrkesmässiga konsekvenser. Nyckelteknologierna har begränsats till att omfatta informations- och kommunikationstekniken, biotekniken samt material- och nanotekniken. Dessutom studeras kombinationer av dessa grupper av nyckeltekniker, s.k. fusionstekniker.

Metodiken är baserad på Delfitekniken. Undersökningen genomfördes i tre etapper. *Det preliminära skedet* omfattade en teoretisk-empirisk studie av de väsentliga utvecklingstrenderna på det tekniska området och en systematisk strukturering av de mest centrala framtida nyckelteknologierna. Under *den första Delfirundan* samlades och analyserades materialet, som baserar sig på experternas bedömningar, med avseende på de framtida nyckelteknologier som definierats i undersökningen.

Det viktigaste resultatet utgörs av analyserna, som gjordes på basis av materialet, av teknologiska fenomen, teknologins teser och bedömningen av hur realistiska teserna är och tidpunkten för eventuellt förverkligande av dem. Följande tekniker samt tillhörande teser bedömdes som mest centrala: selektiva läkemedel, sensorer, integrerad teknik, biomedicinska material, fotoniska material, 3 G-teknik, intelligenta material, diagnostik och virtuell verklighet. Det huvudsakliga målet för *den andra Delfirundan v*ar att på basis av experternas bedömningar göra en analys av de sociala konsekvenserna av de nyckeltekniker som under den första etappen bedömts vara centrala. Det första huvudresultatet utgörs av kopplingen av de teknologiska teser som bedömts som centrala med den klassificering av yrkes- och utbildningssektorer som gjorts vid undersökningen så att det blir möjligt att betrakta ändringarna i yrkes- och utbildningssektorerna skilt för varje teknik och tes. Det andra huvudresultatet är en analys av trovärdigheten av och tidpunkten för de nya framtidsyrken som skapats vid undersökningen.

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Nyckelord
teknologi, framsynthet, framtid, utbildning, arbete

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