APPENDIX E. SELECTED REPORTS AND BOOKS ABOUT CONVERGENCE

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Since the beginning of the National Nanotechnology Initiative (NNI), which contributed to advancing convergence principles, large numbers of experts worldwide have examined technological convergence from many perspectives. The publications described below report the issues raised in their discussions, and their major conclusions. Arranged in chronological order, they begin with early NNI reports that linked that field to biotechnology and information technology, and they include the social and cognitive sciences when ethical and human implications are under consideration. In addition, to provide information plus suggestions of policy issues that require consideration, the listed reports outline research and development agendas within and across many fields of science and technology. Formal mapping of the full NBIC (nano-bio-info-cognitive science) convergence was accomplished by 2003, and the following decade expanded both the scope and the depth of our understanding.

Nanostructure Science and Technology: A Worldwide Study. Siegel, Richard W., Evelyn Hu, and Mihail C. Roco (eds.). 1999. Dordrecht, Netherlands: Kluwer.

This first comprehensive report begins with a decisive sentence: "Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years" (p. 1). This proclaims not only the vast potential of nanoscale research and development, but through the word "interdisciplinary" defines it from the very beginning as both an instance and a source of convergence, both across traditional fields and around the globe. A starting point for this report was a workshop held in the United States May 8–9, 1997, followed by workshops and site visits in France, Germany, Belgium, the Netherlands, Sweden, Switzerland, the United Kingdom, Japan, and Taiwan. Five chapters focused on somewhat distinct nanotechnology technical areas: (1) synthesis and assembly, (2) dispersions and coatings, (3) high surface area materials, (4) functional nanoscale devices, and (5) bulk behavior of nanostructured materials. A sixth technical chapter foreshadowed nano-bio convergence, identifying a wide range of issues in which nanoscale phenomena in biology (such as protein structure and dynamics) could be included within nanoscale science and technology and achieve synergies with non-biological fields. The final chapter surveys the state of nanoscale research around the world, including data on government funding support and the development of research infrastructure that could be the basis of rapid progress.

Nanotechnology Research Directions. Roco, Mihail C., R. Stanley Williams, and Paul Alivisatos (eds.). 2000. Dordrecht, Netherlands: Kluwer.

Offering a research agenda and specific policy recommendations, as well as a detailed overview of the field, this report resulted from a workshop held January 27–29, 1999. The first four chapters outline research issues specific to nanotechnology, the intellectual and empirical tools for research, and the processes for creating nanostructures. The next five chapters cover application areas, at least two of which related directly to NBIC convergence because they cover nanoelectronics and biomedical applications. The tenth chapter concerns how improved understanding of structures and processes at the nanoscale can enhance our abilities to preserve and improve the natural environment, and the eleventh chapter considers the infrastructure required for success in nanoscale research, development, and education. Participants achieved a high degree of consensus that a "grand coalition" was needed to bring together academic institutions, the private sector, government laboratories, government funding agencies, and professional science and engineering societies in support of the multidisciplinary vision of a national nanotechnology initiative.

Societal Implications of Nanoscience and Nanotechnology. Roco, Mihail C., and William Sims Bainbridge (eds.). 2001. Dordrecht, Netherlands: Kluwer.

This extensive examination of the societal implications of nanotechnology was based on the principle that powerful new technologies must serve human well-being and follow good ethical principles. Based on a large workshop held in Arlington, Virginia, September 28–29, 2000, it consists of two parts. In the first part, five chapters survey the field of nanotechnology and conclude with major recommendations that arose from

the groups' consensus, including four that were seen as crucial: (1) A high priority should be given to social and economic research studies in nanotechnology, which would imply a degree of convergence between nanotechnology and the social sciences. (2) An effective mechanism should be developed to inform, educate, and involve the public concerning potential impacts of innovation in this new domain. (3) The knowledge base and institutional infrastructure should be developed to evaluate, on a continuing short-term and long-term basis, the scientific, technological, and societal impacts. (4) A new generation of scientists and workers should be educated in nanoscience and nanotechnology, including giving them the multidisciplinary perspective that nanoscale work naturally requires and that will serve them well in the coming years of more general technological convergence. The second part of the report consists of 37 statements communicating the individual perspectives of participants, written from their own technical and value orientation, many of which link to biomedical or information technologies or to education and ethics.

Converging Technologies for Improving Human Performance. Roco, Mihail C., and William Sims Bainbridge (eds.). 2003. Dordrecht, Netherlands: Kluwer.

This pivotal book-length report resulted from a workshop on Converging Technologies to Improve Human Performance, held at the National Science Foundation, December 2–4, 2001, at which the large number of expert participants deliberated in task forces and plenary sessions. It focused on four major NBIC provinces of science and technology, each of which is advancing rapidly: (1) nanoscience and nanotechnology), (2) biotechnology and biomedicine, including genetic engineering, (3) information technology, including advanced computing and communications, (4) cognitive science, including cognitive neuroscience. It asserted that convergence of diverse technologies is based on the material unity of nature at the nanoscale and on technology integration from that scale and that key transforming tools can achieve advances at the interfaces between previously separate fields of science and technology, accelerate progress within each field through intellectual contributions from the others, and promote the overall unification of science and technology. It demonstrated that developments in systems approaches, mathematics, and computation associated with NBIC convergence will allow us for the first time to understand the natural world and human cognition in terms of complex, hierarchical systems. With this basis, improvement of human performance becomes possible, providing realistic hope of dealing successfully with the challenges of the modern world. The main body of the report is divided into six sections, each reflecting a distinctive theme and beginning with a task-force summary followed by a number of more individual perspectives. The themes are: (1) motivation for advancing convergence and outlooks on major trends, (2) expanding human cognition and communication, (3) improving human health and physical capabilities, (4) enhancing group and societal outcomes, (5), national security, (6) unifying science and education.

The Coevolution of Human Potential and Converging Technologies. Roco, Mihail C., and Carlo D. Montemagno (eds.). 2004. New York: New York Academy of Sciences.

This was the second report emerging from the original NBIC convergence project, stemming from a conference held in Los Angeles, February 5–7, 2003. Its first part consists of three overview chapters, anchoring the conference in the earlier work and looking toward the future: "Science and Technology Integration for Increased Human Potential and Societal Outcomes," "Vision for Converging Technologies and Future Society," and "Collaborating on Convergent Technologies: Education and Practice." The second and larger part consists of thirteen research contributions, many of which reported innovative pilot research on new technologies that could be created via convergence of scientific fields. Among the more striking but plausible information technology examples were basing electronic computation not on solid state devices but rather on excitable vesicles composed of membrane-enclosed liquids, and designing solid state computer vision devices in a biomimetic manner along the lines of the human retina. Other contributions examined the ethnical, legal, and managerial dimensions of technological convergence, the evolution of semantic systems, and human performance enhancement.

Converging Technologies – Shaping the Future of European Societies. Nordmann, Alfred (ed.). 2004. Brussels, Belgium: European Commission.

This report considered Converging Technologies to be the first major research initiative of the current century, having four potentially revolutionary qualities: (1) Embeddedness: The new technologies will be the fundamental infrastructure for society, so profound as to be unnoticed much of the time. (2) Unlimited Reach: No aspect of human life will escape the influence of converging technologies, and solutions based on

them will be proposed for all human problems; in some cases, however, these may be false solutions. (3) Engineering the Mind and the Body: Inspired by the NBIC motto "Improving Human Performance," and the myriad potential health applications, for better or worse there is the real possibility of transforming human nature. (4) Specificity: In such areas as individually targeted medications based on the genetic code of the individual patient, these new technologies will facilitate specialized design and treatment that reverses the trend toward standardization that became the norm in two centuries ago with the Industrial Revolution. The report observes of the four qualities: "Each of these presents an opportunity to solve societal problems, to benefit individuals, and to generate wealth. Each of these also poses threats to culture and tradition, to human integrity and autonomy, perhaps to political and economic stability" (p. 6). While fundamentally enthusiastic about the vast potential of converging technologies, this report sets out a "European Approach" intended to maximize positive social benefits and guard against harm caused by unsophisticated or irresponsible applications.

Converging Technologies and the Natural, Social and Cultural World. Bibel, Wolfgang (ed.). 2004. Brussels, Belgium: European Commission.

While recognizing the innovative contributions of the original NBIC report, this report to the European Commission suggests a slightly different emphasis: "While Europe does not abhor addressing 'mental, physical and overall human performance' of the individual, it lays an equal emphasis on the social and economic dimensions of sustainable development. Examples for the latter are issues of access to information and knowledge and the resulting impacts on societies' and economies' ability to innovate, of equality and justice with respect to access opportunities, and of individual capabilities to learn or engage socially and politically" (p. 7). The report focuses especially on how issues of social cohesion and public decision-making connect to NBIC through new information technologies and potential advances in cognitive science, identified by the new term "ambient intelligence." Among the more visionary topics discussed is the future potential of artificial intelligence. Eight formal recommendations urge innovation that is consistent with traditional culture, undergoes comprehensive empirical evaluation, and is understood in terms of a "whole society" model of benefit.

Nanotechnology: Societal Implications. Roco, Mihail C., and William Sims Bainbridge (eds.). 2006. Berlin: Springer.

This two-volume report resulted from a workshop held at the National Science Foundation, December 3–5, 2003. The first volume chiefly reports the results of deliberations in ten breakout sessions, one of which had converging technologies as its explicit theme. Two other sessions examined the complex interplay of public policy, governance, ethics, law, international activities, risk, and uncertainty. But the societal implications of NBIC convergence was also a frequent topic in each of the other seven sessions that covered productivity and equity in society, future economic scenarios, the quality of life, national security, interaction with the public, and education. The second volume contains 48 contributions by individual participants, arranged in seven groups, one of which is converging technologies. Again, all of the other sections focus on nanotechnology but have great relevance for complete NBIC convergence: economic impacts, social scenarios, ethics and law, governance, public perception, and education. The goal of all these contributions was to examine trends, identify opportunities, and seek the best ways to maximize benefit for humanity.

Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society. Bainbridge, William Sims, and Mihail C. Roco (eds.). 2006. Berlin: Springer.

Based on an NBIC conference held February 25–27, 2004, in New York City, this is a diverse collection of 19 essays. The first five provide an introduction to the NBIC concept, outline the emerging policy implications, sketch a roadmap for convergence in the near-term future, consider the implications for an economy based on innovation, and suggest how to measure the progress of convergence. Other chapters examine one or another area that can contribute to and benefit from convergence: education, cyberinfrastructure, developing countries, medicine, law, social science, services science, and technopolitics. Several concern ethics, including neuroethics or issues of human enhancement, and offer conceptual systems that might be applied across multiple traditional areas to achieve cognitive convergence.

Progress in Convergence: Technologies for Human Wellbeing. Bainbridge. William Sims, and Mihail C. Roco (eds.). 2006. New York: New York Academy of Sciences.

This is a diverse collection of essays by participants in a workshop held in Hawaii, February 24-25, 2005, organized in five main sections: (1) perspectives on convergence, (2) nano-bio-info technology, (3) informatics for convergence, (4), cognitive enhancement, and (5) social and ethical implications. The four perspectives in the first section present the chief orientations that typified convergence at that point in time. The first focused on governance issues, which include how power is exercised in managing resources, how potential conflicts are resolved, and how stakeholders are able to participate in decision processes. The second perspective sought general concepts that could be applied across fields of science, such as laws comparable to conservation of energy in physical processes, potential isomorphisms in material or theoretical configurations across domains, and how random variations may coalesce into similar patterns. The third perspective analyzed the origins and meaning of the consilience goal proposed by Edward O. Wilson, initially applied in sociobiology but transferrable across science and engineering. The fourth perspective suggested that convergence is a new paradigm for higher education, requiring and facilitating major reforms to prepare students for the opportunities and challenges ahead.

Technology Assessment on Converging Technologies. European Technology Assessment Group. 2006. The Hague, Netherlands: Rathenau Instituut.

This is the report from a workshop titled "Converging Technologies in the 21st Century: Heaven, Hell or Down to Earth?" that was held at the European Parliament in Brussels, June 27, 2006. After an opening statement by the workshop chair, presentations were made by authors of a literature study and a vision assessment. While recognizing the importance of the 2001 NBIC workshop, the literature study argues that convergence was already happening naturally across the NBIC fields, and observed: "For decades we have been used to powerful terms such as information revolution and biotechnological revolution. However at the start of this new millennium two revolutionary key technologies came into view: nanotechnology and the cognitive sciences. Nanotechnology is seen as the technology of the 21st century and radical breakthroughs are also expected from the cognitive sciences. There is also a growing realisation that these four key technologies are enabling each other in the journey of human progress" (p. 13). The literature study introduced many of the competing visions, and the shorter vision assessment added several more perspectives. After these orienting presentations came a debate among invited experts and an open session including questions from the audience. The debate focused on three main questions: (1) How can we describe the nature and velocity of the emergence of converging technologies, and the forces that are driving it? (2) What impact will converging technologies have on human nature and moral progress, in a context where nations and groups seem to disagree in significant ways? (3) What role should the European Parliament play, for example in organizing public debate, setting a research agenda, or working through the various pan-European organizations?

Converging Applications Enabling the Information Society. van Lieshout, Marc, Axel Zweck. et al. 2006. Delft, Netherlands: Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek.

This report is based on two 2005 workshops, "Building a Vision for a European Research Strategy on Converging Technologies" held July 13 in Amsterdam, The Netherlands, and "Validation of Converging Technologies for Enabling the Information Society," held October 26-27 in Seville, Spain. The first half of this report considers how each of four other fields is converging with information and communications technologies (ICT) in innovative ways that will accelerate the emergence of the information society: (1) cognitive science, (2) biotechnology, (3) nanotechnology, and (4) materials sciences. Two additional chapters survey the current status of these convergences across major advanced societies, systematically comparing scientific activities and impacts. The concluding chapter focuses on European efforts in the global context, observing: "Based on the information contained in their national R&D programmes, it can be ascertained that virtually all EU25 countries have recognized the importance played by ICT, nanotechnology, biotechnology, and the new sciences. They are deemed as leading areas of importance within the R&D sector and acknowledged as strategic domains for future development, likely to influence a vast array of aspects of both the economic and social life" (p. 127).

Nanoconvergence. Bainbridge, William Sims. 2007. Upper Saddle River, New Jersey: Prentice-Hall.

This monograph provides a sociological perspective on NBIC convergence, initiated by the emergence of nanotechnology, based on material unity at the nanoscale and technology integration from that scale. As often happened in the history of science and technology during a relatively short period, a very wide range of visions coalesced, both practical and impractical, competed, with the result that rapid and demonstrable progress was energized by human enthusiasm and guided by human intelligence. After a chapter on nanotechnology that set the stage for convergence, chapters show how the three other fields were ready to join the unification process. Concluding chapters examine the social processes through which scientists and engineers cooperate, and suggest a set of eight concepts that can be combined in different ways to frame theories applicable across domains: configuration, information, variation, conservation, interaction, indecision, cognition, and evolution.

Konvergierende Technologien und Wissenschaften: Der Stand der Debatte und politischen Aktivitäten zu »Converging Technologies« (Converging Technologies and Sciences: The State of the Debate and Political Activities about "Converging Technologies"). Coenen, Christopher. 2008. Berlin: Bureau for Technology Assessment at the German Parliament.

This background report for the German parliament begins with observations that technological convergence became the focus of unclear but implicitly political debates, such as that between utopians who saw in convergence a way of achieving radical human enhancement, and those dystopians who used it as the opportunity to issue strident warnings about the harmful consequences of ungoverned technological experimentation. Such extreme viewpoints distract from the very real public policy issues concerning technological convergence that have now been debated in many nations, somewhat differently in Europe from in the United States; this report seeks to survey the landscape of legitimate discussion. The report recognizes the key position of nanotechnology in the broader process of convergence, uses the German equivalent of the word political where an English-speaker might use policy or governmental, and acknowledges that from the very beginning serious attention was given to the meaning of convergence for *people*: "The U.S. NBIC convergence initiative was developed as part of the political activities on the ethical, social, and legal implications of nanotechnology, a field in which the question of dealing with futuristic visions played a central role from the outset" (p. 12). The report also stresses the importance of information and communications technologies in achieving convergence, views on convergence as the logical starting point of a much broader political and societal discussion of the future prospects for science and technology, and expresses the European goal to develop valid methods for forward-looking technology assessment or vision assessment. The main text of the report is organized in six chapters: (1) an overview and introduction, (2) the genesis and content of the alternative convergence ideas, (3) a deeper vision analysis of the convergence debates, (4) consideration of how convergence processes, research results, and academic debates are structuring the field, (5) comparative international analysis of political activities on the convergence issue, and (6) a summary outlining policy options and research needs in the German and European context.

Security Applications for Converging Technologies: Impact on the Constitutional State and the Legal Order. Teeuw, Wouter B., and Anton H. Vedder (eds.). 2008. The Hague, Netherlands: Wetenschappelijk Onderzoek- en Documentatiecentrum.

Writing in the context of the Dutch legal system but published in English, this book-length report explores the implications of NBIC convergence in the fields of security, law, crime prevention, and police. After an introduction, four chapters introduce the four NIBC areas, then another chapter explains the principles of convergence. Chapter 7 is pivotal to this report, examining in depth three "cases," general application areas illustrating the potentially revolutionary impact of convergence. Case 1 concerns monitoring the location and condition of humans and objects, potentially with the option to intervene if something goes wrong, using sensors attached to or implanted inside them. Examples include monitoring the location and behavior of prisoners and triggering a "knee-lock" device if they attempt to run away, monitoring the situation of vulnerable persons and defending them if they become endangered, and securing a valuable possession such as deactivating the engine of a stolen car. Case 2 covers forensic research, typically using new nanotechnology-enabled devices to detect and instantly identify evidence at a crime scene that exists only in trace quantities, using "lab-on-a-chip" devices. Case 3 involves profiling, which may use NBIC technologies to screen masses of people for those with characteristics that may indicate they are dangerous, and

identification methods, which may combine biometrics, genetics, and computer vision. The first goal of the study is to identify which technologies might be feasible, then to sketch scenarios for the implementation of those that might prove useful, then to begin to discuss their social, ethical, and legal implications as a prelude to making policy decisions about them.

Knowledge Politics and Converging Technologies. Luce, Jacquelyne, and Liana Giorgi (eds.). 2009. Special issue of The European Journal of Social Science Research, 22(1): March.

This special issue of a journal grew out of a workshop held in Brussels, Belgium, May 6–7, 2008. The editors explained, "The presentations at the May workshop largely focused on practices of anticipatory governance and the analysis of historical and emerging forms of deliberative engagement and policy-making. The articles presented here are concerned with the ways in which discussions about knowledge and technological possibilities unfold and the manners in which social and political debates are circumscribed by pre-existing modes of tackling controversial issues." Steve Fuller offers a social epistemological perspective, suggesting NBIC is based on a fluid conception of human nature in which enhancing evolution may be considered. Adam Briggle argues that the U.S. President's Council on Bioethics was a valuable innovation in knowledge politics that can be applied to convergence. Other articles discuss emerging ethical issues like intellectual property rights, risk assessment, and the role of citizens' panels in deliberations about science and technology policy.

The Fourth Paradigm: Data-Intensive Scientific Discovery. Hey, Tony, Stewart Tansley, and Kristin Tolle (eds.). 2009. Redmond, Washington: Microsoft Research.

The title of this collection of essays about convergence based on information technology came from a visionary talk given in 2007 by the late Jim Gray, for whom this is in part a memorial volume. Gray argued that science has already gone through three stages of evolution, each representing a different paradigm: (1) A thousand years ago, science emerged as an empirical endeavor, describing natural phenomena. (2) In the past few hundreds of years, science became more theoretical, employing models and generalizations to interpret the deeper meaning of empirical findings. (3) In recent decades, science was again transformed as computers were used to simulate complex systems. Now, Gray proposed, a new paradigm is emerging: (4) Data exploration by means of information technology can unify empirical description, theoretical explanation, and computer simulation. This fourth paradigm is a very positive way to view the current trend toward "Big Data," in which scientifically relevant datasets of much greater size and complexity are being managed, often remotely in the "cloud," by information technology.

Nanotechnology Research Directions for Societal Needs in 2020. Roco, Mihail C., Chad A. Mirkin, and Mark C. Hersam (eds.). 2011. Berlin: Springer.

This major report, based on four forums held March through July, 2010, charts the course of nanotechnology research over the following decade (2010–2020) in ways that support NBIC convergence and serve human well-being. The first chapter celebrates the accomplishments of the first decade of the National Nanotechnology Initiative, as inspiration for the second decade. The next three chapters cover the fundamental tools for progress, based on progress in theory, empirical measurement, and manufacturing of nanoscale components. The three following chapters focus on areas of societal impact relevant for all NBIC fields, concerning environmental safety and sustainability. Five chapters survey opportunities for applications in bio-medicine, nanoelectronics, nanophotonics, nanostructured materials, and high-performance materials. Two summary chapters unify and conclude the report, one on development of the needed human and physical infrastructure, and one on innovative and responsible governance. As the book's preface explains, progress should be achieved along four dimensions of human concern: knowledge, material improvement for example in medicine and economics, global cooperation, and moral advance achieving enhanced quality of life and social equity.

The Third Revolution: The Convergence of the Life Sciences, Physical Sciences, and Engineering. Sharp, Phillip A. et al. 2011 Washington, D.C.: Massachusetts Institute of Technology.

This report considers convergence from the perspective of the health sciences research community. The conceptual framework begins by identifying two previous scientific revolutions, first the use in the mid-twentieth century of molecular and cellular biology to understand cells and diseases, second the more recent

attempt to understand health and disease in the context of the organism's entire genome, which of course requires advanced information technology. The third revolution, which this report proclaims is just beginning, "involves combining molecular and cellular biology with genomics, engineering, and knowledge of the physical sciences" (p. 8). Among specific examples given are computational biology to model the immune response, imaging technology to diagnose eye diseases, and using nanotechnology to achieve targeted chemotherapy delivery, attacking tumors with powerful chemicals without damaging healthy cells in the patient's body. The report places such specific benefits in a larger societal context by noting how innovation promotes economic development, the challenge to our healthcare system from the changing demographics of an aging population, and more generally the high returns from Federal research funding. Among the specific recommendations are establishing a "convergence ecosystem" (p. 28) connecting multiple disciplines, revising the peer-review process to make it more interdisciplinary, and educating researchers to work in cross-disciplinary fields.

Leadership in Science and Technology. Bainbridge, William Sims (ed.). 2012. Thousand Oaks, California: Sage.

This hundred-chapter, two-volume reference work employs well-established theories and well-documented case studies to bring together insights from many fields of science and engineering to identify principles of innovative leadership and project management. In addition to containing some chapters that explicitly discuss NBIC convergence, the entire work promotes the unification of all fields of science and engineering, with a special emphasis on social science as a means for accomplishment of this goal. The first volume consists of review essays in four general areas: (1) discipline-based social scientific approaches to leadership in science and technology, (2) key concepts relevant to leadership in all areas of R&D, (3) environmental contexts in which leadership and innovation occur, and (4) tactics and tools that leaders may use to achieve progress. The second volume offers a diversity of multidisciplinary case studies that illustrate issues and opportunities in four broad realms: (1) discovery and scientific debate, (2) collaboratories through which teams can combine forms of expertise and other resources, (3) technology development projects that require convergence, and (4) education approached from multiple perspectives. Across both volumes, the hope is that concepts and techniques developed in one area can be transferred to other areas, and combining people, ideas, and resources across areas will achieve the most rapid advances for knowledge discovery and human well-being.

"Report on the Convergence of Biotechnology and Nanotechnology." Enzing, Christien. 2012. Paris: Organisation for Economic Co-operation and Development.

This brief memorandum summarizes issues for consideration by the Working Party on Nanotechnology of the OECD, incidentally providing an up-to-date catalog of questions of wider relevance for broad scientific and technological convergence. After providing the intellectual and historical background, highlighting information technology as well as nanotechnology, this memorandum considers research about how converges actually occurs, lists a number of national and international efforts to promote convergence between nanotechnology and biotechnology, and then considers the potential ethical, social, and economic consequences. The author debates whether convergence is really a radical idea, concluding that it can indeed be revolutionary but also may lead to subsequent divergence: "convergence is an integral part of scientific practice: it refers to an intermediate stage of the scientific and technological process that tends to diversify again" (p. 30).

Additional summaries are available in a previous volume, ***Progress in Convergence: Technologies for Human Wellbeing.*** Bainbridge, William Sims, and Mihail C. Roco (eds.). 2006. New York: New York Academy of Sciences.