APPENDIX D. REVIEW OF NBIC VISIONARY GOALS PUT FORWARD AFTER 2001

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The primary focus of the 2011–2012 series of NBIC2 workshops was to consider action plans for the next decade of convergence, both in fine detail and in consideration of a CKTS Initiative.[1] Longer-term visions have therefore been kept in the background, yet they are crucial for planning near-term research and development priorities. The 2001 NBIC study and report (Roco and Bainbridge 2003) was a bridge to a new frontier, but there are mountains in the distance that must be climbed after the next decade and that must be approached by the right path. This appendix summarizes some of the earlier NBIC visions for the longer-term future, and extracts representative visions for the future from the ten chapters of this report.

There have been several Converging Technologies conferences, studies, and reports beginning in 2001, which have offered many inspiring visions of the future, but not all of them were positive. Fear can be just as motivating as hope, so candid consideration of the most difficult problems facing humanity needs to be part of the discussion. Most participants agreed that the NBIC2 vision can be achieved, and doing so will create a better future. But it also seems the case that humanity faces grave dangers and may not be able even to sustain current levels of prosperity and peace without focusing on convergence. This appendix begins by emphasizing the reasonable but grand hopes of earlier conferences, then poses some questions based on the discussions of the most recent conference and reflecting the tension between hope and fear.

Besides reviewing the 20 visionary ideas put forward in 2001, this appendix offers 80 other ideas drawn from the full range of applications considered at the five NBIC studies, including this one. Some are framed as predictions and some as problems. Each one could deserve a chapter in its own right, and forty from the 2013 study are indeed discussed in one or more of the chapters of this report. The goal of this brief appendix is not to analyze any of the ideas in depth but to raise them for the reader's own consideration. This 2013 report is especially focused on relatively near-term challenges and applications, so this appendix is designed to place the discussion of convergence of knowledge and technology in a somewhat longer historical context, anchored in the past but looking toward the more distant future.

THE 20 IDEAS FROM THE ORIGINAL REPORT

The original NBIC report listed twenty applications of technological convergence that could benefit humanity in a time frame of 10 to 20 years. (Roco and Bainbridge 2003, 5–6). In 2005, 26 participants in the NBIC meetings of that year completed a questionnaire that used the Delphi technique, asking each of them to predict the year in which each of the twenty applications would be "substantially achieved" and how positive or beneficial that would be on a scale from 0 to 10. Of course, no one can predict precisely, but the median predicted date for achievement of each application was a reasonable indicator of how much research and development time was likely to be required, based on the judgments of those experts on NBIC convergence. The median was the appropriate measure, because it takes account of those cases in which some respondents predicted the application would never be achieved, although in most cases respondents put a date within the current century. The following sections group the original 2001 applications of NBIC convergence according to the 2005 respondents' predictions of when they would be achieved, on five-year marks, and briefly examine some of the implications of those ideas.

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[1] Editor's note: The acronym NBIC refers to the convergence of nanotechnology, biotechnology, information technology, and cognitive science. CKTS refers to a key concept in this report, the convergence of knowledge and technology for (the benefit of) society. The first major NBIC conference was held Arlington, VA, in 2001; there were follow-on NBIC conferences in 2003 (Los Angeles, CA), 2004 (New York, NY), and 2005 (Kona, HI). This 2011–2012 workshop series and 2013 report revisit technology convergence issues. This study originally was termed NBIC2 (meaning "beyond NBIC"), but because it focuses its discussion and recommendations on how convergence can address societal needs—including its recommendation of a Federal CKTS initiative—the study and report now also take the acronym CKTS.

Applications of NBIC Convergence to be Achieved by 2015

The 26 respondents to the 2005 questionnaire predicted on average that three of the 20 application goals would be substantially achieved within a decade, which is by 2015:

1. Anywhere in the world, an individual will have instantaneous access to needed information, whether practical or scientific in nature, in a form tailored for most effective use by the particular individual.
2. New organizational structures and management principles based on fast, reliable communication of needed information will vastly increase the effectiveness of administrators in business, education, and government.
3. Comfortable, wearable sensors and computers will enhance every person's awareness of his or her health condition, environment, chemical pollutants, potential hazards, and information of interest about local businesses, natural resources, and the like.

Indeed, from the perspective of 2013, it seems the conference participants were right. The technology is in place for each of these 2015 predictions, and the remaining questions about them primarily concern implementation. The phrase in prediction one, "most effective use by the particular individual," suggests an open-ended goal, because personalization of information resources can always be improved. Yet for a very wide range of current information needs, desired resources can be consulted from any location that has Internet access. Search engines can be personalized, but it is also easy for individuals to personalize their access to many specific digital libraries and archives. Not many people really have the skills yet to gain maximum benefit, and we may be passing through a period in which a skilled minority temporarily has a great advantage over others, including scientists able to do research better and faster than colleagues whose information technology skills are weaker. However, increasing fractions of the population have the skills, and the quality of interfaces continues to improve, so the first prediction will apply to more and more individual people with each passing year.

Regarding prediction two, many new organizational structures, especially those called "virtual organizations" that employ information technologies to overcome geographic distance, have indeed been developed on the basis of a large number of support technologies. Many of these shift responsibilities from one kind of management position to another, and thus they may also shift power relations between groups within an organization and between organizations. Thus there can be both social resistance to organizational change and interest-based distortions in how change is implemented. These are topics for investigation by the social sciences, which NBIC always conceptualized as the next in line to join the convergence, probably via unification with cognitive science.

A very large fraction of the population currently carries computer-like smart phones or other mobile devices that are equivalent to computers, and many kinds of sensors have been developed to work with them, to monitor either health conditions of an individual or environmental conditions. Implementation of many specific applications implied by prediction three has lagged somewhat, probably due to cost considerations, both the trade-offs for individual money investments in a time of economic problems, and the cost of effort required to learn about and use new devices.

Conveniently, these three predictions suggest valid points about application predictions in general. As the due date for a prediction approach, especially if it is a rather correct prediction, then the meanings of its terms are likely to change, becoming refined and sometimes significantly revised. Each of these three also highlights the importance of a particular context. First, satisfaction of individual needs requires people to articulate what they need and to learn skills that maximize their ability to exploit resources. Second, the organizational context may retard, accelerate, or direct change, as groups and other social forces compete and cooperate in making decisions about the implementation of new technologies. Third, even innovation has a cost, and in a world rich in innovations, economic markets can play crucial roles in determining which applications succeed.

Applications of NBIC Convergence to be Achieved by 2020

4. People from all backgrounds and of all ranges of ability will learn valuable new knowledge and skills more reliably and quickly, whether in school, on the job, or at home.
5. Individuals and teams will be able to communicate and cooperate profitably across traditional barriers of culture, language, distance, and professional specialization, thus greatly increasing the effectiveness of groups, organizations, and multinational partnerships.

6. National security will be greatly strengthened by lightweight, information-rich war fighting systems, capable uninhabited combat vehicles, adaptable smart materials, invulnerable data networks, superior intelligence-gathering systems, and effective measures against biological, chemical, radiological, and nuclear attacks.
7. Engineers, artists, architects, and designers will experience tremendously expanded creative abilities, both with a variety of new tools and through improved understanding of the wellsprings of human creativity.
8. Average persons, as well as policymakers, will have a vastly improved awareness of the cognitive, social, and biological forces operating in their lives, enabling far better adjustment, creativity, and daily decision-making.
9. Factories of tomorrow will be organized around converging technologies and increased human–machine capabilities as intelligent environments that achieve the maximum benefits of both mass production and custom design.
10. Agriculture and the food industry will greatly increase yields and reduce spoilage through networks of cheap, smart sensors that constantly monitor the condition and needs of plants, animals, and farm products.
11. The work of scientists will be revolutionized by importing approaches pioneered in other sciences, for example, genetic research employing principles from natural language processing and cultural research employing principles from genetics.

Aspects of all eight of these applications have been achieved, although by no means completely, and again, the factors determining implementation are important. Several of them express optimism that human beings will possess greater understanding and thus be more effective in achieving their personal and professional goals. This contrasts with the rather significant societal pessimism that began with the financial crises two or three years after the predictions were made, and the increasing dissatisfaction with their governments acutely felt by citizens of Europe, Japan, the United States, and other technologically advanced nations. This observation suggests that these predictions should be translated into prescriptions, things we need to achieve to get the world back on the track to progress.

The national security prediction was somewhat controversial, as indicated by the fact it received the lowest "good" score of any of the 20, 5.5 on the scale from 0 to 10. Most of the predictions got scores in the 7 to 9 range. Of course, what this suggests is that human beings—both scientists and engineers are humans—differ in their values and how they might vote in a referendum about society's defense policies. No one predicted, "Military technology will be unnecessary, because humanity will have found a reliable path to peace." Yet the respondents differed in whether they viewed some of the technology as security-enhancing or as ultimately dangerous.

Applications of NBIC Convergence to be Achieved by 2025

12. Robots and software agents will be far more useful for human beings, because they will operate on principles compatible with human goals, awareness, and personality.
13. The human body will be more durable, healthier, more energetic, easier to repair, and more resistant to many kinds of stress, biological threats, and aging processes.
14. A combination of technologies and treatments will compensate for many physical and mental disabilities and will eradicate altogether some handicaps that have plagued the lives of millions of people.

These three predictions with median dates around 2025 are not close to achievement now, but perhaps by pure chance they collectively identify a crucial question for mid-term thinking about progress related to technological convergence: To what extent will progress be achieved by improving human beings, versus improving human-centered machines? One can take either side of this argument, or try to split the difference by talking about human–machine collaboration—as the National Robotics Initiative does when referring to "co-robots" designed to work well with humans. It may be that a different answer will prove to be best for each application. But the question clearly has profound policy, ethical, and social implications.

Applications of NBIC Convergence to be Achieved by 2030

15. Fast, broadband interfaces between the human brain and machines will transform work in factories, control automobiles, ensure military superiority, and enable new sports, art forms, and modes of interaction between people.
16. Machines and structures of all kinds, from homes to aircraft, will be constructed of materials that have exactly the desired properties, including the ability to adapt to changing situations, high energy efficiency, and environmental friendliness.
17. The ability to control the genetics of humans, animals, and agricultural plants will greatly benefit human welfare; widespread consensus about ethical, legal, and moral issues will be built in[to] the process.
18. Transportation will be safe, cheap, and fast, due to ubiquitous real-time information systems, extremely high-efficiency vehicle designs, and the use of synthetic materials and machines fabricated from the nanoscale for optimum performance.
19. Formal education will be transformed by a unified but diverse curriculum based on a comprehensive, hierarchical intellectual paradigm for understanding the architecture of the physical world from the nanoscale through the cosmic scale.

Application of NBIC Convergence to be Achieved by 2050

The final prediction, set around the year 2050, concerns what is popularly called the "Final Frontier," namely a practical goal for the space exploration program:

20. The vast promise of outer space will finally be realized by means of efficient launch vehicles, robotic construction of extraterrestrial bases, and profitable exploitation of the resources of the Moon, Mars, or near-Earth-approaching asteroids.

There is much room to debate what exactly the promise of outer space is, although this item suggests one particular view on this difficult question. Mention of near-Earth asteroid mining usually implies a new source of rare mineral resources for terrestrial industry. Discussions of exploiting Martian resources could have a very different goal, the colonization of Mars itself. Robotic construction of extraterrestrial bases could be an efficient way of preparing for human habitation without the initial cost of creating a viable ecology and economy prior to the point at which many extraterrestrial resources could be exploited. And efficient launch vehicles would be required to support any significant expansion of physical human activity across the solar system.

Given that nanotechnology was the historical starting-point for NBIC convergence, it is possible to raise a serious issue about exploitation of extraterrestrial resources for terrestrial benefit. The Earth itself has all the chemical elements required for the full range of technologies, and a variety of new means for concentrating rare elements could certainly be devised, from robotic mining of the seabed to scrubbing the wastes that flow from our civilization. Nanoscience stresses the importance of how matter is structured on the nanoscale, thereby reducing the need for vast quantities of rare elements. Considering NBIC further, information can be more valuable than gold, and some of the most valuable materials are created by geological or biological processes native to our own planet.

Thus, if the goal is to increase the power of industrial society, NBIC convergence is the way to achieve it, not mining distant objects in the solar system. If the goal is to increase human understanding of the universe, then indeed, activities in outer space will be important, but probably in the form of deep space probes, robot landers exploring Europa or Titan, and orbiting telescopes scanning the universe across the full electromagnetic spectrum. If the goal is to expand civilization, the colonization of Mars may be an essential step, but so too will be expansion of cognitive science into the realm of cultural diversity.

By placing the promise of outer space farthest into the future of the twenty applications, the NBIC participants explicitly recognized how difficult it will be. But they also imply another perhaps more important truth: As we progress into a bright future, we will come to see things in a different light.

20 SELECTED IDEAS FROM THE 2005 PREDICTIONS—2030 AND BEYOND

The 2005 questionnaire included an additional 50 applications (Bainbridge and Roco 2006a: 340–344) culled from the first three NBIC reports (Roco and Bainbridge 2003; Roco and Montemagno 2004; Bainbridge and Roco 2006b); 20 of these were not expected to be fulfilled until after the first third of the 21st century. The median predicted dates for all 50 were within this century, although we can expect great uncertainty about those that the respondents placed rather far in the future. The following sections list 20 convergence applications predicted to be achieved after about 2030.

Applications of NBIC Convergence to be Achieved between 2030 and 2050

A quarter of this group of selected ideas was judged to be achievable in the 2030s:

1. A fresh scientific approach to culture, based on concepts from evolutionary biology and classification techniques from information science, will greatly facilitate humanities scholarship, marketing of music or literature, and artistic innovation.
2. Three-dimensional printers will be widely used not only for rapid prototyping but also for economical, local, on-demand manufacture of art objects, machine parts, and a host of other things from a variety of materials.
3. It will be technically and economically possible to sequence the genetic code of each unique individual, so we will fully understand genetic variations in human performance.
4. Nano-enabled sensors, implanted inside the human body, will monitor metabolism and health, diagnosing any health problem before the person even notices the first symptom.
5. Assistive technologies will largely overcome disabilities such as blindness, deafness, and immobility.

In fact, the first three of these now look achievable much sooner than the respondents predicted back in 2005. The “fresh scientific approach to culture” is covered in Chapter 2 of this report, three-dimensional (3D) printers are central to the distributed manufacturing covered in Chapter 7, and personalized genetic sequencing appears in Chapter 6. The predictions about implanted sensors and assistive technologies were phrased in somewhat extravagant terms, but progress along these lines is already happening today.

Predictions Judged to be Achievable by around the Year 2040:

6. Humane machines will adapt to and reflect the communication styles, social context, and personal needs of the people who use them.
7. A combination of techniques will largely nullify the constraints associated with a human’s inherent ability to assimilate information.
8. Science will achieve great progress in understanding and predicting the behavior of complex systems, at multiple scales and between the system and the environment.
9. A new form of computing will emerge in which there is no distinction between hardware and software, and biological processes calculate the behavior of complex, adaptive systems.
10. Nanoscale molecular motors will be mass-produced to perform a variety of tasks, in fields as diverse as materials manufacturing and medical treatment.

Achievement of number 6 above, which researchers in human-centered computing call personalization and context-aware systems, is a matter of degree and thus not really capable of having a specific year of achievement. The following four would all seem to require rather major scientific and technological breakthroughs, conceivable and perhaps even capable of being described in some detail, but not achievable in the near term.

The next seven predictions have that same quality and were placed **between 2045 and 2050**:

11. Warfighters will have the ability to control vehicles, weapons, and other combat systems instantly, merely by thinking the commands or even before fully forming the commands in their minds.
12. New research tools will chart the structure and functions of the human mind, including a complete mapping of the connections in the human brain.
13. Molecular machines will solve a wide range of problems on a global scale.
14. Memory enhancement will improve human cognition, by such means as external electronic storage and infusion of nerve growth factors into the brain.
15. A predictive science of the behavior of societies will allow us to understand a wide range of socially disruptive events and allow us to put mitigating or preventive strategies in place before the harm occurs.

16. A nano-bio processor will be developed that can cheaply manufacture a variety of medicines that are tailored to the genetic makeup and health needs of an individual.
17. Nanorobots will perform surgery and administer treatments deep inside the human body, achieving great health benefits at minimum risk.

These last seven applications appear to reflect slightly greater doubts about feasibility and a sense that more work needed to be done to accomplish these seven goals. The statement about a "predictive science of the behavior of societies" is challenging in a different way from the others, because the emphasis in all the Converging Technologies reports on societal implications requires inputs from the best available social science. If we cannot predict the behavior of societies, then we cannot anticipate the second-order consequences of technological innovations.

Longer-Term Applications of NBIC Convergence—2070 and Beyond

Ability to predict and accept varying societal behavior sets the basis for contemplating two predictions not expected to be fulfilled for an additional generation, around the year 2070:

18. Scientists will be able to understand and describe human intentions, beliefs, desires, feelings, and motives in terms of well-defined computational processes.
19. Rather than stereotyping some people as disabled, or praising others as talented, society will grant everybody the right to decide for themselves what abilities they want to have.

Put together, these two predictions raise the specter of social control versus freedom. If scientists really understood their fellow human beings, they could have great power over them. But our job is not to force people to fulfill our hopes for them, but to give people the means to achieve their own goals, even if often those goals may be modest in scope.

The final prediction in this set, with a **median fulfillment date of 2085**, is far out, both technically and ethically:

20. The computing power and scientific knowledge will exist to build machines that are functionally equivalent to the human brain.

If that capability comes into being, should we use it? Countless science fiction authors have imagined possible consequences of such a development, but their aim has been to provide an interesting focus of conflict to motivate an exciting story, not to develop serious design principles for technologies that would enhance human life. A more subtle issue concerns whether "functionally equivalent" means that the machines would operate on the same principles as the human brain, rather than using very different principles to simulate the human mind. In either case, developing such machines would require much deeper understanding of the nature of intelligence than we currently posses, and thus there could be great consequences for our conceptions of ourselves, even if the machines never left the research laboratories.

IDEAS, QUESTIONS, AND TRADEOFFS SUGGESTED BY THE 2013 CKTS STUDY

20 Questions Regarding Applications of Convergence-Based Technology Systems

The section and the following one together contain 40 ideas about the future culled from this report and presented more as challenges than as predictions. They are not discussed here in the context of when each might come to closure, but rather are offered as issues for the reader to contemplate and to evaluate on the basis of the reader's own professional expertise and personal values. This first set of 20 are phrased explicitly as questions, perhaps to be answered by future research, or dilemmas to be resolved through logical analysis. After each question, the chapter number is given in which it is discussed or implied, although information from all parts of this report may be relevant.

1. Can transition to a knowledge-based economy provide new routes to upward social mobility for talented individuals without rendering many unskilled people totally unemployable? (Chapter 1)
2. Will the pervasive use of information technology bring social groups together or push them further apart? (Chapter 1)
3. Can the National Robotics Initiative realize its "co-robot" principle of designing beneficial collaborations between humans and robots, thereby becoming an example for other fields of engineering to follow? (Chapter 2)

4. Will it prove beneficial to expand convergence far beyond its NBIC origins, for example reaching through information and cognitive science to social science, and beyond that to incorporate the arts and humanities? (Chapter 2)
5. Is it possible to achieve environmental sustainability, for example, in use of energy resources, without causing serious negative political, social, and economic externalities? (Chapter 3)
6. Will the governments and other institutions of the world cooperate sufficiently to establish a comprehensive global system for monitoring the natural environment and the components of society that affect it? (Chapter 3)
7. How rapidly will a science of convergence arise, especially if it proves difficult to discover overarching principles to understand varied traditional fields in terms of new shared concepts? (Chapter 4)
8. What systems of evaluation and governance will make it possible to find the right dynamic balance between convergence and divergence, properly integrating the two in the convergence–divergence cycle? (Chapter 4)
9. Will it prove possible to mobilize scientists, medical professionals, and the general public to transform medicine from a reactive into a proactive practice, preventing illness, detecting illnesses early, and thereby reducing the costs of healthcare? (Chapter 5)
10. Will governments, insurance companies, and healthcare delivery systems find ways to mitigate significantly the demographic challenge of an aging population, in the context of extreme and possibly increasing economic inequality? (Chapter 5)
11. What principles of design and manufacture will make it possible for robots to serve diverse populations, from early childhood education to home living assistance for elderly persons? (Chapter 6)
12. In what ways would human culture be forever changed if a unified theory-based rule set for understanding human cognition were developed? (Chapter 6)
13. What organizational principle, such as franchises or guilds, will prove effective to establish distributed manufacturing systems that simultaneously maximize efficiency and local autonomy? (Chapter 7)
14. Is there any way to revive science-and-technology studies, which proper implementation of technological innovation requires, given that social scientists are now largely barred from doing research inside scientific laboratories, industrial corporations, and government agencies? (Chapter 7)
15. Given the many different kinds of infrastructure required for research, education, and manufacturing demonstration projects, will it be possible to prioritize them in a way that is affordable and does not unbalance the convergence process? (Chapter 8)
16. What methods of data collection and criteria of success should be used to evaluate programs to reform education along convergence lines? (Chapter 8)
17. What combination of energy sources and public policies could move the world away from the use of fossil fuels, without plunging humanity back into the limited resource situation experienced in history? (Chapter 9)
18. Given the many disappointments over the years, how can the nations of the world come together to institute effective environmental protection and resource sustainability? (Chapter 9)
19. What measures will encourage a virtuous spiral of creativity and innovation, versus a vicious circle of degradation? (Chapter 10)
20. If the pessimistic argument that we are reaching the end of scientific and technological progress is correct, would there be any way to transition smoothly to an enduring form of benevolent civilization? (Chapter 10)

Superficially, some of these 20 questions might be answered with a simple "yes" or "no," and others by a single sentence. Yet, really, each of them could be the topic of an extended debate today, and could be answered confidently only after years of convergence experience. They tend to emphasize evolution of the technological system based on convergence principles, with secondary consequences for human wellbeing, whereas the final 20 questions explicitly focus on social impact dilemmas that may be created by technology convergence.

20 Potential Social and Ethical Tradeoffs Suggested by Technology Convergence

The point of presenting the following 20 issues as tradeoffs is not to imply each one is an inescapable dilemma, but rather to highlight the ways in which multiple goals are often interrelated. To say that achieving A will prevent achieving B, can be an exhortation to seek a way of achieving both, perhaps through some previously unimagined synergy that removes the conflict between A and B. Some examples are presented as conditionals, rather than tradeoffs, such that A can be achieved, but only if another perhaps even more difficult goal, B, is achieved. Thus, the phraseology in this section is meant to stimulate creative thinking rather than pessimism, with an understanding that many important decisions have implications for each other.

1. Direct stimulation of the human brain will counteract many diseases and disabilities, but in so doing, it raises huge questions about the propriety of technological control of the individual mind. (Chapter 1)
2. Extensive use of open source software will greatly increase the functionality and customizability of information systems, at the cost of innumerable security breaches and cyber attacks. (Chapter 1)
3. The governance of technological innovation could be centralized and authoritarian, or decentralized and democratic. (Chapter 2)
4. Recruitment of nonprofessionals to research teams, in what is often called "citizen science," promises to advance science through their volunteer efforts and to integrate science better into the wider culture, but at the risk of encouraging pseudoscience and politically tainted science. (Chapter 2)
5. General policies based on global risk assessment could benefit humanity as a whole, while damaging the prospects of people living in some specific geographic areas. (Chapter 3)
6. Extensive public debate about the full range of environmental and social implications of nanotechnology could ensure that it achieved maximum human benefit for humanity, or could ensnare progress in popular misconceptions based on fear and ignorance. (Chapter 3)
7. A remarkable range and number of new strategies will be developed for research and development investment and implementation, but one result could be diminished support for tried-and-true older strategies that have not really outlived their usefulness. (Chapter 4)
8. Creation of higher-level, multidomain technical languages could facilitate convergence, but at the cost of a whole new program of education for young scientists and engineers and the obsolescence of older people whose technical training is finished. (Chapter 4)
9. Regenerative medicine and advanced prosthetics will be among the new treatments improving the quality of survivors' lives, while less emphasis may be given to prolonging the lives of the terminally ill. (Chapter 5)
10. Constant monitoring of people's health conditions, using wearable sensors and smart homes, can improve well-being tremendously, at the cost of extensive patient education, deployment of much new and possibly expensive information technology, and potential privacy vulnerabilities. (Chapter 5)
11. Convergent technologies will definitely assist people suffering from mental disabilities, and may do harm to mentally deviant people whose characteristics are simply variant rather than objectively pathological. (Chapter 6)
12. Research and development strategies, both convergent and divergent, can achieve remarkable progress, but only if greatly increased understanding of cognition allows us to implement strategies that are really compatible with the way human minds function. (Chapter 6)
13. With distributed manufacturing methods, capabilities will shift from the hands of the few into the hands of the many, potentially reducing the profits of large corporations and their investors. (Chapter 7)
14. Distributed manufacturing requires shipment of raw materials in small quantities to large numbers of locations, which will increase costs unless methods inspired by nanotechnology can reduce waste, and new systems of transportation can improve efficiency of delivery. (Chapter 7)
15. Online education will lower price and increase accessibility, at the cost of distancing students from their physical subject matter and reducing their opportunities to become members of intellectual communities. (Chapter 8)
16. Three different strategies for siting research and education centers compete: placing them at the most advanced research universities, siting them at geographic locations where several institutions of higher

learning can participate, and locating them in regions of the nation where science is weak in order to improve those regions. (Chapter 8)

17. In all fairness, the developing nations have the right to achieve the same levels of economic prosperity as the most technologically developed nations, yet if this happens the natural environment of the world could be destroyed by pollution and resource depletion. (Chapter 9)
18. Increased use of nuclear energy would allow reduction in the use of polluting fossil fuels and thus reduce global warming, at the risk of proliferation of nuclear weapons and accidents. (Chapter 9)
19. It is essential to develop institutional capacities for enhancing the interactions between science and society, but one result may be rendering some older institutions obsolete and generating resistance from people who are committed to older customs. (Chapter 10)
20. The semiconductor industry provides a good model for convergence to other industries, but relying exclusively on strategies developed in its special context may delay development of good alternative models that might arise in very different areas of human activity. (Chapter 10)

The purpose of this list is not to establish an authoritative viewpoint on the future but to illustrate the range of issues that need to be considered. Real convergence will require transcendence of the differences between the perspectives held by human beings with varied backgrounds, interests, and purposes. The proper response to most of these issues is to conduct scientific research and technology development, typically multidimensional, asking many interrelated questions and seeking to integrate answers as they are found.

CONCLUSION

The experience of the past decade of Converging Technologies meetings shows that there is real value to collecting visionary but professionally grounded predictions and other descriptions of future possibilities. They inspire action, stimulate thought, and anchor debate. Thus it could be valuable to establish a periodic survey of CKTS scientists and engineers, ideally a panel of several hundred with expertise across all convergent fields, probably done each time in two stages. In Stage 1, members of the panel would contribute ideas like those listed above, which would be combined, edited, and selected to maximize diversity by a survey research team that would transform them into a formal questionnaire. In Stage 2, panel members would respond to the questionnaire, as in our 2005 study, rating each idea in terms of the year it might be substantially achieved, and how good that achievement would be for humanity. Conducted over the Internet, this survey process could be quite inexpensive, and the resultant dataset could be analyzed in several ways for multiple publications and purposes.

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