MAX-PLANCK-INSTITUT FÜR WISSENSCHAFTSGESCHICHTE

Max Planck Institute for the History of Science

RESEARCH REPORT 1996 - 1997

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INTRODUCTION

The Max Planck Institute for the History of Science (MPIWG) in Berlin was established in 1994, and is part of the network of research institutes sponsored by the Max Planck Society for the Advancement of Science. The Max Planck Institute for the History of Science is dedicated to the development of a theoretically-oriented history of science, which studies the acquisition of knowledge in interaction with its cultural, technical, and social contexts. Although the history of the natural sciences and mathematics is the primary focus of its research program, the Institute also sponsors a number of projects devoted to the history of the human sciences. The research pursued at the Institute aims to develop a "historical epistemology" for the sciences: a historical understanding of the fundamental categories that shape scientific investigation, explanation, evidence, and proof.

The years 1996-97 continued to be years of steep growth for the Institute. By the end of 1997 the number of Research Scholars employed at the Institute had risen from 22 (1995) to 26; in the period 1996-97, 67 predoctoral and postdoctoral fellows and 36 Visiting Scholars from all corners of the learned world enlivened the Institute's research projects, colloquia, and conferences. An increasing number of these visitors came with support from external research institutions, including the Danish Natural Science Research Council, the French Centre National de Recherche Scientifique, the Schweizer National Fonds, the German Alexander-von-Humboldt-Stiftung, the Deutsche Forschungsgemeinschaft (Heisenberg-Programm), and several universities. The Institute has also participated in research collaborations with the Biblioteca Nazionale Centrale, Florence; the Istituto e Museo di Storia della Scienza, Florence; and the Institut für Geschichte der Naturwissenschaften der Ludwig-Maximilians-Universität, Munich. The Institute library has attempted to keep pace with the increase of resident scholars: since 1995 its holdings have grown from 13,000 to 20,000 volumes; these are to be supplemented by several computer data bases compiled in connection with specific research projects and an ambitious scanning project of key manuscripts and primary sources in the history of science. Most significant of all for the Institute's intellectual and institutional development was the addition of a third Department, under the directorship of Hans-Jörg Rheinberger, which officially began its work in January 1997.

Now that all three of the scholarly Departments originally planned for the

Institute are in place and, as the contents of this Report testify in detail, active, the next intellectual and institutional challenge will be one of integration. Although the research reports contained in this volume cover an extraordinary range of topics, from the workings of ancient balances, to scientific travel, to the construction of a virtual physiological laboratory, certain themes recur throughout. These include the historicity and variety of scientific experience, the role of material culture in science, and the historical processes, cognitive and cultural, that create new objects of scientific inquiry. The specific contexts in which these themes currently are being explored by researchers at the Institute span many disciplines and periods; all, however, aim at a more general level of reflection concerning the historical preconditions for the emergence and disappearance of fundamental epistemological categories like "experience" and "object." In 1996-97 several conferences were dedicated to aspects of these themes (see *WORKSHOPS AND CONFERENCES P. 245)*, and in 1999 all three Departments will host an international conference on "Things that Are Good to Think with: Paradigmatic Objects in the Sciences."

In addition to these connecting research themes, four new research initiatives, all scheduled to begin in 1998, will also contribute to the intellectual life of the Institute as a whole. Two of these are five-year independent research groups to be led by outstanding junior scholars; the selection procedure, conducted by an international and interdisciplinary commission of scholars, is already under way. The third is an independent five-year commission established by the Max Planck Society to investigate the history of its predecessor organization, the Kaiser-Wilhelm-Gesellschaft, from 1998 to 2003, concentrating on the National Socialist period (1933-45). This project is the result of a joint initiative by the historically-oriented Max Planck Institutes and the Max Planck Society Archives, and will be located at the Max Planck Institute for the History of Science. Its scholarly advisors are Professor Reinhard Rürup (Technische Universität Berlin) and Professor Wolfgang Schieder (Universität zu Köln); PD Dr. Doris Kaufmann, Research Fellow at the Institute from 1995-97, has been appointed Research Director of the project. Fourth and finally, the Max Planck Institute for the History of Science was awarded one of ten five-year research professorships for junior women scholars of distinction in their fields. Dr. Emma Spary (University of Warwick, U.K.) will take up her professorship in July 1998.

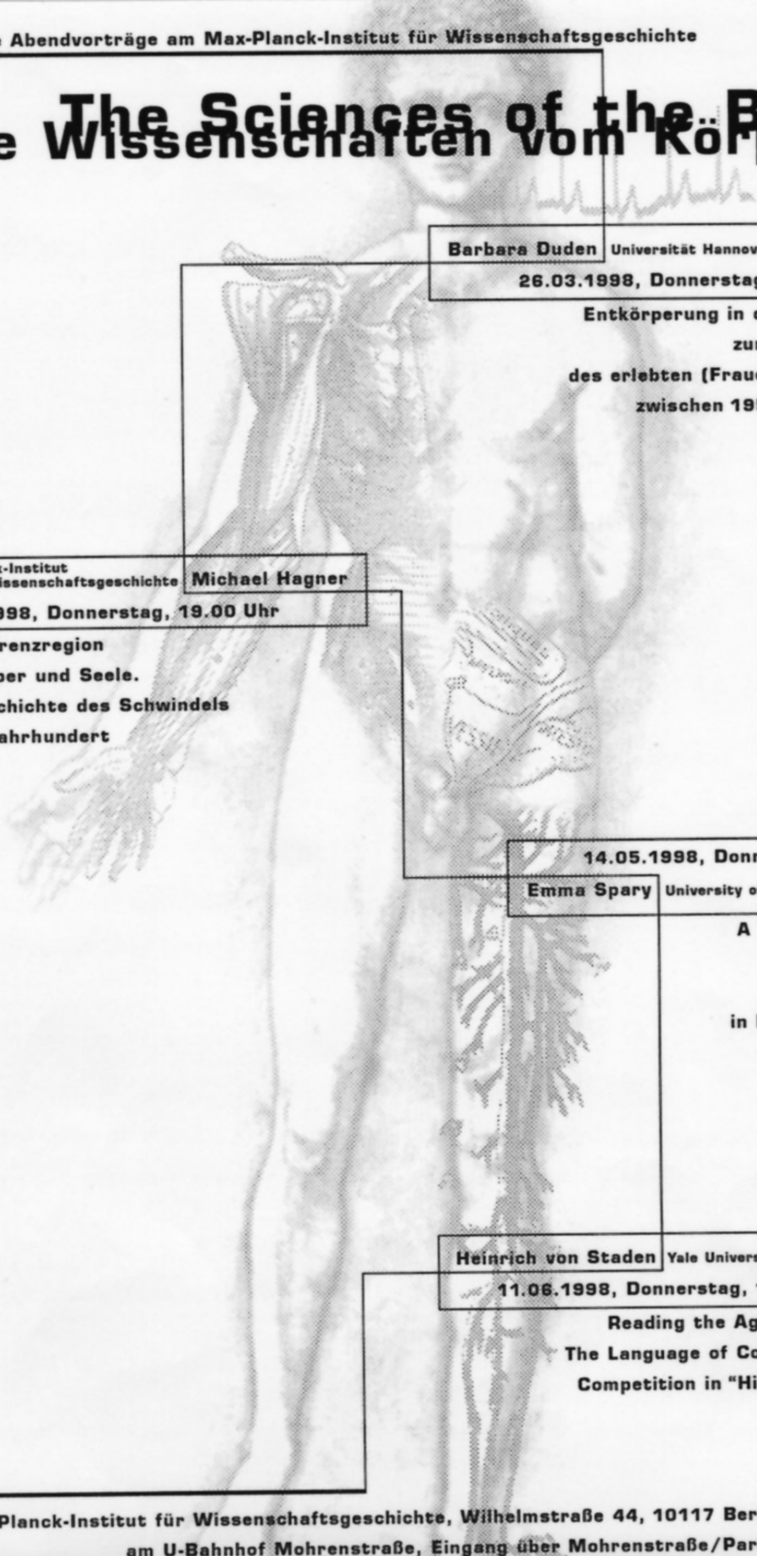
Inquiries of a general nature concerning the Institute and its programs should be addressed to the Research Coordinator:

Mr. Jochen Schneider,
Max Planck Institute for the History of Science
Wilhelmstrasse 44
10117 Berlin Germany
Phone + 4930 226 67 -210, Fax -299
e-mail: jsr@mpiwg-berlin.mpg.de

Further information can be found at the Institute's website
http://www.mpiwg-berlin.mpg.de

Öffentliche Abendvorträge am Max-Planck-Institut für Wissenschaftsgeschichte

The Sciences of the Body
Die Wissenschaften vom Körper



Barbara Duden Universität Hannover

26.03.1998, Donnerstag, 19.00 Uhr

Entkörperung in der Moderne –
zur Geschichte
des erlebten (Frauen-) Körpers
zwischen 1950 und 1990

Max-Planck-Institut
für Wissenschaftsgeschichte **Michael Hagner**

16.04.1998, Donnerstag, 19.00 Uhr

In der Grenzregion
von Körper und Seele.
Zur Geschichte des Schwindels
im 19. Jahrhundert

14.05.1998, Donnerstag, 19.00 Uhr

Emma Spary University of Warwick

A Taste for Learning:
Gastronomy and
the Sciences
in Post-Revolutionary
France

Heinrich von Staden Yale University

11.06.1998, Donnerstag, 19.00 Uhr

Reading the Agonal Body:
The Language of Conflict and
Competition in "Hippocrates"

Max-Planck-Institut für Wissenschaftsgeschichte, Wilhelmstraße 44, 10117 Berlin (Mitte),
am U-Bahnhof Mohrenstraße, Eingang über Mohrenstraße/Parkplatz, Eintritt frei

RESEARCH SCHOLARS AND GUESTS

RESEARCH SCHOLARS

Beurton, Peter J. (Dipl. 1968 [biology], Dr. rer. nat. 1973 [biology], Dipl. 1977 [philosophy] Humboldt-Universität zu Berlin, habil. phil. 1987 [philosophy] Universität Potsdam); research scholar Akademie der Wissenschaften der DDR (1972-1991); research scholar Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1991-1994): research strategies in biological evolutionary theory; modern Darwinism and the philosophy of science (E. Mayr, K. Popper, T. S. Kuhn); genetics, population genetics, the biological species, and reductionism.

Brentjes, Sonja (Dipl. 1973 [mathematics], Technische Universität Dresden, Dr. rer. nat. 1977, Technische Universität Dresden, Dipl. Arabic/ Middle Eastern Studies, Martin-Luther-Universität Halle-Wittenberg, Dr. sc. nat. 1989, Dr. habil. rer. nat. 1991, Karl-Marx-Universität Leipzig); assistant professor, Karl Sudhoff Institute for the history of medicine and science, Karl-Marx-Universität Leipzig (1976-1990); fellowship CNRS, Université VIII, Paris, Saint-Dénis (1991); Rockefeller fellowship, University of Oklahoma, Norman (1991/92); assistant professor, Karl Sudhoff Institute (1992/1993); "integration" fellowship, Humboldt Foundation, Institute for History of Science, Ludwig-Maximilians-Universität München (1993); Feodor Lynen fellowship, Humboldt Foundation, member of the Institute for Advanced Study, Princeton (1994/95); assistant professor, Privatdozentin, Karl Sudhoff Institute (1995/96), visiting professor, Institute for History of Science, Georg-August-Universität Göttingen (1995-96) European travelers to the Middle East (16th-17th centuries) and the sciences in Muslim societies.

Cadden, Joan (B.A. 1965 Vassar College, M.A. 1967 Columbia University, Ph.D. 1971 [history and philosophy of science] Indiana University); assistant professor Harvard University (1971-1976); assistant professor, associate professor, professor Kenyon College (1978-1996), professor University of California at Davis (1996-present): history of medieval scientific and medical ideas on sexuality; medieval scientific arguments in disciplinary, social and political contexts.

Castagnetti, Giuseppe ([philosophy and history] University of Milano), research scholar Max Planck Institute for Human Development and Education, working group Albert Einstein (1990-1995); research scholar Einstein Papers project, The Collected Papers of Albert Einstein, Boston (1989-1996): history of institutions of physics in the 20th century; political and social context of Albert Einstein's activities in Berlin.

Clark, William (Ph.D. [history of science] University of California at Los Angeles, 1986); lecturer, history, UCLA, 1987-88; Lecturer & Mellon Fellow, Bryn Mawr College, 1988-89; lecturer & Kenan Fellow, Columbia University, 1989-91; Akademischer Rat a.Z., Institut für Wissenschaftsgeschichte, Göttingen, 1991-97; early modern German science and academic institutions.

Damerow, Peter (Dr. 1977 [mathematics] Universität Bielefeld, habil. 1994 [philosophy] Universität Konstanz); Max Planck Institute for Human Development and Education: history of science and education, genesis of writing and arithmetic, individual and historical development of cognition, mathematical modelling in the sciences.

Daston, Lorraine (A.B. 1973 Harvard University, Dipl. 1974 University of Cambridge, Ph.D. 1979 [history of science] Harvard University); assistant professor Harvard University (1980-1983) and Princeton University (1983-1986); Dibner Associate Professor Brandeis University (1986-1989); professor Georg-August-Universität Göttingen (1990-1992); professor University of Chicago (1992-1995): history of probability and statistics (16th-19th centuries); history of forms of scientific evidence and objectivity (16th-20th centuries).

Dierig, Sven (Dipl. 1990 [biology], Dr. rer. nat 1995 [neurobiology] Universität Konstanz); postdoctoral fellow Universität Konstanz (1995-1997): history of laboratory physiology in connection with history of technology and urban history; virtual reconstruction of laboratory equipment and historical experiments.

Feldhay, Rivka (1967 B.A. [General History and English Literature] Haifa University; Hebrew University Jerusalem; 1980 Ph.D. [history of science]

Hebrew University, Jerusalem) 1973-80 teaching and research assistant, 1975 master of arts (history of science), 1981-82 instructor at the Department of History Hebrew University Jerusalem; 1984-87 instructor,1987-89 lecturer and since 1990 senior lecturer at the Cohn Institute for the History and Philosophy of Science, Tel Aviv University. History of Science.

Gradmann, Christoph, (M.A. 1987 Universität Hannover, Dr. phil. Universität Hannover 1991 [history]), research scholar Universität Hannover 1991/1992 [history], research scholar Universität Heidelberg 1992-1995 [history of medicine], assistant professor Heidelberg 1995 - [history of medicine]: history of bacteriology, cultural history of science (19th century), medicine and war (19th-20th centuries), theory and history of historical biography.

Graßhoff, Gerd (M.A. 1983, Dr. rer. nat. 1986 [history of science], habil. 1995 [philosophy] Universität Hamburg); Oxford University 1980-81, member of the Institute for Advanced Study Princeton 1987-88, Minerva Associate at Tel-Aviv University 1990-91, Hochschulassistent Universität Hamburg 1988-95, guest professor for philosophy Universität Hamburg 1994-95, chair for the history of science at Georg-August University Göttingen 1997-98: modelling of scientific discovery processes; history of astronomy; methodology of sciences; natural philosophy late 19th and early 20th century.

Hagner, Michael, (Staatsexamen 1986 [medicine], Dr. med. 1987 Freie Universität Berlin, habil. 1994 [history of medicine] Georg-August-Universität Göttingen); research scholar and postdoctoral fellow Freie Universität Berlin (1986-1989); research scholar Medizinische Universität Lübeck (1989-1991) and Georg-August-Universität Göttingen (1991-1995); Heisenberg-fellow (1995-1996): history of epistemic objects in the neurosciences and in teratology (18th-20th centuries); history of experimental cultures (18th-20th centuries).

Hoffmann, Dieter (Dipl. 1972 [physics], Dr. phil. 1976 Humboldt-Universität zu Berlin, Dr. habil. 1989 [history of science] Humboldt-Universität zu Berlin); research scholar Akademie der Wissenschaften der DDR (1976-1991); research scholar Physikalisch-Technische Bundesanstalt (1991-1992); research scholar Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1995): Guest Professor Humboldt-Universität zu Berlin (WS 1996/97), history of physics in the 19th and 20th centuries, esp. institutional history of quantum theory and modern metrology; history of science in the GDR.

Kant, Horst (Dipl. 1969 [physics], Dr. rer. pol. 1973 [history & philosophy of science] Humboldt-Universität zu Berlin); research scholar Humboldt-Universität zu Berlin (1973-1978); research scholar Akademie der Wissenschaften der DDR (1978-1991); research scholar Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1995): history of physics in the 19th and 20th centuries (esp. institutional and social aspects); history of quantum theory and nuclear physics; development of physics in Berlin.

Kaufmann, Doris (Dr. phil. 1983, habil. 1993 [history] Technische Universität Berlin); visiting professor Freie Universität Berlin (1994); visiting professor Universität Tübingen (1994-95); visiting professor Universität Jena (1995); visiting professor Universität Bern (1995-96): modern social and cultural history, history of psychiatry and of cultural anthropology, religious and gender studies.

Klein, Ursula (Dr. phil 1993 [philosophy] Universität Konstanz); postdoctoral fellow Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1993-1995): history and philosophy of laboratory sciences; history of early modern natural philosophy; history of 17th-19th-century chemistry in connection with historical epistemology.

Küttler, Wolfgang (Dipl. 1958 [history] Friedrich-Schiller-Universität Jena, Dr. phil. 1966 Universität Leipzig, Dr. sc. 1976, Professor 1978 [history] Akademie der Wissenschaften der DDR); research scholar (1958-1967) Friedrich-Schiller-Universität Jena and Universität Leipzig; research scholar (1967-1974), head of department (1974-1990), director (1990-1991) Zentralinstitut für Geschichte der Akademie der Wissenschaften der DDR; visiting professor Humboldt-Universität zu Berlin (1981-1990); research scholar Forschungsschwerpunkt für Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1995): theory, methodology and history of historical science, Marxist theory of history, Max Weber research.

Lefèvre, Wolfgang (Dr. phil. 1971 [philosophy], habil. 1977 [philosophy in connection with history of science] Freie Universität Berlin, apl. Professor Freie Universität Berlin [philosophy]): history of science in connection with history of philosophy on the basis of social history; sciences in Greek antiquity; early modern physics and chemistry; history of biology (15th-18th centuries).

Mendelsohn, John Andrew (A.B. 1989 Harvard University, M.A. 1991 Princeton University, Ph.D. 1996 Princeton University); Mellon fellow in the Humanities 1989-94; assistant in instruction Princeton University 1991-92; International Doctoral Research Fellow Social Science Research Council 1992-93; postdoctoral fellow Max Planck Institute for the History of Science 1995-96: life and medical sciences in social context since 1800.

Müller-Hoissen, Folkert, (Dipl. 1980, Dr. rer. nat. 1983, habil. 1993 [physics] Georg-August-Universität Göttingen): general relativity; development and application of modern geometric methods in theoretical physics, history of relativity theory.

Renn, Jürgen (Dipl. 1983 [physics] Freie Universität Berlin, Dr. rer. nat. 1987 [mathematics] Technische Universität Berlin); collaborator and co-editor of Collected Papers of Albert Einstein (1986-1992); assistant, since 1993, associate professor Boston University (1989-1993) [philosophy and history of science, physics]; Simon Silverman Visiting Professor Tel-Aviv University (1993) [history of science]; visiting professor ETH Zürich (1993-1994) [philosophy]; adjunct professor Boston University (since 1994); honorary professor Humboldt-Universität zu Berlin (since 1995) [history of science]: history of early modern mechanics, history of relativity theory; interaction between cognitive and contextual factors in the history of science.

Rheinberger, Hans-Jörg (M.A. 1973 [philosophy], Dipl. 1979 [biology], Dr. rer. nat. 1982, habil. 1987 [molecular biology] Freie Universität Berlin); research scholar Max Planck Institute for Molecular Genetics Berlin (1982-1990); honorary professor (history of biology) University of Salzburg (1989); lecturer (history of science and medicine) University of Lübeck (1990-1994); visiting professor University of Göttingen (1992-1993); Ao. Univ. Prof. (molecular biology and history of science) University of Salzburg (1994-1996): history and epistemology of experimentation, history of the life sciences.

Roux, Sophie (Agrég. 1987 [philosophy], Ph.D. 1996 [history of science] EHESS); fellow École Normale Supérieure (1984-1989); assistant in instruction Université de Paris I (1989-1992); fellow Fondation Thiers (1993-1995); postdoctoral fellow at the Max Planck Institute for the History of Science (1996-1997): early modern physics and its epistemology.

Sauer, Tilman (Dipl. 1990, Dr. rer. nat. 1994 [physics] Freie Universität Berlin, research scholar Max Planck Institute for Human Development and Education Berlin (1990-1995)): history of general relativity.

Schoepflin, Urs (Dipl. 1975 [sociology], Freie Universität Berlin); director of library); scientific information systems, scientific communication, sociology and history of science, scientometrics.

Schüller, Volkmar (Dr. rer. nat. 1972 [physics] Universität Greifswald): research assistant Universität Greifswald (1972-1976); research scholar Akademie der Wissenschaften der DDR (1979-1991); research scholar Forschungsschwerpunkt für Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1994): history of mathematics and physics (16th and 17th centuries).

Sibum, H. Otto, (Dr. rer. nat. 1989 [physics] Carl-von-Ossietzky-Universität Oldenburg) research scientist Department of Physics, Universität Oldenburg (1989-1990); research associate (1991-1993), senior research associate (1994-1995) and affiliated research scholar (since 1996) University of Cambridge, England: history of the physical sciences (18th-century electricity and magnetism, 19th-century electro- and thermodynamics), history of precision measurement and experimentation in relation to knowledge production.

Steinle, Friedrich (Dipl. 1982 [physics], Dr. rer. nat., 1990 [history of science], Universität Tübingen): history of physics (17th-19th centuries); philosophy of science; history and philosophy of experimentation.

Strickland, Stuart (A.B. 1984 [philosophy] Columbia University, A.M. 1989, Ph.D. 1992 [history of science] Harvard University); Walther Rathenau Fellow (1992-93); assistant professor of history, Northwestern University (since 1993); philosophical idealism and experimental science, philosophies of history, literature and science.

Thieffry, Denis (Dipl. 1988 [molecular biology and philosophy of science] and Ph.D. 1993 [theoretical biology] Université Libre de Bruxelles); post-doctoral fellow Université Libre de Bruxelles (1993-1995); assistant professor Universitad Nacional Autónoma de México (1995-1997): history of genetics, embryology and molecular biology (20th century).

Vogel, Klaus A. (Dipl. 1981 [nautical science] Hochschule für Nautik Bremen, Dr. phil. 1995 [history] Georg-August-Universität Göttingen); research scholar Max Planck Institute for History Göttingen (1991-1995): medieval and early modern history; central European humanism; history of cosmography; late medieval and early modern science; history of violence and empathy.

Vogt, Annette (Dipl. 1975 [mathematics] Karl-Marx-Universität Leipzig, Dr. rer. nat. 1986 Karl-Marx-Universität Leipzig); research scholar Akademie der Wissenschaften der DDR (1975-1991); coordinator Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1994): history of mathematics; history of mathematics in Germany in the 19th and 20th centuries; history of the relationships between Russia/Soviet-Union and Germany in the 19th and 20th centuries in mathematics; history of Jewish scientists in Germany; history of female scientists in the 19th and 20th centuries.

Wahsner, Renate (Dipl. 1961, Dr. phil. 1966 [philosophy] Humboldt-Universität zu Berlin, Dr. sc. 1978 [philosophy] Akademie der Wissenschaften der DDR, professor [history of science] Akademie der Wissenschaften der DDR (1987); research scholar Humboldt-Universtität zu Berlin (1963-1970); research scholar Akademie der Wissenschaften der DDR (1974-1991); research scholar Forschungsschwerpunkt Wissenschaftsgeschichte und Wissenschaftstheorie, Berlin (1992-1995); professor Universität Potsdam: history of philosophy in connection with history of science; epistemological fundamentals and problems of physics; German idealism; classical natural philosophy.

Weinig, Paul (Dr. phil., 1994 [German philology], Johann Wolfgang Goethe-Universität Frankfurt/M.); teacher at the Goethe-Institut Frankfurt/M. (1991-1995); history of medieval mechanics in Arabic and Latin sciences; history of humanism in Germany (1400 to1600); science and history of medieval manuscript-writing; history and methodology of language teaching (DaF).

Wunderlich, Falk (M.A. 1995 [philosophy] Freie Universität Berlin); Kant's natural philosophy.

VISITING SCHOLARS AND RESEARCH FELLOWS

Prof. Dr. Mohamed Abattouy, University of Fez, visiting scholar (July 1, 1996 - October 25, 1996 and July 1 - December 31, 1997)

Hanne Andersen, Universität Konstanz, predoctoral research fellow (February 1, 1996 - August 15, 1996)

Prof. Dr. Mitchell G. Ash, University of Iowa, visiting scholar (May 13, 1996 - December 15, 1996 and June 1, 1997 - September 30, 1997)

Dr. Jutta Berger, Technische Universität Berlin, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Conevery Bolton, Harvard University, predoctoral research fellow (June 15, 1996 - July 1, 1996)

Dr. Christophe Bonneuil, Université de Paris 7, predoctoral research fellow (August 1, 1996 - February 28, 1997) and CNRS postdoctoral research fellow (March 1, 1997 - February 28, 1998)

Francesca Bordogna, University of Chicago, predoctoral research fellow (April 1, 1996 - December 15, 1996)

Prof. Dr. Marie-Noëlle Bourguet, Université de Paris 7, visiting scholar (September 22, 1995 - Januar 31, 1996 and September 20, 1996 - October 6, 1996)

Christina Brandt, Georg-August-Universität Göttingen, predoctoral research fellow (October 1, 1996 - December 31, 1998)

Dr. Stéphane Callens, Université de Lille 1, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Dr. Michele Camerota, Università di Cagliari, postdoctoral research fellow (November 16, 1995 - February 15, 1996 and July 8, 1996 - October 8, 1996)

Dr. Yoonsuhn Chung, Seoul, visiting scholar (May 1, 1996 - April 30, 1997 and October 1, 1997 - December 31, 1997)

Nani Clow, Harvard University, predoctoral research fellow (February 1, 1996 - August 31, 1996)

Alix Cooper, Harvard University, predoctoral research fellow (July 1, 1997 - August 31, 1997

Dr. Serafina Cuomo, Christ's College, Cambridge, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Dr. Michael Dettelbach, Smith College, Northampton, Alexander von Humboldt fellow (January 1, 1997 - June 30, 1997

Prof. Dr. Bruce S. Eastwood, University of Kentucky, visiting scholar (July 1, 1997 - September 30, 1997

Dr. Berna Kılıç Eden, University of Chicago, predoctoral research fellow (September 1, 1995 - December 31, 1996), postdoctoral research fellow (September 1, 1997 - August 31, 1998)

Dr. Elisabeth Emter, Freie Universität Berlin, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Prof. Dr. Robert Englund, University of California at Los Angeles, visiting scholar (September 10, 1997 - September 24, 1997)

Prof. Dr. Raphael Falk, The Hebrew University of Jerusalem, visiting scholar (September 20, 1996 - October 20, 1996 and July 15, 1997 - September 15, 1997)

Dr. Raymond Fredette, Fitch Bay, Canada, visiting scholar (November 25, 1997 - December 5, 1997)

Prof. Dr. Gideon Freudenthal, Tel-Aviv University, visiting scholar (June 1, 1996 - July 7, 1996 and July 25, 1997- August 25, 1997)

Dr. Ofer Gal, University of Pittsburgh, postdoctoral research fellow (October 1, 1996 - December 31, 1997)

Dr. Peter Geimer, Philipps-Universität Marburg, postdoctoral research fellow (June 1, 1997 - December 31, 1998

Dr. Martin Gierl, Georg-August-Universität Göttingen and Max-Planck-Institut für Geschichte, Göttingen, postdoctoral research fellow (October 1, 1995 - October 31, 1996)

Prof. Dr. Hubert Goenner, Georg-August-Universität Göttigen, visiting scholar (November 1, 1995 - February 29, 1996 and August 7, 1996 - August 30, 1996)

Prof. Dr. Catherine Goldstein, Université de Paris Sud, visiting scholar, CNRS fellow (July 7, 1996 - September 30, 1996 and October 17, 1997 - November 9, 1997)

PD Dr. Michael Hagner, Georg-August-Universität Göttingen, visiting scholar, Heisenberg fellow (November 1, 1995 - December 31, 1996), research scholar since January 1, 1997 (see *p. 19*)

Dr. Ton van Helvoort, Maastricht University, postdoctoral research fellow (October 1, 1997 - November 30, 1997)

Prof. Dr. Frederic L. Holmes, Yale University, visiting scholar (June 15, 1996 - July 15, 1996)

Dr. Wallace Hooper, Bloomington, Indiana, visiting scholar (August 11, 1997 - August 31, 1997)

Prof. Dr. Blahoslav Hru¡ka, Oriental Institute and the Charles University, Prague, visiting scholar (August 1, 1996 - August 31, 1996 and August 1, 1997 - September 30, 1997)

Dr. Sarah Jansen, predoctoral research fellow (January 1, 1997 - July 31, 1997) and postdoctoral research fellow (August 1, 1997 - September 30, 1999)

Dr. Edward Jurkowitz, University of Toronto, postdoctoral research fellow (December 1, 1995 - December 31, 1996 and June 1, 1997 - August 15, 1997)

Shaul Katzir, Tel-Aviv University, predoctoral research fellow (June 1, 1996 - July 31, 1996 and March 1, 1997 - April 30, 1997)

Prof. Dr. Lily Kay, Massachusetts Institute of Technology, visiting scholar (May 5, 1997 - August 5, 1997)

Dr. Alexei Kojevnikov, Institute for History of Science and Technology of the Russian Academy of Sciences, Moscow, postdoctoral research fellow (April 1, 1996 - September 30, 1996)

Cheryce Kramer, University of Chicago and Wellcome Institute London, predoctoral research fellow (September 1, 1995 - October 15, 1996)

Dr. Morgane Labbé, Laboratoire de Démographie Historique, École des Hautes Études en Sciences Sociales, Paris, CNRS postdoctoral research fellow (October 1, 1996 - December 31, 1997)

Dr. sc. Karlheinz Lüdtke, Friedrich-Schiller-Universität Jena, visiting scholar (July 1, 1997 - January 31, 1998)

Dr. Christoph Lüthy, Harvard University, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Dr. Alexandre Mallard, École Nationale Supérieure des Mines de Paris, Centre de Sociologie de l'Innovation, postdoctoral research fellow (October 1, 1995 - September 30, 1996)

Christopher Martin, University of Pittsburgh, predoctoral research fellow (June 23, 1997 - July 20, 1997)

Dr. Michael May, Universität Hamburg, postdoctoral research fellow (April 1, 1997 - March 31, 1998)

Dr. J. Andrew Mendelsohn, Princeton University, postdoctoral research fellow (October 15, 1995 - December 31, 1996), research scholar since January 1, 1997 (see *p. 21*)

Dr. Alexandre Métraux, Otto Selz Institut, Universität Mannheim, visiting scholar (September 1, 1997 - February 28, 1998)

Dr. Gabriele Metzler, Eberhard-Karls-Universität Tübingen, postdoctoral research fellow, (March 1, 1996 - April 30, 1996)

Prof. Dr. Helmut Müller-Sievers, Northwestern University Evanston, visiting scholar (June 19, 1997 - July 31, 1997)

Dr. Staffan Müller-Wille, Universität Bielefeld, predoctoral research fellow (May 1, 1996 - November 30, 1997), postdoctoral research fellow since December 1, 1997

Dr. Sybilla Nikolow, Centre de Recherche de l'Histoire Science et Technique, Paris, postdoctoral research fellow (September 15, 1995 - October 31, 1996)

Brian Ogilvie, University of Chicago, predoctoral research fellow (September 1, 1995 - July 31, 1996)

Prof. Dr. Dorinda Outram, University of Cambridge and University College Cork, visiting scholar (September 1, 1995 - August 31, 1996 and June 1, 1997 - September 30, 1997)

Prof. Dr. Katharine Park, Wellesley College, visiting scholar (September 11, 1995 - January 31, 1996 and June 10, 1996 - June 28, 1996)

Ohad Parnes, Tel-Aviv University, research scholar (until June 30, 1997), predoctoral research fellow (July 1, 1997 - June 30, 1998)

Prof. Dr. Trevor Pinch, Cornell University, visiting scholar (May 15, 1997 - August 31, 1997)

Prof. Dr. Gianna Pomata, University of Minnesota/Università di Bologna, visiting scholar, (January 1, 1997 - March 31, 1997)

Dr. Albert Presas i Puig, Technische Universität Berlin, Walther Rathenau postdoctoral research fellow (September 1, 1995 - August 31, 1996) postdoctoral research fellow (September 1, 1996 - August 31, 1997)

Dr. S. Ravi Rajan, University of California, Santa Cruz, Walther Rathenau postdoctoral research fellow (January 1, 1997 - September 30, 1997)

Dr. Annelore Rieke-Müller, Universität Oldenburg, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Prof. Dr. James Ritter, Université de Paris 8, visiting scholar (July 7, 1996 - September 30, 1996)

Dr. Sophie Roux, École des Hautes Études en Sciences Sociales, Paris, postdoctoral research fellow (October 1, 1996 - September 30, 1997), research scholar since October 1, 1997 (see *p. 22*)

Prof. Dr. Theodore R. Schatzki, University of Kentucky, visiting scholar (October 1, 1997 - December 31, 1997), Alexander von Humboldt Fellow (January 1, 1998 - March 31, 1998)

Dr. Britta Scheideler, Universität Bochum, postdoctoral research fellow (October 1, 1995 - September 30, 1997)

Dr. Jutta Schickore, postdoctoral research fellow (April 1, 1997 - March 31, 1999)

Dr. Arne Schirrmacher, University of California at Berkeley, postdoctoral research fellow (January 1, 1996 - August 31, 1996)

Dr. Henning Schmidgen, Freie Universität Berlin, postdoctoral research fellow (March 1, 1997 - February 28, 1999)

Dr. Libby Schweber, Princeton University, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Prof. Dr. Marcel Sigrist, École Biblique et Archéologique Française de Jérusalem, visiting scholar (June 1, 1997 - August 31, 1997)

Dr. Skúli Sigurdsson, Harvard University, research scholar (until December 31, 1996), postdoctoral research fellow (August 1, 1997 - July 31, 1998)

Christopher Smeenk, University of Pittsburgh, predoctoral research fellow (June 23, 1997 - July 20, 1997)

Prof. Dr. John Stachel, Boston University, visiting scholar (July 1, 1996 - July 31, 1996 and July 7, 1997 - July 13, 1997)

Dr. Richard Staley, University of Melbourne, postdoctoral research fellow (October 1, 1996 - September 30, 1997)

Prof. Dr. Zeno G. Swijtink, Indiana University Bloomington, visiting scholar (October 1, 1995 - September 30, 1996)

Prof. Dr. Ken'ichi Takahashi, Kyushu University, Fukuoka, visiting scholar (June 2, 1997 - June 20, 1997)

Dr. Bernhard Thöle, Freie Universität Berlin, Lorenz Krüger postdoctoral research fellow (November 1, 1995 - August 31, 1997) postdoctoral research fellow (September 1, 1997 - October 31, 1998)

Carsten Timmermann, University of Manchester, predoctoral research fellow (March 3, 1997 - May 31, 1997)

Prof. Dr. Sabetai Unguru, The Cohn Institute for the History and Philosophy of Science and Ideas, Tel-Aviv University, visiting scholar (September 1, 1997 - February 28, 1998)

R. André Wakefield, University of Chicago, predoctoral research fellow (April 1, 1996 - August 31, 1996)

Dr. Eric Watkins, Virginia Polytechnic Institute and State University, Lorenz Krüger postdoctoral research fellow (September 15, 1996 - December 15, 1996)

Dr. Gabriele Werner, Walther Rathenau postdoctoral research fellow (October 1, 1995 - September 30, 1996)

Prof. Dr. M. Norton Wise, Princeton University, visiting scholar (June 1, 1996 - June 30, 1996 and June 15, 1997 - July 15, 1997)

Michael Witmore, University of California at Berkeley, predoctoral research fellow (June 15, 1997 - August 15, 1997)

PROJECTS OF THE RESEARCH GROUP HEADED BY JÜRGEN RENN (DEPARTMENT I)

The work of the research group headed by Jürgen Renn is primarily dedicated to the understanding of the historical processes of structural changes in systems of knowledge. This goal comprises the reconstruction of central cognitive structures of scientific thinking (both first-order structures such as those associated with the concept of force, and second-order structures such as those associated with the notions of experiment and theory, *e.g.* the concept of causality), the study of the dependence of these structures on their experiential basis and on their cultural conditions (in particular on instruments and external representations), and the study of the interaction between individual thinking and institutionalized systems of knowledge. Thus, the interaction of three major factors in the development of scientific thinking has to be reconstructed: (1) the experiential basis of scientific thinking in a given period (including technical practice as well as scientific experiments); (2) the scientific means and external representations employed (including language, graphical representations, and formalisms); and (3) the cognitive organization and social conditions of the structures of scientific knowledge and thinking. This theoretical program of an historical epistemology is the common core of the various investigations and research projects pursued and planned by the research group.

Historical epistemology in this sense requires an integration of cultural and cognitive studies of science. Methods and results of the cognitive sciences, of the structuralist tradition of psychology as well as of philosophical theories of concept development, can help to compensate for theoretical deficits in the history of science in a narrow sense, in particular when it comes to explaining thought processes. The history of science can, inversely, contribute to overcoming the limitations of theoretical approaches whose claims have not yet been systematically confronted with the results of historical research. However, such an historical epistemology would not only have to add the models and scientific means of the social and cognitive sciences to the traditional methodological arsenal of the history of science, but must also develop a theoretical coherency that goes beyond exploiting historical case studies to flesh out preconceived philosophical opinions.

In order to achieve a broad historical basis for dealing with these theoretical problems and to cover at least some of the major developmental steps in the history of science, research has been inaugurated or is planned in four different areas: the emergence of formal sciences such as mathematics; the emergence of empirical sciences such as physics, chemistry, and biology; structural changes in sciences with developed disciplinary structures and integrated theoretical foundations, such as the transition from classical to modern physics; and the role of reflective thinking and second-order concepts in science.

Present research in these areas focuses on two central projects: (1) the relation of practical experience and conceptual structures in the emergence of science, and (2) studies in the integration and disintegration of knowledge in modern science. Both projects cover several of the above mentioned research areas. The first project seeks to understand the emergence of fundamental concepts of empirical sciences as a result of reflecting practical experiences, prior to the period in which experiments became the dominating experiential basis of science. The second project studies transformation processes of knowledge organization, in particular in developed sciences, and the role of fundamental concepts (both of the first and second order) in such processes. The activities of the two main projects have been supplemented by a project dedicated to the reconstruction of the epistemic dimensions of discovery processes, with the aim of developing dynamic models for specific discoveries in the history of science. A further area of work is dedicated to developing advanced tools for an historical epistemology. In this area, new electronic media are used both to explore new ways of granting access to the empirical basis of the history of science (electronic archives) and to model processes of discovery in science.

Project 1: The Relation of Practical Experience and Conceptual Structures in the Emergence of Science - Mental Models in the History of Mechanics

Jürgen Renn (responsible), in cooperation with Mohamed Abattouy, Jochen Büttner, Peter Damerow, Ofer Gal, Wolfgang Lefèvre, Simone Rieger, Volkmar Schüller, Paul Weinig

General Goals of the Project

The goal of the project is to study long-term developments of scientific knowledge and their causes. The project is focused on mechanics as a part of science with extraordinary significance for the development of science in general. More than other disciplines, mechanics has a continuous tradition from its origins in Antiquity to the elimination of fundamental categories of mechanics by modern physics. Presently, the scope of the project is restricted to the time period from Antiquity to the emergence of classical mechanics in early modern times. It is, however, intended to follow up the research questions of the project up to the twentieth century.

The history of mechanics illustrates that scientific knowledge long predates the emergence of an experimental tradition. Mechanics, or at least certain parts of it, had already achieved the status and the form of a science in Antiquity. Just as did astronomy and mathematics, it played the role of a model science in the Scientific Revolution. It provided basic concepts shared across all disciplines of science in the period of classical physics and chemistry. Eventually it was substituted in this function by generalized concepts of modern science such as the concepts of relativity and quantum theory. Mechanics in the traditional sense became instead a specific subdiscipline of science as we know it today.

The remarkable longevity of mechanics has given rise to speculations that the experiential basis of such scientific knowledge must be of a special kind, distinct from that of other sciences which emerged much later. It has been claimed, for instance, that knowledge in mechanics or in mathematics is rooted in an essentially universal everyday experience or even based on *a priori* structures of thinking. These and other speculations involve a very restrictive notion of experience, however. They exclude the by no means universal experience that human beings acquire in a historically specific material environment when dealing, for instance, with the technology of their times. Therefore, the project is particularly focused on the historical reconstruction of such collective, practical experiences and their influences on the structure and content of scientific knowledge. Its main goal is to study the role of practical experience for the emergence and development of fundamental scientific concepts of mechanics, such as those of space, matter, force, time, and motion, and to reconstruct the patterns of explanation for which they were used.

Any investigation of long-term developments of structures of knowledge and thought in the history of cognition is compelled first to answer the questions of whether such long-term developments exist at all, and what kind of developments are considered to be relevant to the intended investigation.

Concerning the first question, historians of science are generally convinced that such developments do, indeed, exist, and can be identified. Science can be conceived of as the result of a coherent process beginning with its emergence in ancient Greek culture, showing some stagnation in the Middle Ages, being revived in the Renaissance and developed into modern, empirically based science by first the Copernican and later the Newtonian revolution. The nature of such long-term developments, however, remained widely obscure. From the point of view of traditional historiography, changes in the systems of scientific knowledge are reduced to individual achievements of the heroes of transitional periods such as that of the Copernican revolution. Long-term developments of systems of knowledge seem to be only marginal manifestations of the aggregation of such individual contributions and the transmission of these contributions by scientific texts. In spite of ground-breaking innovations in the historiography of science, long-term developments are still studied only rarely.

The present project is based on the assumption that long-term developments of scientific knowledge are central to the history of science. They are widely determined, first, by the entirety of the basic techniques which guarantee the continuity of a particular culture; second, by the means of representing the knowledge inherent in the invention, production, and use of these techniques. These means – and not only the representation of mechanical knowledge in theoretical texts – guarantee its historical transmission from one generation to the other. According to these assumptions, the study of long-term developments of structures of knowledge and thought cannot be restricted to the investigation of scientific discoveries. It rather must include a wider *range of knowledge systems*, a revised *historical definition* of mechanics, and *analytical categories* which make it possible to differentiate scientific concepts not only according to their intrinsic functions but also according to their roots in practical experiences.

As far as the range of knowledge is concerned, the goal of the project inevitably requires that the analysis include those inherited or newly invented techniques and practices which may determine the stability and change of knowledge, under the circumstances of any particular culture at any particular time. While the general relevance of practical experiences for the emergence and development of knowledge systems is obvious, the detailed and systematic reconstruction of the role of practical experience for the development of cognitive structures in science has hardly begun.

Such a reconstruction is certain to encounter numerous difficulties. Practical knowledge is in part tacit knowledge, in the dual sense that it may involve non-verbal experiences such as acquired skills, as well as including experiences which can be verbally expressed but were only orally communicated. An additional difficulty arises from the way in which practical knowledge is usually transmitted. For instance, in spite of important innovations, the tradition of canonical solutions was a characteristic feature of practical mechanics at least until the fifteenth century. To the extent that continuity is achieved essentially by copying well-established model solutions, the practitioners' knowledge necessary to create such solutions often escapes historical reconstruction.

It is an essential characteristic of the research activities in this project that not only the *explicit* mechanical knowledge as it is represented in scientific theories and arguments is studied. The attempt is rather to reconstruct both explicit knowledge and the knowledge *implicit* in the productive use of technology, a common precondition of both science and technology.

The methodological instruments of traditional history of science, such as narrative descriptions, are, however, largely inadequate for the concise analysis of such cognitive implications of practical experiences. An alternative is provided by those methods and analytical tools of cognitive science and of developmental psychology which have been developed specifically for the description and explanation of subscientific and implicit knowledge structures. In particular, the methodology of reconstructing domain-specific mental models from the analysis of activities and of reconstructing default attributions from underdetermined inferences is employed in the project.

Mechanics is commonly understood as a structured system of propositions, in accordance with its definition as a subdiscipline of classical physics. According to this understanding, the historical development of mechanics essentially must be considered as an accumulation of knowledge of laws represented by concepts, propositions and general theorems. This view thus complies with an important characteristic of developing knowledge systems in general, as well as with the body of mechanical knowledge in particular. Some laws, such as the law of the lever, have been used to explain mechanical phenomena since the early stages of the discipline's development and remain important laws in mechanics. As the discipline developed, the body of mechanical knowledge increasingly was supplemented by the discovery of such new laws as those of gravitation or conservation, as, for instance, the law of energy conservation.

This process of accumulation has to be studied in any case, but it represents only one aspect of the historical development of mechanics. Additional aspects which require investigation include changes in the structure of systems of mechanical knowledge, as well as changes in the relation of mechanical knowledge to the solutions of practical problems in technology and everyday life.

Because of such changes, universal definitions of mechanical knowledge have only limited validity when applied to long-term developments in the history of mechanics. The project is therefore based on a *historical definition* of mechanical knowledge that differentiates among partially incompatible systems of mechanical knowledge linked by structural transformations and changes of paradigmatic objects, objects which mediate between theorems and principles on the one hand, and practical experiences and technology on the other. Such paradigmatic objects play a crucial role in the transformation of knowledge structures. Objects such as the balance, the lever, simple machines and devices, the inclined plane, pneumatics, projectile motion, collisions of bodies, springs and oscillators dominated technical as well as theoretical efforts in certain periods, and led to the construction of general mental models which structured mechanical knowledge.

A basic structural transformation which fundamentally altered the meaning of a number of concepts and propositions was the transition from the Aristotelian distinction between mechanics and physics to the integration of mechanics and physics in the Middle Ages. Aristotelian physics dealt primarily with natural motions, whereas Aristotelian mechanics dealt with forced motions. Mechanics and physics were eventually integrated through the construction of a mental model of the interaction of moving bodies which was applicable to both types of motions. This model was essentially based on the assumption that moving forces (impetus) could be impressed into the movables and could be transferred from one to the other.

The relation between practical experiences and conceptual structures as it is assumed in the project requires consideration of a further theoretical dimension of mechanical knowledge, corresponding to different relations of concepts and propositions of mechanics to their origins. This, in turn, requires the introduction of *analytical categories* to classify the contents of knowledge systems according not to their internal functions but to the external conditions of their emergence. In particular, several concepts of mechanics used for the explanation of mechanical phenomena had anthropomorphic origins, concepts such as force, impetus, resistance, atoms, etc. The paradigmatic objects of the emerging mechanical knowledge, however, brought about a different type of concept which obviously played a crucial role in the development of mechanics, namely, instrumental concepts such as metric time, center of gravity, positional weight etc. Mental models based on such concepts explain nature not in terms of human action but rather in terms of machines and mechanical arrangements. The application of this type of categorical distinctions, relating concepts and propositions of mechanics to the conditions of their emergence, is used in the project to reconstruct the interaction of conceptual structures and practical experiences which finally led to the emergence of classical mechanics.

Project Design

As the sources relevant to the study vary widely in terms of type and time periods, many different methods of analysis and ways of drawing conclusions concerning long-term developments regarding the contents and structures of mechanical knowledge are required. Accordingly, research activities related to the project tend to be organized specifically for the case in question. Nevertheless, a general agenda of the project has been worked out in order to coordinate individual research activities and to serve as a general guide.

— *Data collection and electronic data acquisition*: In order to cover a substantial part of the historical sources related to the development of mechanics, a survey of these sources is being prepared. Relevant texts and images are described by abstracts, and texts transcribed and translated if necessary. The sources are being prepared through representation in electronic form for computer-assisted analyses.

— *Data analysis*: Sources used in the project first are analyzed separately by reconstructing the contents and the structures of the mechanical knowledge they represent. Three types of reconstructions are employed. They aim first, at general assumptions on motion and mechanical causations of motion which represent *universal knowledge* in general or within a particular historical setting; second, at the *knowledge of practitioners*; and, third, at *scientific knowledge*. The identification of general assumptions is based primarily on the results of anthropological and psychological research, applied to particular contents and structures of mechanical knowledge. The identification of the knowledge of practitioners is based on the reconstruction of their professional activities and the transmission of their professional knowledge by participation and interaction. The identification of structures and contents of scientific knowledge is based on the analysis of texts applying philological, logical and mathematical methods. This analysis is facilitated by the fact that mechanical knowledge was represented as early as Antiquity by formally structured texts using technical terms and explicit principles and propositions, locally ordered by deductive arguments or even globally ordered by axiomatic theories.

— *Documentation*: The results of data analysis are documented using databases including classifications of concepts and relations between them (propositions, theorem, principles, etc.) as well as glossaries to provide context information.

— *Reconstruction of mental models*: Based on the results of the reconstruction of contents and the structures of mechanical knowledge, the mental models are identified which determine the apprehension of mechanical phenomena universally or in a specific way in different historical settings, and which structure the various systems of mechanical knowledge. This identification is based on an explicit definition of the concept of mental models and on the development of instruments for their theoretical representation.

— *Reconstruction of historical developments of knowledge structures:* Long-term developments of mechanical knowledge are described in terms of the stability and change of mental models in the course of history and their interaction with specific historical contexts. This reconstruction presupposes the identification of mechanisms of historical transmission and the determination of the interaction of intrinsic with external conditions.

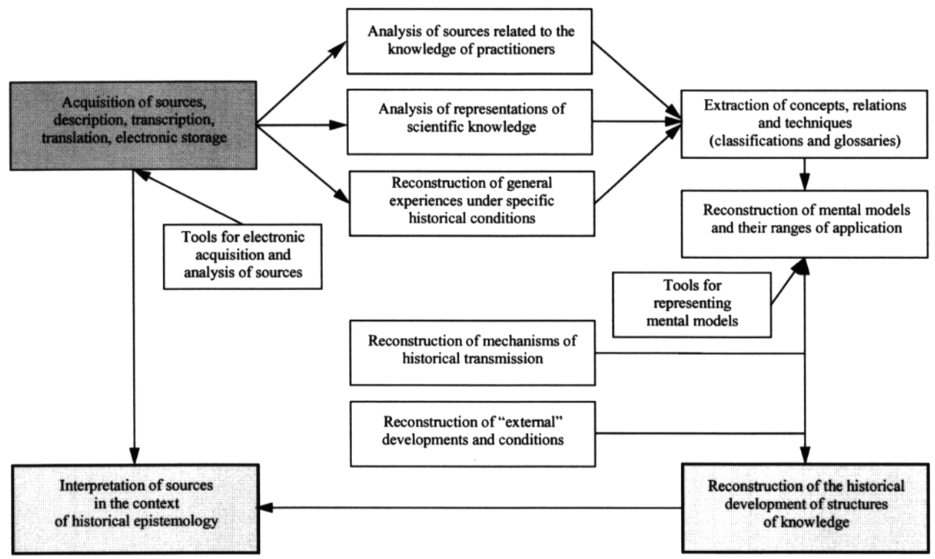
— *Reinterpretation of sources*: The validity of the results finally will be examined by reinterpreting the sources in the context of the long-term developments determined by the research in the course of the project.

For several steps of this research procedure, electronic tools are being developed which facilitate a computer-assisted analysis of text corpora in a reasonable time period. The development of these tools is described separately in the section *"DEVELOPMENT: ELECTRONIC RESEARCH TOOLS AND DATABASES," p. 107.*

Mental Models in History of Mechanics

Longitudinal Study of the Historical Development of the Structures of Mechanical Knowledge

Project Overview



Present State of the Work

The project already was reported on in the Institute's Annual Report 1995. In the meantime, the project formally has been established according to the project design outlined above. It will become clear in the following sections that the initial activities described in the previous report have in part not been pursued further, and in part set the foundation for the established project and have been continued and expanded. In addition, several new activities will be reported for the first time.

A considerable part of the research and development activities planned has already been completed in part or to a large degree. The preparatory work of making texts electronically available for computer-assisted analyses, comparisons, and interpretations has progressed, although still focusing primarily on the theoretical texts on mechanics. The most important ancient and medieval sources for studying the development of mechanics have been scanned or typed into the computer in the original language and in English translation. The same is true for the most relevant sources related to the latest period investigated in the present project: the creation of a deductive system of mechanics by Galileo. The situation is, however, different for the historical period between these two periods. In particular, the rich sources from the sixteenth century are as yet electronically accessible only in small part.

Contrary to what was originally intended, sources from the Arabic text tradition are now also included. These sources are presently being transcribed and translated.

Various analyses and interpretations, as well as comparisons of the texts on mechanics, were performed as soon as the progress of the preparatory work allowed. The preliminary results of these activities will be the main content of the following sections of the report. Systematic work on general or universal cognitive preconditions of the structures of mechanical knowledge has been initiated only now and will not be included in the following report. The collection of sources on the knowledge of practitioners and their interpretation is also still in a rudimentary state. Some results on the construction and use of balances will be reported.

Current Research Activities Related to "The Relation of Practical Experience and Conceptual Structures in the Emergence of Science"

The Structure of Ancient Sources of Mechanics

Peter Damerow, Jürgen Renn and Paul Weinig

The Ancient Greek texts on mechanics are analyzed in order to reconstruct the emergence and developments of the first scientific representations of mechanical knowledge and the relation to mechanical knowledge in general available at that time. First, it is determined what contents of mechanics are represented and how these contents are conceptualized by technical terms. These contents are compared with the technological knowledge of the time. Second, the formal structures of the representations are analyzed and the cognitive operations which structure the mechanical knowledge are identified.

Greek texts on mechanics are among the oldest texts which document the application of the deductive method to what would later become an object of physics. Four of these texts date into the Hellenistic period or even earlier. The oldest is attributed to Aristoteles but was probably written by one of his disciples. Two texts are attributed to Euclid. One text was written by Archimedes. Aristoteles' *Physics* is also relevant since it serves as background for some of the other texts. Some more comprehensive treatises or commentaries date into Late Antiquity, in particular, treatises on mechanics by Heron and Pappos and a commentary by Eutocios.

The analysis of the oldest available sources nearly has been completed, but the Greek terminology must still be checked since none of the existing analyses translated this terminology consistently. It turns out that these texts document not only the early history of mechanics, but also stages of the development of the deductive method which later became characteristic of all disciplines of physics and a paradigm of scientific theory in general.

Further work will focus on the analysis of ancient technology in order to determine what knowledge is presupposed by this technology or emerges from its application. Moreover, the analysis of ancient sources of mechanics will be extended to the texts from Late Antiquity. In contrast to the early texts, these later texts deal more systematically with the contemporary technology.

Concerning the *contents* of the texts analyzed, the most important result so far is that all texts are centered on just one mechanical theorem, the law of the lever. (The Pseudo-Aristotelian text, which is with all likelihood the oldest, plays a special role since it deals only with a precursor of the law of the lever. This precursor, however, intuitively implies the law itself in the framework of Aristotelian physics.) Thus the early theoretical texts are extremely poor in comparison to the rich technological knowledge available at that time. The theoretical core of the texts depends exclusively on experiences with the balance, which provided an explanation for the mechanical principle according to which greater forces can be produced by smaller ones. The balance served as a mental model which was used in order to explain why and how various mechanical devices could be used for this purpose. Some applications of this model turned out to be rather sophisticated, as, for instance, an iterated application based on the idea that a balance may itself be attached to a balance as a weight. Sophisticated abstractions from this model emerged, in particular, the general concept of the center of gravity from the concept of the suspension of a balance.

The dominance of a mental model based on the balance in the ancient theoretical texts on mechanics raises two questions which remain open and must be addressed as the project continues. First, it must be investigated whether a corresponding pattern of explanation also dominated the much richer body of technological knowledge at that time. Second, analysis must investigate when and how a richer body of mechanical knowledge reached the level of theoretical reflection.

Concerning the *formal structure* of the representation of mechanical knowledge, according to our analysis, the texts of the oldest period show the full range from the origins of deductivity to sophisticated deductive systems. All four texts apply the deductive method, but only three of them already follow the Euclidian scheme, including the formal explication of axioms and propositions to be proven.

The Pseudo-Aristotelian text again is an exception here. It contains only one extensive proof of the main proposition: an *a priori* proof lacking any explicitly stated axioms or preconditions. Furthermore, it contains several one-step deductions resulting from the repeated application of the same mental model to several mechanical devices including balances, rudders, wedges, and beams.

The other texts, which exhibit a more developed deductive structure, reveal yet another differentiation. On the one hand, deductivity is used to introduce Aristotelian physics as a foundation for proofs in mechanics. In this case, axioms can show a very sophisticated form due to technical reasons. Axioms are used, on the other hand, to justify mechanical knowledge by seemingly evident, simple experiences with the objects of the theory.

The Development of Balances and the Law of the Lever

Peter Damerow, Jürgen Renn and Paul Weinig

Balances are investigated in order to reconstruct what mechanical knowledge practitioners needed for their invention, production, and usage. In particular, it is being studied whether the invention of balances with unequal arms was a consequence of the discovery of the law of the lever, or whether, conversely, the discovery of the law of the lever was a consequence of the invention of the balance with unequal arms. For this purpose, all extant and accessible balances from the time of the emergence of ancient mechanics, in particular the rich findings in Pompeii and Herculaneum, are examined and analyzed with regard to cognitive prerequisites of the details of their construction.

Even an initial survey of the sources indicates that the long-term development of techniques related to the use of balances shows surprising peculiarities. The balance with equal arms is a very early achievement. It is attested both in Egypt and Babylonia as early as the middle of the third millennium B.C., it also existed in China, probably before the beginning of the first millennium B.C. In all cases the result was a developed metrology of weights, but nothing resembling the typical abstractions of mechanical concepts. In the middle of the second half of the first millennium, the first indications of the usage of balances with unequal arms, the so-called steelyards (with movable counter weight) and besmers (with movable suspension point) appear. These types of balance obviously require a deeper understanding of the relation between the construction of the balance and its function to determine weights. During exactly the same period, the first theoretical treatises on mechanics appeared (in Greece and probably also in China), focusing on the law of the lever (which should better be called the law of the steelyard).

Unfortunately, the archeological attestations of steelyards/besmers from this transitional period are very poor, with the exception of one extremely rich source of artefacts (weights and balances) which survived as a consequence of the destruction of Pompeii and Herculaneum by the eruption of the Vesuvius in 79 A.D. While isolated findings of balances generally do not permit specific judgements about the knowledge of the persons who used them, a collection of balances which were used at the same place at the same time allows the individual attributes of single artefacts to be discriminated from the general patterns of their production and usage.

Work done so far therefore has concentrated on the analysis of balances and weights from these archaeological sites. In particular, all balances have been examined and the scales, markings and dimensions essential for their function have been measured and recorded (in total, 43 balances from the first century AD, including two balances from the Pergamon Museum in Berlin). Of these balances, 25 had equal arms, sixteen were steelyards, and two besmers. In addition, all objects which may have served as weights or counter weights have been measured (ca. 150 weights from the museums of Pompeij and Naples). Analysis of the data accumulated is still in progress.

Some preliminary conclusions can be drawn. A surprising finding was that, after cleaning and close inspection, all balances with equal arms were discovered to have a scale for an additional movable weight. Thus all balances examined seem to be dependent on knowledge of the law of the lever. The assumption seemed plausible that the steelyard was produced by calculating the scales according to the law of the lever. However, a survey of the steelyards data showed that this assumption must be wrong. Due to the complex construction of the steelyard, which is far from an ideal balance as a result of its production, the weight to be measured is, in fact, not simply related to the distance of the movable weight from the sponsion point according to the law of the lever.

Instead, another remarkable characteristic of the construction of the balances was observed. For a set of twelve steelyards with a total of twenty scales, the original counterweights are preserved and could be identified. In spite of significant errors due to the state of conservation of the balances, it could be established that in all cases the following rule holds: the length of the short part of the beam divided by the length of the unit of scale equals the counterweight measured in the unit of weight.

A tentative explanation for these unexpected results is suggested by the reconstruction of a conceptual structure in later texts, which apparently incorporate remnants of the older traditions of practical knowledge:

weights have sometimes been identified with length. This leads to a weaker rule which may have been a precursor of the law of the lever in the context of the knowledge of practitioners. Adding a constant weight on one side of an arbitrarily formed balance always requires the counterweight to be moved a constant distance.

Based on the identification of this rule, it has been possible to reconstruct the production process of the steelyards. This reconstruction, in turn, made it possible to offer a plausible interpretation of the only known, somewhat obscure description of this process in the extant literature, in al-Khåzin•'s *Book of the Balance of Wisdom* from the twelfth century.

Two particular problems require further elaboration. In addition to the well-known metrology of Roman weights, a second system of weight measures has been found which could not yet be identified with any measures attested by literary sources. A further problem which could not yet be solved is the construction of the scales of the besmer and the determination of its historical role in the development of balances with unequal arms.

The Arabic Transformation of Mechanics

Mohamed Abattouy and Paul Weinig in cooperation with Sonja Brentjes (archival research in Indian archives and libraries)

A survey of extant Arabic treatises on mechanics is compiled, at present focusing on texts related to the development of the balance, excepting the numerous treatises on mechanical engineering. The texts are transcribed into Arabic and Latin script and translated into English, in most cases for the first time. The technical terms are identified and translated consistently, and their relation to technical terms of the Greek and the Latin tradition is analyzed. A glossary is prepared containing the technical terms together with their Greek and Latin counterparts. The contents of the Arabic treatises are compared with the contents of the Ancient Greek and the medieval Latin mechanical traditions. Whenever possible, information about the social and technical context of the Arabic mechanics tradition is collected, in order to determine the relation of the treatises to the practical aspects of weighing and to the knowledge of practitioners focused on the construction and use of balances.

Beginning with the eighth century, Greek mechanics became known to the

Arab world and played an important role in the emerging development of the Arabic tradition of mechanics. Several Greek texts were translated into Arabic, and in some cases, these translations are the only extant versions of the original texts. These Arabic translations set the stage for the emergence of an original and self-contained tradition of Arabic treatises on the balance and weights which lasted for many centuries. The authors of this scientific and technical patrimony are known as scientists as well as artisans and masters of the art of weighing. Their treatises and other writings in Arabic literature (*e.g.*, the manuals of ˙*isba*) gave birth to a scientific tradition with theoretical and practical aspects, debating mathematical and physical problems, and involving questions relevant to both the construction of instruments and the social context of their use. Some of these Arabic treatises were translated into Latin in the twelfth century and influenced the medieval Latin tradition.

While it is clear in principle that this Arabic tradition represents ancient mechanical knowledge in part, but developed such knowledge to a great degree independently, it is still largely unclear precisely which ancient texts were known to Arabic scholars, which knowledge was their own contribution, and what part of this contribution was transmitted into the medieval Latin mechanics tradition. Only a survey of the extant Arabic texts and a careful comparison of their contents with the better known Greek and Latin traditions can provide new clues to answer these questions.

To date work has focused on establishing the corpus of extant manuscripts. Surprisingly, this corpus is much larger than usually assumed in history of science. Up to now about thirty different treatises dating from the ninth through the nineteenth centuries could be identified which deal with theoretical and practical aspects of balances and weights in the narrow sense. The majority of these treatises has never before been edited or studied, and only exists in one or more manuscript copies. Some important manuscripts have been discovered or rediscovered even in the course of the present research activities.

Texts dating from before the fifteenth century (about half of the corpus) have already been transcribed. These texts currently are being translated using a computer-assisted methodology which assures the identification and consistent translation of the technical terms (see *Edition of Sources Related to the Medieval Tradition of Mechanics p. 60).*

Although at present the analysis of the texts hardly has begun, due to the laborious work necessary to make the Arabic treatises accessible, the importance of the Arabic tradition for the development of the body of mechanical knowledge already can be established. With regard to contents, the Arabic treatises on mechanics turned out to be much richer than what is known from the ancient tradition. Besides translations of Greek texts, the treatises contain foundations of deductive systems of mechanics different from those of extant Greek texts, as well as new propositions and theorems. In particular, the Arabic treatises also represent knowledge about practical aspects of the construction and the use of balances missing in ancient treatises.

The most influential text of the Arabic tradition of the balance is undoubtedly Thåbit ibn Qurra's *Kitåb f• 'l-qaras†¥n* (Book of the Steelyard), which presents a deductive theory of the steelyard implicitly based on Aristotelian assumptions. This text (possibly together with lost treatises on the *qaras†¥n* by Banu Musa, Qustå ibn Luqå and al-Hasan ibn al-Haytham) established the theoretical foundation for the whole Arabic tradition in this field.

The attempt to provide a deductive Aristotelian foundation of the body of mechanical knowledge is one example of the productive assimilation and further development of ancient mechanics in the Arabic tradition, continuing the program of Pseudo-Aristotle's *Mechanical Questions*. That the Arabs knew this Greek text now could be firmly established. A passage of Pseudo-Aristotle's *Mechanical Questions* has been discovered in an Arabic manuscript dating from the twelfth century and extant in five copies. This discovery definitively closes the long debate among historians about whether or not Pseudo-Aristotle's treatise was known among Arab scholars.

Yet another finding illuminates the creative continuation of the Greek mechanical tradition by Arab scholars. The work of al-Isfizår• (eleventh century) on the steelyard, entitled *Guiding the Learned Men in the Art of the Steelyard*, provides, among other topics, alternative geometrical demonstrations for the propositions of Pseudo-Euclid's treatise *On the Balance*.

As far as treatises on mechanics dealing with balances are concerned, the textual constituents of the Arabic tradition can be classified chronologically into three successive units. The theoretical basis of this scientific and technical production was defined quite early, in the ninth and tenth centuries, closely related to the Greek foundations (extant treatises of Thåbit ibn Qurra, al-Ahwåzi, Qustå ibn Luqå, and Is˙åq ibn Óunayn). The second period covers the eleventh through the thirteenth centuries (extant treatises of Ilyå al-Ma†rån, ab¥ Óåtim al-Isfizår•, and al-Khåzin•). The representative texts belonging to the third and last period, covering the thirteenth through the sixteenth centuries, are mainly practical text whose authors are known as mathematicians, astronomers and artisans (extant treatises of Najm al-D•n ibn al-Rif›a, Ya›•sh ibn Ya†mak al-Amaw•, Mu˙ammad ibn ab• al-Fat˙ al-Í¥f•, and ›Uthmån b. ›Alå‹ al-D•n ibn al-Malik al-Dimashq•).

In all three periods numerous anonymous texts are found on different aspects of the theory and practice of balances and weights.

The Jordanian Revolution

Paul Weinig, Peter Damerow, and Jürgen Renn

A survey is compiled of extant manuscripts attributed to Jordanus Nemorarius, including a codicological analysis of the context of their transmission and their use. Attention is paid, in particular, to the role of these treatises in the tradition of medieval scholarship. For the transmission of mechanical knowledge, the medieval scholars seem to have played a role similar to that of the practitioners who formed the social background for the Arabic tradition of mechanics. The structure and content (deductive structure, terminology, reference body of theoretical and practical knowledge) of Jordanus' main texts on mechanics are analyzed in the same way as those of the ancient and Arabic traditions. The results of these analyses are compared in order to identify developments in the body of mechanical knowledge and its social context.

The medieval tradition of mechanics was initiated by the translation movement culminating in twelfth-century Spain. By the beginning of the thirteenth century, Latin scholars had access for the first time to a substantial collection of ancient and Arabic treatises on physics and mechanics by authors such as Aristotle, Archimedes, Euclid, and Thåbit ibn Qurra.

This situation makes plausible the unique role of Jordanus Nemorarius, the focus of this study. The treatises on mechanics attributed to Jordanus or to his immediate followers constituted the core of medieval knowledge in mechanics. The study of his work has two main goals, the exploration of the extent to which the ancient traditions were adopted and modified, and the scope of the ancient traditions emulated, as well as the study of the impact of these medieval treatises on the emergence of classical mechanics in the early modern era.

A survey covering almost 100 manuscripts has been completed, resulting in a systematic record of the corpus of the Jordanus codices. The codices have been extensively catalogued, described, and subjected to a codicological analysis. The manuscripts on mechanics listed in Thomson's catalog of manuscripts ascribed to Jordanus could be supplemented through the identification of a number of previously unknown Jordanus manuscripts. This systematic survey traced the origin of the majority of extant manuscripts and analyzed their context in the codices of other contemporary writings. The main treatises of the medieval tradition have been carefully studied; a comparison of the contents of the propositions and structures of the proofs with corresponding theorems from the ancient and Arabic text traditions has begun. A systematic documentation of the results in a database presently is being prepared.

The results concerning the diffusion and influence of treatises on mechanics written by or ascribed to Jordanus cannot be reported here in detail. They allow the conclusion that his achievements in mechanics became well known among medieval scholars throughout Latin Europe. This wide diffusion shows the extent to which Jordanus' treatises represent *the* medieval mechanics. Analysis of the context of transmission supports this result. Jordanus' texts not only were copied together with translations of older mechanical treatises but, as early as the thirteenth century he was himself considered to be an author worthy of dedicated collections, of the same caliber as the ancients; he was identified with Euclid, in particular. Furthermore it has become apparent that his mechanical writings were read together with the canon of the quadrivium.

The analysis of the contents of Jordanus' treatises is beyond the scope of this report, but the most important result deserves mention here: It has been possible to identify precisely the continuities of Jordanus' work with the ancient and Arabic body of mechanical knowledge. Against this background, the novelty of his writings could be judged, and an explanation sought for his unique contributions. Among these is Jordanus' solution to a problem which already was well known in ancient mechanics but could not be adequately solved by means of a direct application of the mental model of the balance (as attempted by Heron and Pappus): the determination of the reduction of the weight on an inclined plane. A detailed publication of this result is currently being prepared.

The distinct character of Jordanus' contribution, together with his overwhelming influence on medieval mechanics, the working group has dubbed "the Jordanian revolution." It irreversibly restructured the body of mechanical knowledge, creating necessary preconditions of later preclassical mechanics. The Jordanian revolution paved the way for the quantification of and innovations into Aristotelian physics by the calculatores of the fourteenth century. Moreover, it served as a necessary precondition of the dramatic conceptual changes in the physics of the fifteenth and sixteenth centuries, which eventually led to the deductive system of Galileo and the creation of classical physics.

Engineering and Mechanical Thinking

Wolfgang Lefèvre

The "Project 1" of the research group headed by Jürgen Renn is particularly focused on the historical reconstruction of collective, practical experiences and their influence on the structure and content of mechanical thinking. As a part of this program, research was launched recently to reconstruct structures and contents of mechanical thinking in connection with engineering in early modern times, and its significance for and within preclassical mechanics.

As is generally acknowledged, the preclassical mechanics of the early modern period (Leonardo to Galileo) acquired its distinctive form by merging theoretical traditions going back to Antiquity with a new wealth of practical experience. In order to reconstruct the role of practical experience in this process, several historical preconditions for the emergence of preclassical mechanics have to be examined. Of particular interest to this project are the rise of a "reflecting practical mechanics" and the emergence of instances of mediation between practical and theoretical knowledge.

1) Reflecting Practical Mechanics

Preclassical mechanics encompassed not only the work of those who more or less directly picked up ancient or medieval theoretical traditions, but also a specifically early modern "reflecting practical mechanics." This mechanics dealt with highly complex technical problems (rigidity of bodies, friction, etc.) which could not be addressed successfully with the means of theoretical mechanics then available. Typical examples of this reflecting practical mechanics are the notebooks of Leonardo, Tartaglia's treatise on ballistics (*Nuova Scientia* 1537), and Galileo's "two new sciences" represented in the *Discorsi* (1638). The first of these "new sciences," dealing with the rigidity of bodies and almost entirely neglected by historians of science, shows in particular that the separation of this mechanics from theoretical mechanics is an artefact of the history of science. This separation of practical from theoretical mechanics, and the almost exclusive concentration on theory rather than practice, reflects the difficulty of reconstructing adequately the peculiar cognitive structures of practical mechanics.

As a result of initial investigations undertaken to investigate this reflecting practical mechanics, some general considerations on its significance for preclassical mechanics were outlined and submitted to *Science in Context* (W. Lefèvre: "Galileo Engineer - Art and Modern Science").

Technical innovations in the construction of machines in the fifteenth and sixteenth centuries are important aspects in this context and will be a main topic of further investigations. Their study does not aim at a history of technology, but at a comprehension of objects of experience which could have played a role in the reflections of both practical and theoretical mechanicians. These innovations consisted in new combinations of traditional elements of machines, such as lever and wheel, and in the introduction of new elements, such as flywheel and pendulum. New experiences constituted in any case the basis for an enlarged range of application of the traditional concepts of motion and force, which may have also had structural consequences for the meaning of these concepts.

2) Instances of Mediation between Practical and Theoretical Mechanics

Since Antiquity, practitioners have employed geometrical construction techniques as well as arithmetic algorithms for the solution of complex tasks. The application of mathematics, which spread in early modern times in the context of the use of perspective and the construction of scientific instruments, distinguished itself from this tradition of practical geometry by presupposing a more or less complete understanding of the theoretical foundations of geometrical techniques. Thus points of contact between practical and genuinely theoretical knowledge emerged, creating mediatory instances between practical and theoretical mechanics – between engineers and instrument makers, educated in mathematics and mechanics, on the one hand, and scientists familiar with practical problems on the other. A close study of the emergence and the actual function of these mediatory instances will be a main task of the research activities with respect to engineering and mechanical thinking.

Documents which reveal the use of practical geometry in architecture, in the construction of certain machines and devices, and in geodesy are important indicators for the reconstruction of cognitive structures underlying challenging engineering tasks, and hence constitute an important focus of the research. Such documents are especially important because the reconstruction of such cognitive structures presents numerous serious difficulties. As generally known, for example, from the differences among historians of architecture regarding the pyramids of ancient Egypt or the Gothic cathedrals of the Middle Ages, it is not possible to deduce solely from preserved buildings or technical devices the knowledge applied by their creators. Without further evidence, any conclusions drawn from such objects remain highly speculative and uncertain. Furthermore, practical knowledge is in part "tacit knowledge," in the dual sense that it may involve not only non-verbal experiences such as acquired skills, but also experiences which can be verbally expressed but were only orally communicated and transmitted. Often, however, such experiences and insights were not communicated at all since practitioners, and especially innovative ones, deliberately kept secret those parts of their professional knowledge which they regarded as decisive for their economic success. It is exactly these secrets that especially interest historians of their work.

Initial efforts are currently under way to better understand the graphical representations – sketches, drawings, plans – drawn or constructed by architects and engineers of that period. For what purpose were these images actually used by practitioners? Were they rhetorical means, means of communicating, means of reflection, means of designing, or means of manufacturing buildings or complex devices? How did those possible functions depend on the "syntax" of the images - on their being either pictures or plans? And most important in this context, did such graphical representations themselves constitute mediatory instances between practical and theoretical mechanics? First results achieved have been summarized in written form and will be submitted as a chapter of a book, edited by Jürgen Renn, on *The Emergence of the Scientific Image*.

Challenges to Preclassical Mechanics

Michele Camerota, Peter Damerow, Simone Rieger, and Jürgen Renn

New objects that raised the interest of “engineer-scientists” in the early modern period and challenged the methods of preclassical mechanics are studied in order to find out how they were assimilated into the existing body of mechanical knowledge, and how the contents and structure of this knowledge were changed by this assimilation.

The early modern period saw the creation of a preclassical mechanics which merged theoretical traditions going back to antiquity with a new wealth of practical experience. It is an inherent characteristic of early modern science that a variety of mechanical phenomena and arrangements, such as the trajectory of projectiles, the stability of constructions, the oscillation of a swinging body, or the curve of a hanging chain aroused the interest of scientists. Even though sixteenth- and seventeenth-century scientists did not necessarily address such phenomena in their publications, their extended scientific correspondence shows that they became at that time a perpetual concern of their investigations.

From today’s perspective, such objects represent a very particular subset of physical systems, one of whose distinct features turned out to be their tractability in terms of relatively simple differential equations. This fact alone suggests that the specific properties of these objects were an important factor in the development of early modern science, contributing to its contemporary form. Although this observation is straightforward, it tends to be neglected by historians of science even when the role of experience in the creation of classical mechanics is at issue, let alone where studies of the social and cultural conditions of scientific developments are concerned.

Adequate explanations of the mechanical devices and machines which were subjects of investigation in the sixteenth and seventeenth centuries were often provided only later by classical physics. The explanations based on the emerging modern mechanics were insufficient in various respects and notoriously confounded with theoretical assumptions of the ancient tradition which ultimately turned out to be incompatible with classical physics.

In the last year, the study focused on two outstanding objects of Galileo’s mechanics, the trajectory of projectiles and the catenary, that is, the curve of hanging chains. Galileo’s discovery and proof of the parabolic shape of the trajectory is quite familiar and has much been studied; his attempts to provide a proof for the parabolic shape of the catenary, however, have been virtually neglected.

The question of when and how he discovered the parabolic shape of projectile motion has been the subject of over a century of intensive research by historians of science. Nevertheless, it is still an essentially open question. The dating of his discovery ranges anywhere from 1602 to 1632. Even more diverse are the assumptions about his sources. These cover the spectrum from pure empirical evidence achieved exclusively by means of careful experimentation and precise measurements, to predominantly theoretical speculation in direct continuation of scholastic traditions only scarcely supported by empirical demonstrations.

Based on new evidence attained by analyzing manuscripts of Galileo and Paolo Sarpi and from Galileo's correspondence, it could be shown that his famous discovery was based on a combination of simple experiments and obvious mathematical conclusions, achieved as early as 1592. It could further be demonstrated that Galileo confounded his discovery with his erroneous conviction, also based on theoretical and empirical evidence, that the shape of the projectile trajectory and the curve of a hanging chain are identical. Galileo planned to treat this relationship in a final chapter of his *Discorsi* which he was unable, however, to complete before his death in 1642.

On the basis of this new reconstruction of Galileo's discovery, the study has led to the conclusion that the qualitative experience with objects such as projectile motion or the hanging chain was crucial for his achievements in mechanics, even though these objects were, strictly speaking, neither experimentally nor theoretically accessible given the means of the time. The study thus provides evidence that neither the reliance on experiments, the continuity of theoretical traditions, nor the social context, taken by themselves, sufficiently account for the when and how of Galileo's discovery.

Not without a certain degree of contingency, objects which entered the intellectual horizon of the new engineer-scientists such as Galileo from outside the dominating academic traditions inevitably became a challenge for them. Although they generally were unable to meet this challenge adequately, these objects nevertheless triggered the development of scholastic physical concepts oriented toward classical mechanics. The origin of these challenging objects in the accumulated knowledge of the practitioners and engineers of the time reveals their role as important and irreducible mediatory instances between early modern science and its social context.

The Development of Galileo's Deductive System of Mechanics

Jochen Büttner, Peter Damerow, Simone Rieger, and Jürgen Renn

The available sources (publications, manuscripts, notes) documenting the development of Galileo's deductive system of mechanics are investigated in order to find out what, after a long period of earlier developments of ancient and preclassical mechanics, finally brought about the transition to classical mechanics. Proofs are analyzed according to their implicit and explicit preconditions. Propositions and theorems are classified according to the preconditions needed for their proof, and according to the propositions with proofs assuming them as a precondition. The results will be used to reconstruct the role of deductivity in the development of Galileo's mechanics and to reconstruct the original order in which Galileo arrived at his propositions and proofs.

Galileo's early manuscripts show that he initially was close to the common Aristotelian way of conceptualizing mechanics. But at least by 1604, a letter documents that he already was deeply concerned with attempts to build a deductive theory on different foundations. The long process of developing this theory is documented in Galileo's surviving notes on mechanics (Ms. Gal. 72 of the National Library at Florence, see the report below on the development of an electronic representation of this manuscript *p. 108*). Finally, Galileo's *Discorsi,* first published in 1638, indicates the emergence of a new mechanics that soon afterwards developed into a core theory of classical physics. The "Second Day" of the *Discorsi* contains a deductive theory of the rigidity of bodies, while the "Third Day" and the "Fourth Day" are focused on a deductive theory of free fall, motion on inclined planes, and projectile motion. These theories fundamentally differ from the medieval tradition of mechanics. They deal with new contents, and they are built on axioms which no longer try to establish an Aristotelian underpinning of mechanics.

Research activities first have been concentrated on preparing the sources for a computer-assisted analysis and on analyzing the deductive structure of the final outcome, the deductive system of mechanical knowledge in the

Discorsi. A database has been established containing the full texts of the manuscripts, references to scholarly interpretations reported in the scientific literature, and the results of the research activities so far. In particular, the deductive structure of the *Discorsi* has been represented electronically and the notes and proofs of the manuscript pages of Ms. Gal. 72 have been linked to the theorems of the final publication to which they contributed. Currently these entries are being analyzed in order to determine which are closely related to the final proofs and which represent earlier stages of the development of the theory.

The analysis of the manuscript has provided evidence that the extant folio pages represent only part of the notes Galileo kept about his work. Yet the manuscript still contains notes on a substantial part of Galileo's final theory. For 85 percent of the propositions on accelerated motion, and for more than 50 percent of the propositions on projectile motion, at least some notes have been preserved.

The work on the deductive structure of the *Discorsi* itself has shown that the final theory has a peculiar structure deviating from what one can usually expect from a deductive theory. This is particularly evident in the case of the theory of accelerated motion. Eighty-seven percent of all propositions are not repeated in order to derive further propositions. In fact, most of the propositions are proven but *never* used in the proofs of other propositions (28 out of 38). A small number of further propositions (five), which also are not used repeatedly, only served to prove those immediately subsequent.

On the other hand, there is a very small group of propositions (four), which are the only ones used repeatedly in the proofs. These propositions are the law of fall, two basic propositions on motion along an inclined plane, and a scholium relating two fundamental concepts of Galileo to each other, the concept of velocity and the concept of the degree of velocity. These key propositions not only play a singular role in the deductive structure of the *Discorsi*, but are also well-known early achievements of Galileo's work on mechanics.

The analysis of the deductive structure thus reveals that Galileo's new system of mechanics is much less complex than the sophisticated mathematical structure of his arguments suggests. Essentially Galileo's *Discorsi* merely evolve inherent conclusions of his most prominent findings without adding anything to the physical content.

Associated Research Activities

Edition of Sources Related to the Medieval Tradition of Mechanics

Mohamed Abattouy, Thomas Berchtold, and Paul Weinig

The main treatises on the balance of the Arabic tradition and of its continuation in the medieval Latin tradition are prepared for critical editions (in the case of hitherto unedited texts), or for re-editions with consistent English translations, commentaries, and glossaries of technical terms. The edition covers works composed between the ninth and the sixteenth centuries. Arabic texts dating from the seventeenth through the nineteenth centuries are also taken into account as supplementary sources in order to reconstruct the older tradition.

By making accessible the Arabic tradition of mechanics, it is possible to give a comprehensive picture of the entire Greek-Arabic and Latin traditions for the first time. Work on such an edition started in fall 1996 and yielded important results, in particular, the rediscovery of two manuscripts by Thåbit ibn Qurra, the *Kitåb f• 'l-qaras†¥n*, and his edition of Pseudo-Euclid's *On Heaviness and Lightness*, originally kept in Berlin, but lost during World War II. This discovery makes it possible to prepare for the first time a critical edition on the basis of all extant copies according to modern standards.

The entire codicological tradition of the Arabic works on the balance was surveyed and organized in a sytematic overview. By now almost half of the corpus has been edited, transcribed and translated.

Contrary to the case of the Arabic sources, work on the medieval Latin tradition of mechanics can build on a considerable number of previous scholarly contributions comprising editions, English translations and commentaries. There is nevertheless occasion for further work on these sources as well. In the course of the research on the Jordanus text tradition, several new manuscript findings have made it necessary to update the existing editions. Furthermore, the available English translations are not always consistent in translating technical terms; a reworking of these translations has therefore turned out to be particularly important for a comparison with the Arab tradition.

The edition will include the following texts:

— The Book of Euclid on the balance,

— The Book of Euclid on heaviness and lightness and the measure of bodies by each other (both in the version edited by Thåbit ibn Qurra and in the Latin version),

— The Book of Archimedes on heaviness and lightness (both in the Arabic and the Latin versions)

— Chapters 1 and 2 of Ps. Aristotle's *Mechanical Questions*

— Chapters 24-31 of Book I of Hero's Mechanics dealing with centers of gravity and balance of weight

— Al-Ahwazi: Treatise on the balance

— Thåbit ibn Qurra's two works on the balance: Book of the steelyard and Book on the equilibrium and disequilibrium of weight

— Excerpts from Qustå ibn Luqå's Book on weighing and measuring and Is˙åq ibn Óunayn's Treatise on weights and measures

— Ilyå al-Matrån: Book of measures and weights

— Al-Isfizår•: Guiding the learned men in the art of the steelyard

— Al-Khåzin•'s Kitåb mizån al-hikma, Book I, presenting an abridged version of al-Quhi and ibn al-Haytham's achievements on the theory of centers of gravity, the texts of which have not yet been found.

— Cause karastonis (by anonymus),

— Liber karastonis (translated by Gerard of Cremona),

— Liber de canonio (by anonymus), Elementa Jordani,

— Liber de ponderibus,

— *Liber de ratione ponderis*.

— Najm al-D•n ibn al-Rif'a: The elucidation and the demonstration of the knowledge of the measure and the balance

— Ya'•sh ibn Ya†mak al-Amawi: Problems related to the balance

— Mu˙ammad ibn ab• al-Fat˙ al-Íufi's three works on the steelyard: Guiding the weigher how to weigh with the steelyard, Treatise on repairing the defectuosity of the steelyard, Treatise on the division of the steelyard.

— ›Uthman ibn ›Alae‹ al-D•n ibn al-Malik: The Selected part of the art of the steelyard

Ink Analysis of Galileo’s Notes on Mechanics Ms. Gal. 72 (joint project together with the Biblioteca Nazionale Centrale, Florence, the Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, and the Istituto e Museo di Storia della Scienza in Florence)

Peter Damerow, Wallace Hooper, Simone Rieger, and Jürgen Renn (Max Planck Institute for the History of Science), Paola Pirolo and Isabella Truci (Biblioteca Nazionale Centrale), Piero del Carmine, Franco Lucarelli, and Pier Andrea Mandó (Istituto Nazionale di Fisica Nucleare), Paolo Galluzzi (Istituto e Museo di Storia della Scienza)

Galileo’s notes on mechanics (Ms. Gal. 72) represent the most important source on the emergence of classical mechanics (see *p. 108* on the electronic edition of this manuscript). However, the understanding of these notes still is limited severely by the difficulties in arranging these notes (texts, drawings and calculations in partly chaotic arrangements) into the order they were written. Up to now, the entries have been dated primarily according to internal criteria (logical dependencies, type of handwriting, etc.) and the physical characteristics of the paper (watermarks).

Methods of the natural sciences offer opportunities to attain additional clues which could aid in the reconstruction of the original order of the entries. To exploit such opportunities, the Institute has established a joint project together with the library in which the manuscript is located, a nuclear physics institute, and a history of science research institute in Italy. The project aims at analyzing the compositions of inks used in the manuscript and comparing the results with ink compositions in letters and manuscripts for which the dates of origin are known. A method based on the analysis of the energy spectra of particle-induced X-ray emission (PIXE), which uses a low energy proton beam with a diameter of less than 0.1 mm, allows the determination of relative amounts of certain metallic elements (iron, copper, zinc, lead and nickel) within a spot smaller than the ink lines on the paper. Since the relative amounts of these metals vary considerably in the inks used at the time of Galileo, they can be used as indicators for the time when different entries on a folio page were written.

Following up promising measurements made previously by Wallace

Hooper and Pier Andrea Mandó, a pilot study has been launched in order to answer three questions.

- Is it possible to identify the different inks on a folio page?
- Is it possible to identify the same ink on different folio pages?
- Is it possible to increase the efficiency of the method so that it is possible to determine the inks in a substantial part of the manuscript within a reasonable amount of time?

During two beaming sessions of one week each (October and December 1996), about 370 ink spots on 13 folio pages were analyzed. First interpretations of the results were achieved in two workshops (November 1996 and August 1997). During the second workshop it was decided to include the data from the earlier measurements of Hooper and Mandó with the later work. This ultimately raised the number of measurements to 670 ink spots on 29 folio pages. Furthermore, the data included contain 124 ink spots on dated letters (Ms. Gal. 14) and 186 ink spots in a household book with dated entries (Ms. Gal. 26).

Concerning the research questions of the pilot study, the preliminary analysis of the data has provided the following answers.

- With some exceptions, different inks on a folio page could clearly be identified, provided that the number of measurements taken was sufficient to distinguish variations due to different inks from the rather high error variation.
- The identification of the same ink on different folio pages seems to be possible only under favorable circumstances (*e.g.*, closely related pages), because in general the variation of the ink is too high and the number of criteria distinguishing different inks too small for an identification of inks over long time periods.
- It is, unfortunately, impossible to investigate a substantial number of folio pages within a reasonable time frame. The strategies of choosing the spots for measurements could be improved by real-time analysis of the incoming data, but the time for one measurement could not be reduced below an average of ten minutes for each measurement.

When it became clear even during the measurements that only selected pages could be investigated due to the time-consuming procedure, the strategy of the pilot study was changed. Instead of including further pages selected for testing the method, folio pages were selected for which the identification of the different entries is crucial for their interpretation. Thus, several results could be achieved which were significant for the interpretation of the folio pages. It turned out that the variety of entries on the folio pages is much smaller than generally assumed.

A first project report has been prepared documenting the measurements and the reconstruction of the different inks on the four folio pages investigated during the first beaming session. A second report will document the measurements of the second beaming session together with the earlier data from the measurements of Hooper and Mandó.

The results of the ink analysis are presently being analyzed by systematically relating them to the results of a thorough study of the contents of the manuscript pages. This combination of historical analysis with the results of the ink analysis has already yielded unexpected and promising outcomes. In the case of one manuscript page, for example, it seems possible to establish at least a partial internal time-line for Galileo's entries on this page. Such an achievement would be inconceivable without ink analysis and may have important consequences for the micro-reconstruction of Galileo's discoveries. In particular, the identification of entries related to an empirical check of the shape of the chain line (see *Challenges to Preclassical Mechanics p. 56)* could be based on results of the ink analysis. In another case, it has been possible to reject a historical claim concerning an alleged discovery by Galileo of an essential error in his proof of the law of fall as late as 1618. This claim was based on cancellations of the erroneous ingredients in copies made by Galileo's disciples at that time. The ink analysis has revealed, however, that the cancellations were made at the time of copying by his disciples and thus did not constitute later additions. It should be stressed, however, that the evaluation of the bulk of the data is still in progress.

Edition of Galileo's Letters on Mechanics

Peter Damerow, Jutta Miller, Fiorenza Renn, and Jürgen Renn

An edition of a selection of Galileo's correspondence is prepared, containing the letters in original language and in English translation. The edition will contain all preserved letters from, to and in some cases about Galileo which can provide not only information about the development of his work on mechanics, but also on the various intellectual contexts relevant to this development. Technical terms will be translated consistently. A glossary is prepared containing all technical terms used in the correspondence.

Although Galileo's correspondence represents a significant source for any reconstruction of his discoveries, there is no edition of this correspondence available in the English language. Only a small, eclectic selection of the letters has been translated to date, scattered across a number of publications of historians of science. The correspondence of Galileo has been taken into account systematically only in publications of Italian scholars.

Currently the relevant letters have been selected and scanned; more than 400 letters will be included in the planned edition (about half of them by Galileo). Almost all are found in the *Edizione Nazionale* prepared by Antonio Favaro around the turn of the century. Although this edition provides a virtually complete collection of Galileo's correspondence, additional contemporary letters relevant for understanding Galileo's science were sought with some initial successes. The translation of the letters is assisted by a specially-designed translation environment, supporting the consistent translation of technical terms in particular, and the creation of the glossary Fifty letters have been translated so far, comprising Galileo's complete correspondence with Guidobaldo del Monte in particular, as well as several previously unpublished letters by Guidobaldo to other scientists which turned out to be relevant to his exchange with Galileo.

A New Translation of Newton's Principia

Volkmar Schüller

The transition from early modern physics to Isaac Newton's physics still is understood insufficiently. A proper understanding of the emergence of the modern Newtonian physics also requires intimate knowledge of Isaac Newton's physics. The major work of Newton's physics is his *Philosophia Naturalis Principia Mathematica*, which he wrote in Latin. Hence, a translation of this volume into a modern language which meets modern standards of science history is required and will be welcomed by philosophers and historians of science.

In 1729 the third edition of Newton's *Principia* was translated by Andrew Motte into English, and la Marquise du Chastellet published her French version in 1756. In 1936 Florian Cajori revised Andrew Motte's English translation relying heavily on a German translation published by J. Ph. Wolfers in 1872. This German translation, however, introduces nineteenth-century terminology uncritically, thus falsifying Newton's intentions in many places, and, for instance, transforming a number of his propositions into mathematical equations. Moreover, this translation ignores the variant readings in Newton's manuscripts and differences between the first and second edition, as well as the annotations made by Newton in his own copies. These important additional textual elements were assembled by Koyré, Cohen and Whitman in their edition of Newton's *Principia*, which they published in 1972.

The present German language edition of Newton's *Principia* will be published by de Gruyter Verlag Berlin and contains the three versions of the *Principia* published by Newton in the years 1687, 1713 and 1726, respectively, and also Newton's manuscript for the 1687 edition. The annotations by Newton's hand in his copies of the two first editions and in a copy given to Locke are included. Furthermore, this new edition contains translations of the reviews published in *Acta Eruditorum, Philosophical Transactions, Bibliothèque Universelle et Historique, Journal des Scavans* and *Journal de Trevoux*. Some of Newton's manuscripts found in the bequest of David Gregory, which contain unique information pertaining to his *Principia*, are also added. In the second edition of 1713 Newton included the famous *Scholium generale* in which he defends himself against Leibniz' objections. Some important drafts of this *Scholium generale* found in Newton's bequest are also added. Moreover, the present edition gives a detailed account of the intricate genesis of Newton's *Principia* along with information about the sources used by Newton.

A Commentary on Newton's Principia

Volkmar Schüller

The significance of Newton's *Principia* as a unique intellectual achievement in the history of science calls for a comprehensive commentary. Such a commentary should deal with the problems considered by Newton from the perspective of his own time. The analysis should establish, whenever possible, precursors to Newton's own reasoning, in order to delineate more clearly Newton's own genuine, innovative contributions. It is also important to explain Newton's suggestions in terms of the development of his own ideas, notions and mathematical tools.

In preparation for such a commentary, Schüller has written a study on Newton's calculation of the figure of earth. It is shown that Newton did not derive the earth-figure from the laws of motion, but by means of a hydrostatical model of the earth. In the case of the real earth, the centrifugal force of a particle and the force of gravity of the same particle are in equilibrium; from this condition Newton derived the ratio between the earth's major and minor axes. In this manner Newton convincingly demonstrated that the oblateness of the earth at the poles is due to the interplay of universal gravitation of all the earth's particles and the centrifugal force of these particles.

Currently Schüller has completed approximately one fourth of the commentary on Newton's theory of the tides, which derives from Newton's principle of universal gravitation. In addition to the commentary, he has been working on an important Newtonian manuscript which was published in the paper "Newton: The classical Scholia" by Paolo Casini (*History of Science* 22 (1984) 1 - 58). This manuscript was hitherto unknown. These manuscripts include important historical and philosophical explanations by Newton about the propositions IV - IX of Book III, in which Newton formulated his principle of universal gravitation. These manuscripts have not yet attracted much attention, probably for two reasons: they were written by Newton in Latin, and they were not translated into a modern language by Casini. Indeed, their translation will be a difficult undertaking, because the Latin in these texts is corrupt in numerous places. These corruptions must not be attributed to Newton, for the comparison of these texts with Newton's manuscripts reveals Casini as the source of these corruptions. Therefore Schüller is now working on a new edition of these texts. This edition will contain the authentic text together with a German translation, as well as a new compilation of sources to which Newton referred directly and indirectly. These texts are crucial to the understanding of Isaac Newton's physics and its genesis, because they prove incorrect the opinion held by many historians of physics: that Newton's ideas of universal gravitation derive from his investigations into alchemy. In fact, Newton refers only to the Ancients, and not to alchemistical authors, in his justification of the universal gravitation.

A New Translation of Galileo's De Motu

Raymond Fredette

Galileo's earliest treatise on mechanics, the manuscript *De Motu*, which he never published, is the most important source documenting the starting point of his years of work an a new science of mechanics. An edition of the treatise is included in Volume I of the *Edizione Nazionale* of Galileo's Works, and an English translation has been published by Drabkin.

Nevertheless, various problems continue to make the role of this treatise for the development of Galileo's work on the foundations of classical mechanics difficult to understand. Several different versions of the manuscript have survived which can be dated only by internal criteria such as the use of specific technical terms.

This is the background for a recent initiative aiming at a new English and French translation and edition of the treatise. The emphasis will be on a consistent translation of the technical terms into both languages. This endeavor is supported by a working environment for computer-assisted translation developed at the Institute for this specific purpose.

Newton and Hooke

Ofer Gal

The study was dedicated to a historical-epistemological analysis of the work of Robert Hooke (1635-1703), organized around his most celebrated theoretical achievement: the proposal to "compoun[d] the celestial motions of the planets of a direct motion by the tangent & an attractive motion towards a central body." The suggestion that planetary orbits should be calculated solely on the basis of the parameters of rectilinear motions and rectilinear attractions, understood as the outcome of continuous deflection of a motion along their tangents by the attraction of the sun, has come to be known as Hooke's Programme. The traces of Hooke's construction of this Programme for celestial mechanics lead through his investigations in microscopy, practical optics and horology, and thus offer a survey of the epistemic operations of this central figure of late seventeenth-century science. Hooke's unique capacity to move freely between the theoretical, experimental and technological realms, as well as in and out of the circles occupied by gentlemen-philosophers, instrument makers, servants and technicians, provides an opportunity to examine the social and epistemological boundaries, relations and hierarchies between them.

The chapter completed this year offers an analysis of Hooke's Programme through its influence on the work of Isaac Newton following their correspondence in 1679-80. It suggests a reading of the correspondence as one continuous text, written by both, analyzing the outcome as a common product for which both men's skills, tools and techniques were essential. It explicates the manner in which communication is established, common grounds for exchange are created, and new knowledge – Hooke's Programme as it is came to function in Newton's Kepler Motion Papers and *De Motu* – is created by a combination of collaboration and careful positioning. One essential element of the Programme is crystallized: the notion that planetary motions are curved from original rectilinear paths into closed orbits by an external power (Hooke's term), itself operating along straight lines. This clear and simple depiction of planetary motion is compared to the formulations of the question employed by young Newton and Huygens, and its surprising originality is substantiated by short references to Kepler, Descartes and Borelli. Another, more subtle element of the Programme – a particular conception of the relations between power, motion and trajectories – arises from considering Newton's changing understanding of it. A comparison of the three versions of the Programme – the one gradually delivered in the correspondence; the one published at the end of Hooke's 1674 *Attempt to Prove the Motion of the Earth*, and the original version, delivered as an address to the Royal Society in 1666 – reveals that this conception, still vague in the earliest, 1666 version, is fully developed in the 1674 publication.

Project 2: Studies in the Integration and Disintegration of Knowledge in Modern Science

Jürgen Renn (responsible), in cooperation with Peter J. Beurton and Ohad Parnes (biology), Gerd Graßhoff, Wolfgang Lefèvre, Renate Wahsner, and Falk Wunderlich (philosophy), Leo Corry, Hubert Goenner, Dieter Hoffmann, Michel Janssen, Edward Jurkowitz, Horst Kant, Alexei Kojevnikov, Folkert Müller-Hoissen, James Ritter, Tilman Sauer, Arne Schirrmacher and John Stachel (modern physics), Giuseppe Castagnetti and Britta Scheideler (history)

General Goals of the Project

It is remarkable that in some fields and in some historical situations, a vast array of scientific knowledge is structured by only a handful of concepts. The concepts of space, time, force, motion, matter, and a few others played this role for classical Newtonian mechanics; together with the concepts of energy, entropy, and charge, they also played this role in developed classical physics. The concepts of field, energy-momentum, and space-time continuum structured modern relativistic theories; the concepts of species, gene, selection, variation, and adaptation for classical evolutionary biology; and the concepts of cell, bacterium, pure culture, and infection for classical microbiology. In retrospect, such core groups of concepts may appear to constitute the starting point for gaining scientific knowledge in their respective fields. A closer historical examination shows, however, that such core groups of concepts usually achieved their privileged position in the organization of knowledge only *after* a long process of knowledge integration, in a material, social, and cognitive sense. Knowledge integration, in turn, requires material embodiments, such as an experimental arrangement or a formalism which can be assimilated to the cognitive structures belonging to the different branches of knowledge to be integrated, and a social organization allowing scientists actually to bring the combined knowledge of the different branches to bear on such material embodiments. The emergence of a core group of foundational concepts in the course of or as the sequel to such integration processes therefore must be analyzed as a restructuring of the cognitive organization of previously acquired knowledge. Earlier studies of this process by participants of the project were dedicated to the reconstruction of the emergence of key concepts of evolutionary biology (Lefèvre) and of classical mechanics (Renn). A case study pursued in the context of the project has complemented these earlier studies through a parallel analysis of the little-known case of the emergence of foundational concepts of microbiology (Parnes).

Reflective thinking plays an important, but not yet well understood role in such restructuring processes. This role is evident, for instance, in Newton's philosophical integration of physics and mechanics, which necessarily interacted with the creation of Newtonian mechanics. It is particularly evident in historical attempts to provide an explicit philosophical synthesis of scientific knowledge. An outstanding example of the role of reflective thinking in philosophical integrations is the long-lasting influence of Kant's natural philosophy on the self-understanding of classical science. It emerged from the reflective integration of key concepts of early modern science and remained the dominant philosophical background of the ever more specialized scientists, whatever changes of systems in philosophy took place. When classical science ultimately reached a crisis at the end of the nineteenth century, Kantianism saw a spectacular revival, not only in the modified form of Neo-Kantianism, but also in the emergence of a new type of philosophical integration by the "linguistic" turn of positivism (the Köhnke thesis). It was a common feature of earlier integration attempts that foundational, first-order concepts of a particular body of knowledge, such as the concept of force, were exploited in order to achieve such a philosophical integration. In the process, these then were assimilated into new second-order, reflective structures of knowledge. These new structures, such as a new concept of nature, in turn transformed and stabilized the meaning of the first-order concepts. The novel feature of philosophical integrations after the linguistic turn was, in contrast, that they were based on a reflection on the syntactic structures of the representation of scientific knowledge by language. As a consequence, the basic concepts of this integration no longer had any direct relation to first-order concepts, such that the integration was content-independent and formal.

Contrary to philosophical integrations, processes of integration and disintegration within disciplines always remained closely connected with first-order concepts. Two outstanding examples are the disintegration of neo-Darwinian evolutionary biology in the 1960's, and the disintegration of classical physics around the turn of the century and the subsequent partial reintegration into global theories such as general relativity and quantum mechanics. Both examples are examined in the context of this project.

Work on the second example has made particularly clear the complex structure of long-term developments of such processes of integration and disintegration.

The foundational concepts which emerged from the first ground-breaking periods of knowledge integration, such as those of space and time in the case of classical physics, proved to be extremely stable in the face of an enormous growth of knowledge in the course of the further development of science. In fact, on occasion they even were considered to have *a priori* status, not subject to any changes by the accumulation of knowledge. Nevertheless, most scientific disciplines have witnessed fundamental changes of precisely this core group of foundational concepts in the past century. These fundamental changes were preceded by more or less extended periods of knowledge disintegration, in which the established cognitive organization of knowledge became problematic. Paradoxically, it appears that the essential mechanisms at work in these periods of destabilization were of the same nature as those which functioned in the original processes of knowledge integration. For the case of the transition from classical to modern physics, this affirmation is supported by the crucial role of borderline problems for this transition.

By the end of the nineteenth century, physics had evolved by cumulative integration of magnetic, electrical and thermal phenomena into three major branches, each treating a set of interconnected physical problems on the basis of a relatively stable theoretical foundation. The oldest of the theoretical foundations of physics was classical mechanics. However, in the course of this process of integration, these three branches developed increasingly into independent theories of mechanics, electrodynamics (including optics) and thermodynamics. By creating new concepts such as charge and entropy, these theories became relatively independent with stable specific foundations for their respective ranges of phenomena.

Among the many concrete, unsolved problems studied by contemporary scientists, several were related to more than one such specific foundation, such as the problem of the electrodynamics of moving bodies, which requires the application of both the laws of electrodynamics and the laws of motion from mechanics. Heat radiation is another example of this class of borderline problems produced by a progressive integration of knowledge, which requires the application of both the laws of radiation – covered by those of electrodynamics – and those of thermodynamics. Since these problems fall under the range of application of two partially different theoretical foundations, they represented not only a potential locus of conflict between different conceptual frameworks, but also points of departure for their integration into more developed theoretical frameworks. This in turn required a revision of fundamental concepts underlying all of classical physics, and hence a disintegration of traditional knowledge structures. Thus, the electrodynamics of moving bodies became the core of the later special theory of relativity, with its new concepts of space and time to which the rest of physical knowledge had to be adapted. Planck's law of heat radiation, another example, was later seen as the first decisive contribution to quantum theory, with its new concepts of matter and radiation which also required a reconceptualization of traditional physical knowledge.

Such processes of reconceptualization frequently lead to a new type of foundational problems of scientific theories. This is, for instance, the case for the reconceptualization of the entirety of classical physics on the basis of special relativity theory. In particular, the classical Newtonian concept of gravitation with its implication of instantaneous propagation was obviously incompatible with the limit-speed imposed on any physical interaction by special relativity. Any attempt to eliminate this problem by reconceptualizing gravitation within the theory of special relativity failed, so that fundamental assumptions of the theory ultimately had to be substituted by the assumptions of general relativity. The need to describe gravitation in terms of re-revised concepts of space and time led to an even more extensive disintegration of the knowledge structures of classical physics.

Several case studies are dedicated to examining the structural changes of physical knowledge associated with the introduction of these new theories, as well as the disintegration of classical evolutionary biology due to analogous challenges. In the case of relativity theory, the focus is on the emergence of the general theory of relativity, and in particular on the disintegration of knowledge structures of classical physics induced by the need to describe gravitation in terms of the new concepts of space and time resulting from the special theory of relativity. In the case of quantum theory, work is concentrated on reconstructing research policies relevant to the emergence of quantum mechanics, and in particular on analyzing the refocusing of traditional research activities induced by the discovery of a new common thread ("the quantum"), connecting hitherto separate problems. In the case of evolutionary biology, a case study analyzes attempts to reinterpret its fundamental concepts as a reaction to new insights, such as the increased knowledge about genes due to molecular biology, and the consequences of such reinterpretations for the integrative role of these concepts.

All these cases are characterized by an interaction of heuristic programs, which aim at knowledge integration, and traditional structures of knowledge, be they cognitive or social, which are disintegrating. The heuristic programs are comparable to the philosophical programs of an earlier period mentioned above, although they now usually are formulated from an inner-scientific perspective (which, of course, does not exclude effects from the field of philosophy), and although they may even take the form of a science policy. Thus, in spite of the diversity of the studies pursued in this project, they focus on the same crucial problem, the still insufficiently understood role played by reflective thinking in processes of restructuring scientific knowledge.

Current Research Activities Related to "Studies in the Integration and Disintegration of Knowledge in Modern Science"

Knowledge Integration and Concept Formation in Microbiology

Ohad Parnes

Ohad Parnes' research project looks at the origins of fundamental concepts of medical bacteriology and microbiology as a consequence of processes of knowledge integration in the nineteenth century.

The conceptual foundation of modern microbiology was established in the last quarter of the nineteenth century, and is commonly associated with the work of Louis Pasteur, Robert Koch, and their disciplines. But the emergence of its core concepts, such as "parasitism," "pure-culture," and "bacterial species," was merely a successful culmination of the gradual development of concepts and methods since the beginning of the nineteenth century. The aim of the project has been to trace the various strands of this knowledge integration and to reconstruct the processes of cognitive reorganization by which a seemingly self-evident conceptual foundation of this knowledge was created. During the period of the report, the work by Ohad Parnes has been integrated into the projects of the research group headed by Hans-Jörg Rheinberger, where it is now being pursued under a slightly different perspective. (For a detailed report, see *p. 215.)*

Newton's Synthesis of φυσις and τεχνη and its Reception in the Hegelian System

Renate Wahsner (responsible) partly in cooperation with Horst-Heino v. Borzeszkowski

In his work *Philosophiae Naturalis Principia Mathematica*, Newton discusses the relation of practical mechanics to universal mechanics, as determined by his theory. He shows the former to be the basis of geometry, which "is nothing but that part of universal mechanics which accurately proposes and demonstrates the art of measuring," and is the precondition for and the core of the measurement-theoretical foundation of his theory. Under practical mechanics, Newton understands ancient mechanics or, more precisely, the theory of the so-called five simple machines: lever, wrench, pulley, wedge, and inclined plane. In his view, this mechanics treats the forces of the hand, while his own, *i. e.*, universal mechanics, treats the forces of nature. This means that Newton understands his classical mechanics as a theory of the forces of nature, including the forces of hand. To the extent that mechanics was not considered a theory of nature or a theory of φυσις but of τεχνη in classical Antiquity, a synthesis of φυσις and τεχνη inheres in this integration of the forces of nature and hand. Therefore, classical mechanics founds a new concept of nature, a concept that is characteristic of the thinking of the *Neuzeit*.

This project seeks to investigate the problem of how this new concept of nature, synthesizing nature as the objectively existing and the humanly acting, occurs as the subject of classical mechanics, as in its concept of motion, and how this synthesis is reflected by Hegel's natural philosophy. In this context, it will be clarified what role Hegel – in reference to Kant's idea of an organism – ascribes to teleology in his system.

As has been shown in previous investigations, Hegel's adoption of mechanics was determined considerably by the mechanistic concept of mechanics. This project intends to investigate the reasons for and manner in which the mechanization of mechanics was initiated by Voltaire.

The project includes the following activities: a German edition of Voltaire's work *Élémens de philosophie de Newton* (in cooperation with Horst-Heino v. Borzeszkowski); a discussion on the topic "Hegels Rezeption des neuzeitlichen Bewegungsbegriffs;" a paper on the reasons for the mechanization of mechanics (in cooperation with Horst-Heino v. Borzeszkowski);

and a paper on Hegel's natural philosophy.

The work on the German edition of Voltaire's works *Élémens de philosophie de Newton* and *Défense du Newtonianisme* was finished. The material was issued as a preprint of the Institute, and an expanded version was published in book form. The analysis of the intellectual circumstances under which Voltaire was writing shows that Voltaire, initiating the popularization of classical mechanics on the continent, simultaneously 1) founded a completely new type of popular literature on physics, 2) unified empiristic English Newtonianism with Cartesean rationalism in France, and 3) added fuel to the confrontation between Newtonianism and Leibnizian rationalism in Germany. As a consequence he made metaphysics aware of problems that hitherto were only considered by empirism. In so doing, Voltaire identified Newton's physical theory with the philosophical mechanistic conception of the world. This identification essentially molded the notion of mechanics, primarily that of German idealism.

The continuation of the work on Hegel's natural philosophy (publication of the book *Zur Kritik der Hegelschen Naturphilosophie. Über ihren Sinn im Lichte der heutigen Naturerkenntnis*, two seminars, a paper on Hegel's system and evolution concepts) demonstrates the lasting influence of this notion of mechanics. As was shown, this notion determines the way in which the evolution from Mechanics over Physics to Organics occurs in Hegel's natural philosophy, as well as what function for evolution is fulfilled by the concept of teleology.

The Philosophical Integration of Classical Science

Wolfgang Lefèvre and Falk Wunderlich

The classical modern sciences of the seventeenth and eighteenth century consisted not only of single theories – for instance, theories of motion in free fall, of percussion, of gravity, etc. – which reached a hitherto unknown level of intersubjective acceptance on the basis of experiments and methodically controlled observations. They were also characterized by attempts to construct overall theories of nature based on such single theories, which were to replace universal natural philosophy in the tradition of Aristotle. Examples are Kepler's "Weltharmonik," Descartes' mechanistic cosmology, Newton's speculations on "active principles," Leibniz' philosophy of "monads," Boscovic's and Kant's dynamism, and Le Sage's atomistic theory. These theories failed, however, to achieve a status of being intersubjectively shared. In retrospect it seems clear that the contemporary level of modern sciences provided too small a basis for these ambitious enterprises. Except among historians of philosophy, these universalist theories are forgotten today or mentioned only as metaphysical embryos of this early stage of the modern sciences.

These theories do deserve attention, however, if one wants to reconstruct a full picture of the emergence of the modern sciences. In particular, these theories represent, despite their entirely obsolete scientific bases, outstanding examples of the role of reflective thinking in integrating disparate pieces of scientific knowledge. From the perspective of historical epistemology, it is especially interesting to study how first-order concepts of the scientific theories which were to be integrated interacted with second-order concepts in the construction of these global theories. Reflections based on first-order concepts from the whole range of science played a role in both integration and in concept formation in single fields of scientific knowledge.

These processes are being investigated through the example of Kant's natural philosophy. A detailed documentation of the scientific concepts in Kant's pre-critical writings, based on an electronic version of the entire body of writing involved, is nearly finished. This documentation comprises in particular a list of Kantian notions used in his writings until 1780. Most of these notions will be supplemented by glossary entries which clarify their meaning and show parallels to contemporary usage. References to Kant's writings which contain definitions or give particular insights into the Kantian use of a notion will also be provided, and these notions will be cross-referenced to create a net of interrelations among them. The system of cross-references is differentiated into the categories "Synonyms," "Antonyms," and "Related Notions." In order to show the diachronic dimension, each notion will be associated with a brief note about the work (represented by year of appearance) in which it occurs.

In 1996 and 1997 the main task of the project, the research for and the writing of the glossary entries, was continued. Explorations and preparations regarding the technical possibilities for eventually publicizing the documentation with all of the facilities of an electronic database were started in 1997.

The Disintegration of Nineteenth Century Physics and its Reflection in Wittgenstein's Philosophy

Gerd Graßhoff

The physics of the last decades of the nineteenth century was confronted with a striking conceptual heterogeneity among its major subfields. As a response to this heterogeneity, several attempts were made at a conceptual unification, mostly based on proclaiming the core concepts of one subfield to be the basis for the unification of all of physics, if not of all of science. Examples are the "mechanistic" and "electromagnetic" world views, and also the world view of "energetics," based on fundamental concepts of thermodynamics. A unifying mechanical theory of all physical phenomena was pursued, in particular, by Kirchhoff, Helmholtz, Hertz, and Boltzmann. Such unifying programs lost their centrality due to the further progress of physics. Attempts to create a consistent, all-encompassing conceptual framework of physics were in fact pushed into the background, as were their claims to an integration of physical knowledge, by the conceptual incompatibilities that became visible with the borderline problems emerging at the boundaries of the competing theoretical frameworks.

In his investigation of late nineteenth-century natural philosophy, Gerd Graßhoff shows that these unificatory programs nevertheless had a lasting impact on the philosophy of science, which transformed some of the first-order concepts relevant to these programs into second-order reflective categories with a normative methodological character. This process is reconstructed for Wittgenstein's *Logisch-Philosophische Abhandlung*, which is shown to represent such a transformation, in this case of the program of natural philosophy laid out by Hertz's *Prinzipien der Mechanik*, Boltzmann's lectures in Vienna, and works on the theory of engineering in the tradition of F. Reuleaux. Details of Wittgenstein's studies of engineering in Berlin-Charlottenburg could be reconstructed and related to the project since new archival material from Wittgenstein's later friend Paul Engelmann has been found. New findings of documents from Heinrich Hertz draw a much more detailed picture of what was commonly referred to as "exact sciences" as a scientific research program, for which Wittgenstein believed his early philosophy to be a valuable contribution. It confirms that with a full grasp of its physical content, Wittgenstein used Hertz's *Prinzipien* as the foundation for the philosophical architecture built in close contention with the logical theory proposed by Russell and Frege.

The Relativity Crisis and the Reorganization of Classical Knowledge on Gravitation – the Reconstruction of Einstein's Discovery Process

Jürgen Renn, Tilman Sauer, John Stachel (Max Planck Institute for the History of Science), Michel Janssen (Boston University), and John Norton (Pittsburgh University)

The study is devoted to a reconstruction of the emergence of the General Theory of Relativity. On the basis of an exhaustive examination of all available historical sources, comprising, in particular, published papers, correspondence and research notebooks, the development of Einstein's thinking on gravitation is traced from his first publication on the subject in 1907 to the publication of the final version of the theory in 1915. The aim is to reach a systematic understanding of both the knowledge basis in classical physics for Einstein's achievement, and of the nature of the developmental process by which his research overcame some of the conceptual foundations of classical physics. The results of the reconstruction are documented in the form of detailed commentaries on the historical sources and in the form of a new interpretation of the early history of General Relativity.

Einstein's general theory of relativity emerged in reaction to a fundamental conceptual crisis of classical physics, characterized by foundational inconsistencies between classical mechanics, classical electrodynamics and special relativity. Even though the challenge of reconciling classical mechanics and classical, special-relativistic electrodynamics was recognized and taken up by many contemporaries, the conceptual breakthrough to the theory of general relativity was achieved largely by Einstein and his immediate collaborators in the years between 1907 and 1915. The theory he finally published in 1915 provides the successful revision of the classical theory of gravitation and eventually became part of the canonized knowledge of modern physics.

The emergence of the general theory of relativity has been the object of extensive joint research by a group of scholars associated with the Institute. This work was originally pursued in the context of the Arbeitsstelle Albert Einstein and since has been essentially completed at the Max Planck Institute for the History of Science. In particular, a meticulous line-by-line analysis of a key document from the period between 1912 and 1913, the so-called "Zurich Notebook," has been completed by a joint effort of the members of the research group. A preliminary discussion of the interplay between formalism and heuristics, based on the joint analysis of the Zurich Notebook, has been published. The subsequent work of the group focused on the question of how Einstein overcame the misconceptions of an intermediate version of his relativistic theory of gravitation, the so-called "Entwurf theory," established by his efforts from 1907 to 1913. Several interpretative essays on this question have been written by members of the group. Furthermore, an extensive, line-by-line commentary on Einstein's published papers on gravitation from 1907 to 1915, analogous to the commentary on the Zurich Notebook, has been completed in large part. Although the work of the group mainly focused on Einstein's search for the gravitational field equations, the systematic efforts to analyze all available sources on his thinking on gravitation from the perspective of this study also have led to several conclusions concerning other aspects of the history of general relativity; these results have been published in papers by members of the group. It is planned to publish the cumulative results of the reconstruction of Einstein's discovery process in a comprehensive monography which is currently in preparation.

On the basis of the results achieved to date, a comprehensive reassessment of the emergence of the theory of general relativity from the point of view of an historical epistemology has now become possible and will be the main topic of the planned monography. This reassessment cannot be discussed here in detail. However, the overall structure of the emergence of General Relativity resulting from our study, as well as some of the concepts we have used in order to describe this structure, deserve mention.

Einstein's path to general relativity essentially began in the year 1907 with the formulation of the later "equivalence principle," and ended in the fall of 1915 with the discovery of generally covariant field equations for gravitation. The equivalence principle, embodied by such mental devices as the freely falling elevator, served as a basic *mental model* for the relation between gravitation and inertia. By linking effects in accelerated frames of reference to gravitation, it provided an *integrative perspective* from which separate branches of classical physics could be related to each other, thus establishing connections, *e.g.*, between gravitational and optical phenomena. Searching for an understanding of gravitation with the help of this mental model, Einstein achieved striking qualitative insights into the empirical consequences which the new theory of gravitation should have, for instance, the deflection of light in a gravitational field. In the course of

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this reconstruction it became clear that even as early as 1912 he elaborated this insight into a quantitative prediction of gravitational lensing.

Other fundamental structures of knowledge relevant to Einstein's search for a new theory of gravitation were those incorporated in the understanding of what an equation of motion and what a field equation mean in classical physics and the special theory of relativity. This understanding involves concepts such as those of force, energy, momentum, potential, field, source, and mass. In order to capture the role of these concepts as heuristic orientations for Einstein's search, beyond their role as elements of any specific physical theory, the project has used the concept of *frame*. With the help of this concept, those common properties which relate the understanding of the Poisson equation in classical physics to the Einstein equation of general relativity have been described, to substantiate the claim that these common features played an important role in the historical development linking the two equations.

In addition to the identification and systematic description of basic structures of knowledge relevant for Einstein's achievement, the role of mathematical representations for the evolution of his thinking has been studied. It has been possible, in particular, to provide a detailed account of the interaction between his exploration of these representations and the basic physical concepts used in his emerging theory of gravitation. Two distinct heuristic strategies have been identified in Einstein's research which mediate between the available mathematical representations and his physical understanding. One strategy was to take as the starting point physical considerations derived from classical physics, such as energy-momentum conservation and the recovery of Newton's gravitational theory in a suitable limit; the other strategy was to begin from mathematical considerations concerning the covariance group of candidate field equations and then to attempt to find a consistent physical meaning – from the point of view of classical physics – for the mathematical objects under consideration.

The reconstruction of the calculations in the Zurich Notebook led to the astonishing result that, following the mathematical strategy, Einstein had already considered the correct field equations of 1915 (albeit in linearized approximation) in 1912, and had thus come within a hair's breadth of the final general theory of relativity. He failed to recognize the physical meaning of these equations, however, and turned to the alternative, physical strategy. In the sequel he published the "erroneous" "Entwurf" field equations of 1913.

The work in the time covered by the report mainly focused on the question of how Einstein was nevertheless able, in the period between 1913 and 1915, to overcome those obstacles which prevented him from realizing that the correct field equations were the ones derived in his notebook and not the ones he published in 1913. The answer to this question found in the course of this project leads to the surprising insight that, contrary to what is commonly accepted, the long interval between the publication of the erroneous field equations and the dramatic return to the correct equations at the end of 1915 was not simply a period of stagnation. It was rather a period during which Einstein arrived at a number of insights creating those crucial preconditions which made the dramatic events of November 1915 possible. Paradoxically, this state of elaboration itself had to be reached under the guidance of the erroneous "Entwurf" theory. This result suggests that the establishment and stabilization of the new physical concepts that emerged with general relativity first required a degree of elaboration of the mathematical formalism which went considerably beyond finding the correct field equations.

A comparison with Hilbert's contemporary work on gravitation, performed in the context of this study, has shown, on the other hand, that an exploration of the relevant mathematical formalism cannot have been the only process driving the conceptual changes associated with the emergence of General Relativity. In fact, it turned out that Hilbert, in spite of his superior mathematical competence and contrary to commonly held views, did not arrive independently at the field equations of general relativity (see also the *History of Alternative Approaches* below). Our study suggests rather that the reconceptualization of gravitation, space, and time brought about by General Relativity could only succeed under the guidance of Einstein's peculiar heuristics which represented his integrative perspective on the knowledge of classical physics.

The Relativity Crisis and the Reorganization of Classical Knowledge on Gravitation – the History of Alternative Approaches

Leo Corry, Shaul Katzir, Christopher Martin, Jürgen Renn, Tilman Sauer, Matthias Schemmel, Christopher Smeenk, and John Stachel

Several research activities have been dedicated to the study of theories of gravitation before and after the advent of Special Relativity. The primary aim is to reach an understanding of the "*horizon of possibilities*" of reacting to the crisis provoked by the conflict between the understanding of gravitation in classical physics and the challenge represented by the special theory of relativity. In this sense, the study also aims at providing a broader context to the reconstruction of Einstein's singular achievement, thus contributing to an explanatory history of modern physics. It is being examined, in particular, which approaches to the problem of gravitation existed in late classical physics, on which intellectual resources the different approaches relied, the extent to which they were able to respond to the crisis of classical physics, what potential alternative scenarios to the one actually realized existed, and for which reasons Einstein's General Relativity eventually came to be accepted as the resolution of the crisis.

As mentioned above, the crisis became apparent when it turned out that Newton's gravitational force law was incompatible with the new concepts of space and time introduced by the special theory of relativity in 1905. Whereas the classical theory of gravitation postulated an instantaneous action at a distance, the concept of velocity in Einstein's new kinematics excluded any physical action at speeds greater than that of light. It is therefore no surprise that not only Einstein but also several of his contemporaries addressed the problem of formulating a theory of gravitation which complied with the new kinematics of relativity theory. The analysis of these alternative approaches, as well as of earlier alternative approaches to gravitation within classical physics, helps to identify the necessities and contingencies in the actual historical development.

The history of alternative approaches to the problem of gravitation in late classical physics is still largely unexplored. A first step undertaken in this study was therefore the creation of a survey of primary sources, recorded in a database. In addition, several in-depth studies have been completed during the period covered by this report, each dealing with specific aspects of the historical development. Preparatory work has been done on a volume including three types of texts: selected original papers translated into English, editorial notes on the primary sources, and detailed studies of specific aspects, in particular those prepared at the Institute. The volume will be supplemented by a CD-ROM containing a broader selection of primary sources.

The volume will contain, in particular, the following contributions:

- a study by Jürgen Renn on the conceptual resources for solving the problem of a relativistic theory of gravitation in the traditions of mechanics and field theory;
- a study by John Norton on the elaboration of a special relativistic alternative to Einstein's approach by Gunnar Nordstrøm and others;
- a study by Julian Barbour on the role of the Machian tradition of mechanics on the development of General Relativity;
- a study by Leo Corry on David Hilbert's work on relativity in the context of his attempts to develop a unified axiomatic approach to the whole of physical science;
- a study by Jürgen Renn and John Stachel on the relation between physical interpretation and mathematical formalism in the evolution of Hilbert's thinking on gravitation;
- a study by John Stachel on the possible alternative scenario that a reformulation of Newton's theory of gravitation using the concept of an affine connection had been developed before Special Relativity.

In the period covered by the report new results have been found, in particular concerning Hilbert's role in the development of General Relativity. Earlier research on his role essentially followed the common view that Hilbert independently derived the field equations of General Relativity five days before Einstein on 20 November 1915 – after only half a year's work on the theory. The studies on which we have reported in the section on *The Reconstruction of Einstein's Discovery Process* have led to an essential correction of this view. Here we focus only on the peculiarities of Hilbert's contribution which recently have become clear. It was generally known that Hilbert's approach had two separate starting points, Mie's special relativistic electromagnetic theory of matter and Einstein's early attempts to base a theory of gravitation on the metric tensor. It has now turned out that not only his starting point but also his results were different from Einstein's. Hilbert's path did not, in fact, actually lead to General Relativity, but to a theory whose physical meaning was quite different from that of Einstein's final achievement and rather more closely related to both Mie's speculative theory of matter and to Einstein's earlier, non-covariant versions of a theory of gravitation. Only by adapting elements of Einstein's approach in the course of his work did Hilbert rederive results in General Relativity – and then, only at the price of inconsistencies with his own physical approach.

The Relativity Crisis and the Reorganization of Classical Knowledge on Gravitation – the Contexts of the Establishment of General Relativity

Giuseppe Castagnetti, Peter Damerow, Hubert Goenner, Folkert Müller-Hoissen, Jürgen Renn, and Britta Scheideler

The aim of the studies reported here is to analyze various contexts of the establishment of General Relativity as part of the canon of modern physics. One study is dedicated to the academic context of General Relativity, in particular to the integration of the theory into a teaching tradition. This study focuses on an edition of student lecture notes from Einstein's courses on General Relativity. Several other studies deal with the political contexts of the creation and reception of General Relativity. They are dedicated to Einstein's political engagement during and after World War I, to the evolution of his political thinking and its relation to his role as a scientist, and to the conflicts with his colleagues and with his institutional context, in particular with the Berlin Academy.

Teaching constitutes an essential intermediate step in the process of the social mediation of scientific research results. While the processes underlying the development of the physical theory, documented by research notes and publications in scientific journals, form one pole in the communication chain, the other pole comprises the mediation of research results in textbooks and popular expositions. The oral teaching tradition lies between these poles; in its early phase, the reflection on topical research problems and the constraints arising from the need to embed the new theory in the canon of scientific tradition are close to each other. Here one has the chance to study in detail the rise of a generally accepted "context of justification" from the individual "context of discovery" and to relate questions of the reconstruction of individual cognitive processes to questions of the social development of knowledge.

Einstein's early courses are a valuable source for the reconstruction of this academic context of the history of relativity theory. Tilman Sauer and Folkert Müller-Hoissen have concentrated on student lecture notes from Einstein's courses for which his original notes are not preserved. They worked, in particular, on a course on General Relativity probably held in the summer semester 1919 at the University of Berlin. For this course there are notes from Hans Reichenbach preserved in the Reichenbach archives in Pittsburgh. The aim was to edit a transcription of these notes, to be accompanied by extensive editorial and historical comments and by brief reviews from the perspective of modern physics of central topics addressed in the manuscript. Although work on transcription and commentary is well advanced, the edition project had to be suspended for the time being since both Tilman Sauer and Folkert Müller-Hoissen left the Institute in order to take up more permanent positions in other fields.

The analysis of Reichenbach's notes has turned out to be particularly valuable for an assessment of the relation of the early teaching tradition of General Relativity to Einstein's discovery process. Einstein did not give an axiomatic introduction to the theory of general relativity in these lectures, but followed a course which very much parallels the actual historical development. He started by pointing out deficiencies of both the theory of special relativity and of classical mechanics, and discussed in particular those elements which had played a major role in the heuristics and had guided his search for a general theory of relativity. The lectures end with a discussion of problems at the cutting edge of research at the time, namely the "cosmological problem" and a modification of the field equation in order to set up a theory of the electron, related to a paper he presented in April 1919 to the Prussian Academy of Science.

Einstein's fame after the confirmation of the bending of light in 1919, predicted by General Relativity and generally taken as a proof for the validity of this theory, was a central reason for the intense reaction to him as a political figure in the public sphere. Understanding and assessing Einstein's historical role as a prominent public figure, who simultaneously became a symbol of successful scientific creativity as well as of heated ideological dispute, was at the center of an investigation by Hubert Goenner and Giuseppe Castagnetti, based on earlier work in the context of the Arbeitsstelle Albert Einstein, as well as on further extensive archival research.

The results of this work since have been published. The paper by Castagnetti and Goenner discusses, among other issues, Einstein's radicalization, and clears up the circumstances of his public appearance during the revolution in November 1918. Einstein's role in the Bund Neues Vaterland and other pacifist organizations, as well as his interaction with other pacifists in Germany and abroad, could be exposed and analyzed in detail. In contrast to the generally accepted view, the study has led to a reappraisal of Einstein's pacifist activity. It shows that he only rarely applied social and political categories to the events during the war and that Einstein's pacifism remained one more of creed than of deed.

The research on Einstein's political biography was complemented by a study by Hubert Goenner and Britta Scheideler on Einstein's political thinking and behavior in the context of the reaction of natural scientists to the cultural and social changes between 1914 and 1933. Due to Britta Scheideler's departure for a more permanent position at another institution, the study could, however, not be completed. First results were presented at an international colloquium on Einstein in Berlin, held in March 1997 in Boston and co-organized by the Center for History and Philosophy of Science at Boston University, the Collected Papers of Albert Einstein and the Max Planck Institute. The preliminary results will be published as a paper.

In particular it could be shown that, contrary to his scientific thinking and contrary also to a view that is widespread in the literature, Einstein's political thinking and behavior were not characterized by radical breaks with respect to his contemporaries' politics. Rather, his thinking and behavior were influenced by his self-image as a scientist. Einstein grew into the role of an involved intellectual whose political thinking was based on generalizing the model of the "true scientist" to that of an ideal individual, opposed to dominant values of the society. This role with its critical distance from the dominant social and political standards set him apart from the majority of both humanities professors and natural scientists. But Einstein's understanding of this role was largely structured by traditional ideas on the role of the individual, and in particular that of the elitist individual in society. In fact, as an intellectual, Einstein felt that he belonged to an "elite of values," a position that determined his understanding of democracy. Surprisingly, it turns out that his political thinking was *not* pluralistic, in the sense that he did not acknowledge competing social groups with conflicting interests. While witnessing the contemporary disarray of the social and political foundations, Einstein remained under the influence of rather old-fashioned and naive ideas about society, and essentially denied part of the social and political reality with which he was confronted in his Berlin years.

That Einstein's political attitudes and actions nevertheless brought him into conflict with his colleagues and with his institutional context is shown by a study of Giuseppe Castagnetti, Peter Damerow, and Jürgen Renn begun in the period covered by the report. Analyzing Einstein's relation to the Berlin Academy in the years between 1914 and 1933, the study indicates that his forced retreat from the Academy in 1933 was not only the result of increased external pressures by the rise to power of Nazism. It rather seems that Einstein's ultimate conflict with the Academy was a consequence of the Academy's loyalty to the state, an effectively political role that was shunned by its apolitical self-understanding. The persistence of this role is illustrated by the position that the Academy had taken all long with regard to Einstein's political attitudes and actions since he assumed membership in 1914. Preliminary results of this study were presented at a colloquium of the Berlin-Brandenburg Academy in November 1996.

The Quantum Crisis and the Reorganization of Research Strategies in Classical Physics – the Cases of Einstein and Bohr

Giuseppe Castagnetti, Hubert Goenner, Dieter Hoffmann, Edward Jurkowitz, Horst Kant, Alexei Kojevnikov, Jürgen Renn, and Arne Schirrmacher

The goal of the study was to undertake collaborative research with the intention to reconstruct the reorganization of physical research as a reaction to the emergence of "quantum problems" early in the twentieth century, meaning the problems which contributed to a disintegration of classical physics and which were eventually recognized as pertaining to the range of quantum theory. The study's central interest was the question of the extent to which such a reorganization took place as a result of explicit reflections on the disintegration of classical physics. It was planned to concentrate activities on four of the major sites of exploration of quantum theory, where some of the most powerful and successful physicists and organizers of the work toward the elucidation of quantum problems lived: Berlin, Munich, Göttingen and Copenhagen. For each of these locations, the various social and cognitive processes behind the shift that put the quantum at the *center* of research activities were to be investigated.

The problems later recognized as quantum problems pertained to such different areas of research in classical science as black body radiation, spectroscopy, or solid state physics. Typically they were "borderline problems," in the sense explained in the introduction to Project 2, that is, located at the frontier between partially distinct conceptual frameworks of classical physics. The incompatibility of these problems with the foundations of classical physics and their mutual interrelationships were only recognized gradually. This process extended over a quarter of a century, roughly between 1900 and 1925, and involved a considerable number of physicists, chemists, and mathematicians from several countries. While the emergence of new theoretical concepts and new experimental results have been extensively studied by historians of science, the processes of knowledge integration underlying this development still require further study. The focus of research at the Institute concerned only one specific aspect of this integration: the effect of contemporary scientists' recognition of quantum problems and their interrelationships to the shifting of their research foci, reallocation of their resources, and reorganization of research structures and policies. In this way, the study has sought to answer the question of whether quantum theory was developed, like Einstein's theory of relativity, primarily by the individual contributions of a few distinguished scholars or, in contrast to Einstein's discovery, by the joint effort of a scientific community interacting according to principles also at work in modern research institutions. The study thus had the aim to bridge the gap between work on individual physicists' paths of discovery and research on the institutional history of science.

In the period covered by this report, however, the study could not be completed as originally planned for two main reasons: the departure of junior visiting scholars for more permanent positions, and other activities of research scholars of the Institute, in particular due to outside obligations partly incurred prior to their participation in the study. Archival work in the Sommerfeld Archive in Munich (Horst Kant) was temporarily suspended and has only recently been resumed with the aim to provide material for a future study of Sommerfeld's research policies. It is generously supported by the cooperation of the Sommerfeld project (Michael Schüring, Michael Eckert), with which transcriptions of primary documents are being exchanged. Work on the research policies of the Physikalisch-Technische Reichsanstalt (PTR) during the early history of quantum theory (Dieter Hoffmann) has also been pursued only on a reduced scale.

Although the major comparative study between different research centers could not be completed as originally envisaged, the more limited goal of performing a comparison between at least two institutions with different research policies and their impact on the development of quantum theory could nevertheless be reached, in particular due to contributions by visiting scholars of the Institute. Work has therefore been refocused on the cases of Einstein and Bohr and is, within this narrower scope, essentially finished. Two major studies, one on Einstein's role at the Kaiser-Wilhelm-Institut für Physik in Berlin (by Giuseppe Castagnetti and Hubert Goenner), the other on Niels Bohr and his institute in Copenhagen (by Alexei Kojevnikov) have been completed. They have prepared the ground for a detailed comparison of the readjustments of research policies – in reaction to the quantum crisis – in one institution at the "center" (Berlin) and another institution rather more at the "periphery" (Copenhagen) of the academic world of the time. It is planned to publish the results of the joint work with an extensive introduction in a book edited by Jürgen Renn. A related study by Jürgen Renn, completed in the period covered by this report, was dedicated to the tension in late classical physics between specialization along traditional borderlines and the possibility of integrating knowledge accumulated in and spread over various disciplines and subdisciplines. The study has focused on the origin of statistical mechanics and its applications, including those to the early quantum problems.

The work on the research policies of the Kaiser-Wilhelm-Institut für Physik (Castagnetti and Goenner) has shown that the foundation of an institute under Einstein's directorship, promoted by an influential group of Berlin physicists, administrators, and industrialists, was a reaction to the increased differentiation within physics and to the increasingly important role of Planck's quantum as a germ of crystallization of a growing field of knowledge. The creation of the institute was a concrete reaction to this situation which attempted to take advantage of Einstein's ability for conceptional integration for an organization of science. It turned out, however, that this attempt was essentially a failure. The integration of the knowledge from physics and chemistry that was required for the formulation of the later quantum mechanics could, it appears, neither be achieved by the intellectual work of a single outstanding individual such as Einstein nor by traditional types of intellectual cooperation. In particular, the failure of the Kaiser-Wilhelm-Institut to promote regular and lasting collaboration among scientists on a set of challenging research problems, across traditional disciplinary specializations, can be interpreted as a failure of the "academy model" of research policy and funding. (The role of the academy model is also the subject of a study on Einstein and the Berlin Academy by Giuseppe Castagnetti, Peter Damerow, and Jürgen Renn, see also *The Relativity Crisis and the Reorganization of Classical Knowledge on Gravitation – the Contexts of the Establishment of General Relativity p. 87).*

The study on the history of Niels Bohr's research policies from 1913 to the advent of quantum mechanics in 1925 (Kojevnikov) is based on extensive archival research in the Niels Bohr Archive in Copenhagen and in other archives. It not only shows that the political circumstances of the time provided a neutral country like Denmark with a special opportunity to play a new and more important role in the international scene. It also makes it clear that these circumstances, in particular after the First World War, weakened traditional scientific institutions and, at the same time, the traditional professional and intellectual loyalties fostered by them. As a consequence, the relatively small Bohr institute could create new, transnational bonds between scientists which were more flexible than the established ones. These new, less rigid connections also allowed for the integration of a variety of local scientific traditions, which were then brought to bear on specific problems of the emerging quantum theory. This development is exemplified by several case studies treated within the study. In the period covered by the study so far, Bohr's intellectual agenda evidently played an important role for the identification of research problems. The present study will be supplemented by a more detailed analysis of this agenda, possibly in comparison with that of Einstein.

The Disintegration of Evolutionary Biology

Peter J. Beurton

In the period extending roughly from the early 1930's to the 1960's, the neo-Darwinian paradigm, founded by scholars like R. A. Fisher, S. Wright, T. Dobzhansky, and E. Mayr, which also has become known as the "synthetic theory of evolution," seemed to provide an all-embracing, monolithic framework of evolutionary biological thought. By approximately 1970 this paradigm was replaced or complemented by a number of new evolutionary approaches which called even the most fundamental concepts of the previous period into question. There are no longer unequivocal definitions of "adaptation," "gene," "species," or, in fact, "Darwinism."

While evolutionary biology can no longer be viewed as a unified field of knowledge, its foundational concepts, such as the concept of the gene, nevertheless still play a role for knowledge integration in biology – relating insights in molecular biology to knowledge in population genetics, for example. We are thus confronted with a protracted, still open-ended period of scientific turmoil. Analyzing the implications of this integrative function of the foundational concepts of evolutionary biology is one of the central objectives of the studies pursued by Peter J. Beurton. His present research project, which builds on his previous work on the history and structure of the synthetic theory of biological evolution as well as on his investigations into the biological species concept, concentrates on the concept of the gene.

Peter J. Beurton, Wolfgang Lefèvre, and Hans-Jörg Rheinberger have organized an international working group to investigate the historical development of this concept. A first workshop of this group was held two years ago (see the preprint no. 18 based on this workshop). A second workshop on this topic was held in the fall of 1996 and has been followed in the meantime by the preparation of a book manuscript by the participants of the workshop (see *p. 247*). Peter Beurton, Raphael Falk, and Hans-Jörg Rheinberger prepared written comments for the external reviewers and the authors, as well as an early draft of a "Commentary Overview" paper that should summarize the notions discussed in the workshop and in the submitted papers. A comprehensive literature list of all the papers also was compiled.

Moreover, Peter J. Beurton has worked to provide an outline towards a comprehensive view of the synthetic theory and has made a biographical sketch of two major figures (T. Dobzhansky and S. Wright) involved directly or indirectly in the synthesis. As a case study to elucidate the principles of the development of the evolutionary theoretical argument, he has submitted an essay on the development of the young Darwin's thinking.

Peter J. Beurton has continued with the construction of a database for conceptual problems in evolutionary biology which builds on a core collection of 2500 papers deposited at the Institute (at present 4000 entries).

Associated Research Activities

History of Atomic and Nuclear Research

Horst Kant

In preparation for a project on the history of atomic and nuclear research (from radioactivity to nuclear fission), which will start in 1998, a number of single contributions were completed by Horst Kant. Many of these were also connected with some of the author's previous projects, concerning among others the history of the German Uranium Project and the history of the Kaiser-Wilhelm-Institut für Physik.

One group of papers concerned the early history of radioactivity, dealing with the contributions of A. H. Becquerel and the younger E. Rutherford in particular, and comprised the first steps of the new study.

Another set of papers dealt with issues subsequent to the above mentioned project. Among these was a lecture given on the German Uranium Project at an international conference on the History of the Soviet Atomic Project in Dubna in May 1996. Results of this conference were included in a lecture on the history of physics in the Soviet Union at the Freie Universität Berlin in January 1997; a publication will follow in 1998.

Aspects of Institutional History

Horst Kant

In connection with previous projects, a smaller-scale study on the history of physics at University of Strasbourg during the Second World War was carried out within the framework of an international project on the history of Strasbourg universities (the "HISA"), coordinated by GERSULP at the University of Strasbourg. For this subject, for which only a minimum of preliminary work has been performed, extensive archival studies were necessary, complemented by interviews with persons involved in the subject at that time. The result of this activity was a manuscript, completed in mid-1997, which will be included in a book of collected papers on this subject (to be published in 1998). An extended form of this manuscript appeared as preprint no. 73.

In addition, in early 1997 Kant completed the edition of a book with the title *Fixpunkte - Wissenschaft in der Stadt und der Region*, which dealt in a wider sense with science and urbanization. Included in this book is a paper by Kant on regional aspects of communication structures, concerning the development of physics in Berlin at the turn of the last century. In this connection, in-depth studies of the physicist Emil Warburg and his work, and of other scholars in Berlin, also were completed and published. Additional related studies were carried out on Helmholtz, presented at such fora as a conference of the Interdivisional Group on History of Physics of the European Physical Society in Bratislava in August 1996, and published in the proceedings of this conference.

The Contribution of the Physikalisch-Technische Reichsanstalt to Quantum Physics

Dieter Hoffmann

Connected with the general approach of the quantum project, the aim of this study is to investigate the role of the Berlin Physical Institute (Physikalisch-Technische Reichsanstalt) in the early history of quantum physics. As a reaction to the challenges of the new quantum theory, the institute's scientific research program turned to related problems: photochemistry, lowtemperature physics, radioactivity. In these fields the PTR was able to contribute important solutions to special quantum problems and to establish a fruitful, but limited and traditionally oriented interaction between theory and experiment. These achievements made the PTR an important center in the early period of experimental quantum physics, and allowed it to become a leading power in a highly developed culture and long working tradition of precision measurement. Since the general approach to quantum problems was quite conservative and the contributions were focused on very special problems, the PTR's contribution to the history of quantum theory was both timely and of short endurance.

An Exhibition on Max Planck

Dieter Hoffmann

In 1997 Dieter Hoffmann organized an exhibition, "Max Planck – Leben, Werk, Persönlichkeit." The exhibition was co-sponsored by the German Physical Society and was held in the Magnus-Haus Berlin. The activities connected with this exhibition are a starting point for further research on Planck. This research will focus on two subjects. Firstly, research has shown that Planck's position in German society and his role as a scientific organizer and politician should be investigated in more detail and in a more general perspective. A comparative study of Planck and Harnack and their behavior at points of rupture (*Umbruchsituationen*), and their reaction to both political and scientific crises is under way (together with J. Renn and G. Castagnetti). This study will continue with a detailed documentation of Planck's role and behavior during the Third Reich. Already completed is a paper dealing with the myth and legends of Planck's personality during the post-war period and its instrumentalization in the framework of the Cold War, especially in connection with the celebration of the Planck centenary in Berlin in 1958.

Secondly, as a continuation of the research on the role of the PTR in early quantum physics, the reception of Planck's radiation formula will be documented. While Planck's formula generally has been discussed in the framework of quantum history, this study will treat the formula as a problem of precision measurement, as only a few laboratories in the world had achieved the technical capabilities and the experimental tradition of the PTR which enabled it to carry out measurements in this field.

Science and Technology in the GDR

Dieter Hoffmann

A project on the history of science and technology in the former German Democratic Republic, which was started in 1993 under the direction of Dieter Hoffmann and Kristie Macrakis (Michigan State University) and sponsored by the Humboldt Foundation and its transcoop project, was completed during the period covered by the report. The edited volume of papers gives a representative overview of the development of specific areas and disciplines, ranging from studies on science policy and special scientific institutions, to the history of disciplines and professions as well as the biographies of scientists whose careers were typical for GDR society. Most of the studies had a comparative perspective – between East and West, among the socialist countries, and between Nazi Germany and the GDR.

Future research in this field should continue with additional biographical studies and with more general investigations into the conditions of scientific research in totalitarian societies.

Project 3: Dynamic Models of Scientific Discoveries

Gerd Graßhoff, Bruce Eastwood, and Michael May

General Goals of the Project

The project studies the development of scientific discoveries as a genesis of a network of scientific ideas, research practices, and their material preconditions in specific historical contexts. Historical explanations of discovery processes must identify the ingredients of concept formation processes and the generative steps by scientific actors who utilize those ingredients as means to create new hypotheses, instrumentation and research practices.

To investigate such processes, an explanatory framework is assumed. The set of cognitive components relevant for the discovery process forms an epistemic system, which can be described by a dynamic model of scientific discovery. Such a model should represent epistemic goals that direct the agent to the solution of his problem; propositional attitudes such as beliefs, assumptions, or considerations, regardless of their truth value; and heuristics, which are rules of action according to which either propositional attitudes (*e.g.*, belief in a causal hypothesis) are generated or physical actions (*e.g.*, experiments) are performed. Finally, epistemic actions realize the proposed steps in the discovery process.

Although discovery processes clearly have to do with scientific beliefs and their changes, it is strongly emphasized that models of the dynamics of beliefs alone are insufficient for a theory of scientific discovery. Instead, practical reasoning related to human action both for physical and mental acts provides the generative frame for a historical explanation of cognitive processes as they are exhibited in the development of science. Surprisingly few heuristic rules suffice to coordinate hypothesis creation processes and form the ‘motor’ of changes during a scientific discovery process.

The focus of the reconstructed historical events are cognitive states and their preconditions related to scientific discovery, among them:

— scientific hypothesis;

— goals to be pursued in the course of scientific activities;

— scientific practice, which rules scientific experimentation, creates observable effects or crafts computer programs that evaluate the data obtained through scientific actions and their material preconditions;

— scientific objects (*e.g.*, objects of study), material devices for experimental and observational contraptions, and material tools of scientific reasoning (*e.g.*, computers or graphical representations).

The close connection between goals, actions and theoretical knowledge lies at the heart of the analysis of scientific discovery processes. This connection is far from obvious, since the link between scientific enterprises and actions is no more direct than that between actions and theoretical content. For example, the goal that a certain hypothesis should be empirically validated does not specify a particular action to pursue that goal. Hence, on the general level, this model focuses on those intentions which relate to scientific actions. Furthermore, the model does not differentiate principally between physical actions like performing an experiment, and mental acts like constructing a hypothesis.

The history of a scientific discovery process is manifest in the changes of the state of the epistemic system. These similarly affect goals, actions and beliefs, and the state of the material things relevant for the discovery. Models of historical processes are tested by comparing the sequence of the model's states with documents produced by the researcher throughout his work. These historical investigations cover both experimental scientific activities (the case study of the discovery of the urea cycle) and theoretical development (history of planetary theory). The experimental study will concentrate on a micro-study of one single discovery process of a team of just two researchers, while the long-range study examines the development of planetary theory by many participants.

Discovery of the Urea Cycle

Gerd Graßhoff, Michael May

This study focuses on hypothesis formation by experimental means. It investigates the discovery of the urea cycle, a major biochemical discovery made by Hans Krebs and his assistant Kurt Henseleit in the 1930's at Freiburg. Before Krebs and Henseleit, the synthesis of urea in mammals had been investigated for a long time, but without definitive results. In a long series of skillfully arranged experiments, Krebs and Henseleit were able to establish the cyclic nature of this process. The laboratory notebooks of both researchers have survived and provide detailed historical data for studying the strategies of hypothesis formation based on experiment. The case is especially suited to this task since the theoretical background knowledge available to Krebs at that time was comparatively shallow. This forced him to perform much experimental work during hypothesis construction and testing, leading to a materialization of thought processes in a series of experimental setups. Since experimental setups and results are written down in lab books practically at the time of their conception, the danger of false recollections from memory is reduced significantly. Krebs and Henseleit executed more than two hundred experiments in all stages of their approximately ten-month investigation, producing data for most activities related to experimental research, such as the design of a measurement process, the search for a reproducible effect, the formulation of a hypothesis, or its final verification.

In contrast to a reconstruction by Frederic L. Holmes (Yale), it is assumed that the discovery process as documented in the laboratory notebooks can be explained up to a fair level of detail by assuming some very general principles of causal reasoning. To this end, the concept of a causal structure is given a precise meaning, and the close link between such a structure and strategies of experimentation is elucidated. These principles are embedded in a larger structure called an epistemic system, which, through computer simulation techniques, allows the explanation of a discovery process as a goal-oriented activity guided by heuristic principles. Thus the importance of cognitive factors in an explanatory framework is emphasized. That this framework proves to be fruitful for a historical study is shown by providing a detailed historical and methodological commentary to all of the more important experiments documented in the notebooks.

To make available to the public the primary data, including Krebs' and Henseleit's laboratory notebooks and the relevant literature, these have been collected in a database which will be made available in its final version on the Internet. Additionally, the database will contain the commentaries of the project group, and also the relevant parts of Holmes' previous reconstruction. Thus it will document ongoing discussions of the group with Holmes and Herbert A. Simon (Carnegie Mellon University) on the adequate reconstruction of this case, both historically and methodologically. Since the database provides immediate access to most of the relevant primary and secondary sources, it is also intended to invite other scholars to participate in this discussion, possibly using the database itself as a discussion forum.

After completion of the database the project again will take up the task of providing a computer simulation of this discovery. A previous model provided a reproduction of the historical path leading to the discovery (Graßhoff & May 1995): based on the relevant knowledge available to Krebs and Henseleit at the time of their investigation and assumptions about their heuristics and reasoning strategies, the system simulates the history of the discovery. The next step will be to allow for counterfactual interferences at some crucial episodes. How will the model behave if relevant knowledge is removed or additional knowledge added? Does it prevent the epistemic system from attaining its goal? Does it take an interesting alternative path? Such counterfactual simulations do more than provide a test for the adequacy of a proposed model, since it should act reasonably under such variations. The tables can be turned by provisionally accepting the adequacy of the heuristical structure and starting from the diagnosis of what knowledge Krebs needed in order to be able to make his discovery. Alternatively, simulation can determine which items of knowledge were crucial and which were not, thereby addressing the question of why Krebs was able to make the discovery while his competitors were not.

Here interaction with the database becomes important. By giving access to the laboratory notebooks, literature, etc., the database allows to check efficiently which items were available at Krebs' time and which were not. When the simulation model is used as a heuristical device for generating historical hypotheses, as described in the last paragraph, such hypotheses can be validated or refuted with reference to the historical documents.

Associated Research Activities

The studies described in the following are complementary to the one on which the last section reported. Firstly, the formation of planetary theories from their early Babylonian origin to their transformation into a physical theory by Kepler is a paradigmatic case of theory formation not driven by experimental means. In fact, here experimentation plays no role at all. This allows an approach which counters potential objections that the theory of Epistemic Systems is built upon an empirical basis that is not varied enough. Secondly, the epistemic system under study is not confined to a single person or single group of persons: it embodies a process of collective scientific model building with cooperative actions and the expansion of scientific knowledge, as later generations of researchers draw from the results of their predecessors and work with them under new context conditions. Therefore, social and macroscopic aspects of scientific theory formation are in focus. Thirdly, it does not deal with a process which takes place in a short period of time, but covers several historical periods. Taken together, both sub-projects provide support for the viability of the assumed explanatory framework, by systematically varying important historical and methodological dimensions of science. The development of early astronomy will be studied in close connection with the simultaneous development of mechanics. Manifest knowledge transfer is evident between these fields, culminating in the sixteenth century with a theory change induced by Copernicus' method of using mechanical models of epicyclic motion. Throughout the history of astronomy, one can see the development of calculatory devices that enable even laymen to conduct astronomical calculations from standard tables. With this shift in thinking, the possibilities of mechanical motion then reflect the motion of heavenly bodies – the mechanics of the world. This development reaches its apex in Kepler's work and the inclusion of the law of the lever as the basic theorem of motion. Such close interrelations between astronomy and mechanics will be analyzed more closely by the two respective research projects.

Early Babylonian Observational Diaries

Gerd Graßhoff

In recent studies, N. M. Swerdlow, L. Brack-Bernsen and J. Britton developed new accounts of the rise of Babylonian planetary theory. The type of planetary models developed by Babylonian astronomers and successive changes to these models are fairly well known today. Lacking is a better understanding of their constructive goals, their means and aims for improvement and change of models – a reconstruction within the dynamic framework of epistemic system. A basic requirement for such an attempt is a reconstruction of the observational data employed, the quality of Babylonian astronomical practices, and the stability of observational practice over six hundred years in Mesopotamia. This study established for the first time what kind of observations were recorded consistently in ancient observational sites and kept well documented by the Royal Palace. On that basis, future studies of changes of observational practice will be undertaken, and finally brought together with the history of Babylonian astronomical theories.

Several types of astronomical texts attest to the earliest elaborate form of astronomy, which flourished in the first millennium B.C. in Ancient Mesopotamia.

Early astronomy dealt with events such as eclipses and the observation of the first and last visibility of the moon, planets and stars after (or before) their close proximity to the sun prevented them from being seen. The Babylonian theories could predict these events accurately. Their basic parameters are of such good quality that they merged into Greek astronomy and continued to comprise the backbone of astronomical knowledge up to the time of Kepler. Although we have a clear picture of the precision and predictive scope of Babylonian astronomical theories, their empirical basis has remained unclear. Which types of observations provided the information necessary to construe those theories? All information points to a different epistemological relation between observation and theory in prehistoric astronomy.

The recently published *Astronomical Diaries* are a collection of astronomical cuneiform texts in Akkadian, which was the language used for Babylonian astronomy during the first millennium. These texts report a variety of astronomical events over a certain period, including eclipses and the visibility phenomena of the moon and planets. Despite a careful analysis of possibly false assumptions, all previous reconstructions failed to provide a consistent interpretation of the *Diaries* as observational reports.

New forms of computer representations of the Akkadian texts and a systematic hermeneutic search for a consistent interpretation have been developed, and all texts are now represented as linguistic Akkadian tokens. According to a trial interpretation of the astronomical language, these sentences can be translated automatically into corresponding observational scenarios. A highly accurate recalculation of the historical sky over Babylon then allows a comprehensive test of the validity of numerous interpretation models in reference to all known cuneiform tablets of that type. With these methods, it could be established that the observational reports of the *Diaries* are indeed coordinate measurements suitable to found Babylonian theoretical astronomy and to play a specific role in the formation of one of the earliest scientific theories. With these findings, the earliest routine observational practice could be established – a practice that is very stable over at least six hundred years despite drastic political and social changes through Babylonian, Persian, and Greek rule in Mesopotamia. The observational practices were taught, archived carefully and evaluated systematically through generations of early astronomers. Only this stable set of observations allowed the construction of the accurate planetary theories as they are known today.

Diagrams in Medieval Planetary Astronomy

Gerd Graßhoff and Bruce Eastwood

While the Ptolemaic planetary theory is well known, the transmission of planetary theory to Early Medieval Europe has been widely neglected. In a comprehensive study, a major portion of all available manuscript material from the ninth to the twelfth centuries on planetary astronomy is evaluated and it is shown that the process of theory formation which takes place during this period differs from those occurring before or after. The analysis demonstrates that these results have an impact as late as the sixteenth century.

The generally received opinion among historians of science and even among historians of astronomy is that there existed no planetary theory and virtually no astronomy in medieval Europe before the twelfth century, when Greco/Arabic astronomical texts were translated into Latin. Contrary to this opinion, materials reveal the essential concepts of Hellenistic astronomy in the Latin West from the early ninth century onwards. The traditional opinion may be motivated by a concept of theory formation which assumes mathematical or natural language as a necessary medium. It is shown however, that the most important evidence is provided by planetary diagrams. From the early ninth century onwards, scholars invented diagrams for three essential purposes: teaching, textual study, and theory construction.

Scholars during the ninth through the early twelfth centuries had certain foundations upon which to build. Lacking any mathematical astronomical texts, the medievals had a group of four Roman works with relevant materials: the *Natural History* of Pliny the Elder, the commentary of Calcidius on Plato’s *Timaeus*, Macrobius’ *Commentary on the Dream of Scipio*, and the astronomical textbook in the survey of the liberal arts composed by Martianus Capella, *The Marriage of Philology and Mercury*. Of these, only Calcidius' work originally contained diagrams with materials for planetary theory, and some of these had become severely corrupted by the ninth century, providing more confusion than instruction.

Beginning almost anew in the Carolingian revival of the ninth century, students of astronomy clarified the texts, invented diagrams, corrected corruptions in earlier diagrams, extracted especially relevant parts of the texts for further study, employed diagrams to apply planetary models to new texts, and showed, in their planetary diagrams most fully, both a willingness to interpret old texts in new ways and an ability to construct complex planetary theories. Teaching, textual study, and theory construction come to light through this research into early medieval planetary diagrams.

Theory formation in this context has a close proximity to hermeneutic problems of text understanding. The medieval commentators did not undertake astronomical observations of significance for the purpose of planetary theory. Their primary goal was text understanding, as can be shown by the fact that unclear or difficult passages of the ancient authors were those most commented upon, especially with the help of diagrams. There are also instances, however, when diagrams clearly function as more than just commentaries of the text and develop a life of their own, extending beyond the geometrical information expressed by the medieval commentator. Commented manuscripts circulated further and were copied again by others, who themselves changed diagrams according to their understanding of the cosmological order. The epistemic goal of this period was refined to the search for qualitative, two-dimensional representations of planetary motion that could account for a standard set of qualitative planetary phenomena for planetary positions without predictive power. Based on a large collection of more than eight hundred diagrams from manuscripts of the early medieval period, the theory of epistemic systems can be tested for its ability to explain these changes in diagrams.

Kepler's Physical Astronomy

Gerd Graßhoff

As a continuation of Neugebauer's and Swerdlow's work on Copernicus, Kepler's heuristic techniques in his reform of traditional mathematical astronomy are analyzed in the last case study.

In his *Astronomia Nova*, Kepler describes his extensive struggle to base a physical theory of the motions of the planets on Tycho Brahe's observational data. While the impact of those laws of planetary motion he eventually discovered on the further development of mechanics and, in particular, on the development of Newtonian dynamics, is well known, Kepler's own dynamics and its heuristic role for his research are still insufficiently understood.

Continuing earlier unpublished work by Otto Neugebauer, and using special software to construct computer models of geometric and kinematic relations, Gerd Graßhoff analyzes Kepler's numerical calculations, both in the *Astronomia Nova* and in his manuscripts. His aim is to reconstruct Kepler's intermediary models of planetary motion and the heuristics motivating these models within the framework of epistemic systems. Research goals are the causal requirements of a planetary theory which Kepler tried to realize with traditional means of epicyclic astronomy. These goals allowed him to abandon both the Copernican and the Ptolemaic models and seek his own solution. Construction steps are well documented by a variety of intermediary planetary models, some of which left their only traces in peculiar numerical parameters used in the context of other problems. The strength of determining epistemic goals and sequences of model construction steps becomes apparent when the impact of famous physical models is assessed, like those of the magnetic forces and boat models described by Kepler in the *Astronomia Nova*. It is argued that these aspects were only introduced into the model construction process after Kepler reached the stage of attempting a physical explanation. However, they also were abandoned quickly whenever further geometrical exploration showed a need for a modification of geometry. Kepler's criteria of model evaluation are indeed causal and of the same sort of causal reasoning established in the experimental study on the formation of the urea hypothesis. These findings indicate that Kepler's research can be described as 'preclassical astronomy,' analogous to the 'preclassical' character of contemporary mechanics: close familiarity with the ancient and medieval traditions of theoretical astronomy; extensive and flexible use of their techniques in order to reflect new empirical knowledge; the treatment of astronomical problems in the context of other aspects of natural philosophy, including applications of mechanics to these problems; and the elaboration of new consequences of traditional means of deduction, such as the construction of an elliptic orbit by means of an epicyclic model. Similar to preclassical mechanics, Kepler's research in preclassical astronomy also involved mastery of techniques familiar from practical experience, in particular, the determination of orbital positions in his models by a method of triangulation, not common in traditional theoretical astronomy.

DEVELOPMENT: ELECTRONIC RESEARCH TOOLS AND DATABASES

Jürgen Renn (responsible), in cooperation with Michele Camerota, Peter Damerow, Gerd Graßhoff, Simone Rieger, Bernd Wischnewski, Michael Schüring, Marcel Sigrist, Mohamed Abattouy, and Paul Weinig

General Goals of the Developments

Recent developments in electronic data processing have changed fundamentally the potential of research in the history of science, as in other historical disciplines. Although the new possibilities are still realized only to a limited extent, they already offer important new research methods.

On the one hand, the electronic storage of historical sources improves their accessibility and makes new and powerful methods of the retrieval of information possible. In the past, documenting, interpreting, and publishing of new sources was a major focus of the work of historians. The electronic storage of sources offers improved methods of searching and combining information to such an extent that problems of integrating historical details into coherent models of historical developments turn out to become increasingly important. In the special case of the history of science, electronic data storage and retrieval challenges the traditional picture of the history of science as a history of accumulating knowledge, and potentially offers for the first time an opportunity to reconstruct not only the history of representations of knowledge, but also the development of knowledge structures themselves. On the other hand, electronic data processing also provides new methods for constructing models of mental structures and activities. Thus, by means of computer models, the traditional methods of history of science for reconstructing discovery processes can be complemented by computer simulations of such processes under different conditions and compared to the results of historical case studies.

Even though preparing electronic editions of historical sources and constructing computer models of mental processes are not at the center of activities at the Institute, the new opportunities offered by electronic data processing are used as much as possible with the available resources:

- scanning and optical character recognition techniques are being used to build an electronic archive containing sources important for the research at the Institute
- databases and working environments are being developed to assist research and editorial activities
- software tools are being developed which are suitable for the presentation of sources in formats compatible with a variety of different computer platforms
- mental processes involved in scientific thinking are being modeled and computer simulations of research processes applied to case studies of major scientific discoveries.

Current Work Related to "Electronic Research Tools and Databases"

Electronic Edition and Representation of Galileo's Notes on Mechanics Ms. Gal. 72 (joint project together with the Istituto e Museo di Storia della Scienza and with the Biblioteca Nazionale Centrale in Florence)

Michele Camerota, Peter Damerow, Simone Rieger, Jürgen Renn, and Bernd Wischnewski (Max Planck Institute for the History of Science), Paolo Galluzzi (Istituto e Museo di Storia della Scienza, Florence), Isabella Truci (Biblioteca Nazionale Centrale, Florence)

An electronic edition of Galileo's notes on motion and mechanics, kept as Ms. Gal. 72 in the Galilean collection of the Biblioteca Nazionale Centrale in Florence, is prepared. The edition will make the manuscript accessible from CD ROM or through the internet. The part of the manuscript containing Galileo's notes (folios 33-194) is represented by digital images of the folio pages, transcribed texts, reconstructed calculations, and redrawn figures and diagrams. The images of the folio pages are related to the transcriptions and interpretations by electronic links. Additional information about the manuscript, including a description of the history of the manuscript, data about the physical characteristics of the folio pages, references to interpretations of pages of the folio published by historians of sciences, is also provided. A navigation system is developed according to the requirements of scholarly work on the manuscript. Indices are created for Latin words, Italian words, numbers in the text, numbers in the calculations, variables in the texts and variables in the calculations, with direct links to the locations in the manuscript where the items occur. The edition uses a HTML format so that it can be used with standard Internet retrieval software on any computer platform.

Galileo's notes on motion and mechanics document his work on mechanical problems over a period of more than forty years. The manuscript consists of more than 300 pages. They contain numerous short texts in Latin and Italian, representing sketches of proofs, but also extended drafts intended for publication, calculations, tables of calculated numbers, diagrams, and even some documents pertaining to experiments performed by Galileo. The manuscript is considered the essential source of information on the intellectual route followed by Galileo in achieving the insights he submitted in the *Discorsi* (see the sections above on *Challenges to Preclassical Mechanics p. 56* and on *The Development of Galileo's Deductive System of Mechanics p. 58)*.

Making this manuscript accessible is a joint endeavor of the Institute together with the Biblioteca Nazionale Centrale and the Istituto e Museo di Storia della Scienza in Florence. In February 1997 a first complete version officially was presented by the three institutions in Florence to historians of science. In the meantime, the edition has been improved technically and by further work on its content. Presently, the access through the World Wide Web is under preparation. The intention is to update the edition from time to time by integrating results of the research of Galileo scholars working on the manuscript.

Database of Proto-Cuneiform Texts from Archaic Babylonia (joint project together with the Seminar of Near Eastern Archaeology of the Freie Universität Berlin, with the Vorderasiatisches Museum der Staatlichen Museen zu Berlin, and with the Computer Center of the Universität Lüneburg)

Peter Damerow and Michael Schüring (Max Planck Institute for the History of Science), Robert Englund (University of California at Los Angeles), Hans Nissen (Freie Universität Berlin), Martin Schreiber (Universität Lüneburg)

In cooperation with the editors of the proto-cuneiform tablets of ancient Mesopotamia (3200-3000 B.C.), an electronic representation of these tablets is prepared in order to make them accessible through the Internet. The tablets are represented by images and transcriptions. Access is provided through a catalog and through sign glossaries.

Documents that give evidence of the development of mathematical thinking in ancient civilizations provide an important source for studying the emergence of formal thinking. The corpus of proto-cuneiform texts contains some 5800 tablets and fragments. Eighty-five percent of these texts are administrative documents; the others are "lexical lists," a special type of school texts. This text corpus represents not only the first step to literacy, but also the transition from proto-arithmetic control devices to the use of measures and numbers.

The catalog of the texts contains detailed archaeological information as well as information about the present owner of each text, related publications, and interpretations. The texts themselves are represented by photos and by drawings, both in natural size and enlarged four times. Furthermore, transcriptions are provided for each text. The texts are accessible both from an alphabetically arranged list of excavation numbers and from a sign list via a glossary with references to all texts containing the signs in question. Programs have been developed to automatically generate systems in HTML format to make the image and text data thus accessible through the Internet.

At present, the project essentially is completed and the result is being tested in the Intranet of the Institute. Final corrections are being made, and the layout will be improved before the text corpus is presented to the public. Later updates are possible and intended. In particular, a classification of the texts according to their contents will be added later.

Electronic Research Environment

Gerd Graßhoff, Michael May

In this project a comprehensive electronic environment is developed to support research activities of the type described in the project on the discovery of the urea cycle. It is designed to assist the researcher in various phases of research: accessing data, data collection, transcription, interpretation and electronic publication. It includes a database containing bibliographical data, scanned images of laboratory notebooks, articles, books and drawings, as well as various kinds of transcriptions. Extensive search capabilities are included to allow the efficient exploration of historical data. Also provided are graphical tools for commenting historical documents: whole documents, individual pages, or parts of pages. Comments on these documents are also saved in a database. These comments are indexed by information such as commentator, type of comment or the date the comment was written. Also, different levels of keywords (which can be defined by the user) can be attached to a comment and accessed in graphical form. All of this information is searchable.

Special attention has been paid to the choice of technology. The system runs on several platforms and is based on a Java client accessing a relational database (SQL) server via TCP/IP. The relative hardware independence and the use of standard technologies which are SQL or prospected to be ISO-certified (Java) offer some security against tapping into technological dead ends, especially for long-term projects and data that need to be stored for long periods of time. In order to integrate an electronic source of historical data with the simulation tool for the discovery of the urea cycle, high-level internet technology using Java was required. This computer language supports the development of modular software components which easily can be maintained and extended for future applications. The modularity of the software components allows their simple integration into the other electronic tools developed at the Institute. The electronic research environment can be mixed with HTML environments for Internet presentations, and configured with ease for the specific requirements of each project.

Since the data can be accessed over the Internet, they are available regardless of a researcher's location. Data may be distributed over several places and yet can be accessed by the user as if they were stored together. Thus a research team composed of scholars working in different countries and cities can work on a joint historical commentary without the problem of inconsistencies arising from having different versions of a text or other data.

Medieval Scientific Manuscripts

Gerhard Brey, Gerd Graßhoff, Michael May

A version of the International Computer Catalog of Medieval Scientific Manuscripts (ICCMSM), assembled by Prof. Folkerts and his research group at the University of Munich, was developed for complex search inquiries via the intranet of the MPIWG. The catalog contains comprehensive information of the huge Munich collection of Medieval mathematical manuscripts. The Munich research group kindly supplied a copy of the catalog's raw data, from which a subset for a relational database (SQL) was derived. Two technological versions were developed in order to test the following objective: it should allow multiple user search of the catalog from all different computer platforms of the MPIWG's local computer network. One version was based on an LINUX implementation of a very fast database SQL (MYSQL) that can be accessed via HTML and CGI-Perl scripts. The advantage of that implementation is its high speed, robust operation and easy accessibility through standard WWW-browsers. Its disadvantage is its limitation of the complexity of search requests (it lacks outer join commands) and lack of integration into other tools currently under development at the institute for the display of graphical images such as microfilm scans. Since an extension of the catalog in that direction is possible, a second version of the catalog interface has been developed on the basis of an Oracle database and a JAVA user interface.

Mesopotamian Year Names

Marcel Sigrist and Peter Damerow

A list of Babylonian year names, compiled as a tool for the dating of cuneiform tablets as well as for supporting historical studies on early bookkeeping techniques, is made accessible through the Internet. The tool essentially consists of a collection of date formulae in administrative documents as they were used by the scribes in ancient Mesopotamia, of computer-generated indices for a quick identification of incomplete date formulae on damaged cuneiform tablets, and of issues and events mentioned in these formulae. Access is provided through a list of cities and kings, a list of words, and a list of words in English translation.

The basic list currently contains more than 2,000 year names. The compilation covers the time period from the time of the empire of Sargon to the end of the Babylon dynasty. Its preparation is an outcome of a cooperation over a period of over ten years.

Originally it was intended to prepare a computer-generated publication of the data and suitable indices. Some seven years ago a preprint of this publication was made available to interested scholars, at that time including only the year names of the Ur III period and Old Babylonian period. It turned out, however, that an electronic representation is more suited to the intended purpose, since it facilitates the continuous improvement of the list by the correction and further addition of year names and variants known from newly published texts.

The data are stored in a database from which a representation in HTML format is automatically generated. A first version recently was made available for scholarly use on the Web server of the Institute. A complementary bibliography is currently in preparation.

Cuneiform Texts of the Third Millennium B.C. in the Vorderasiatisches Museum, Berlin (joint project together with the Vorderasiatisches Museum, Berlin, and scholars of universities in Berlin, Wien, and Los Angeles)

Peter Damerow and Michael Schüring (Max Planck Institute for the History of Science), Joachim Marzahn (Vorderasiatisches Museum), Hans Nissen (Freie Universität Berlin), Robert Englund (University of California at Los Angeles), and Gebhard Selz (University of Wien)

An electronic representation of the Babylonian cuneiform texts from the third millennium B.C. which are kept in the Vorderasiatisches Museum der Staatlichen Museen zu Berlin, is prepared. For the first time, a substantial collection of cuneiform texts kept in a museum will be made completely accessible through the Internet.

The documents derive from the following periods of the third millennium.

- Uruk IV/II, ca. 3200/2700 B.C. (ca. 1900 tablets)
- Fara period, ca. 2600/2500 B.C. (ca. 400 tablets)
- Old Sumerian period, ca. 2500/2350 B.C. (ca. 400 tablets)
- Old Akkadian period, ca. 2350/2200 B.C. (ca. 100 tablets)
- Neo-Sumerian period, ca. 2100/2000 B.C. (ca. 800 tablets)

With their wide range of chronological distribution, these texts constitute the most important collection in the world currently available for the study of the third millennium. The scientific value of this collection lies in its unique importance not only for the study of the early development of writing, but also for the history of household economies, of administration and of science during the early period of state formation.

The project to make this collection accessible through the Internet is a joint endeavor together with the museum and scholars specialized in the archaeology and philology of the third millennium B.C. The methods of electronic representation applied have been developed at the Institute. The clay tablets are directly scanned using a suitable flatbed scanner. Data for the catalog are administered by means of a database. The HTML system, including the catalog and the digital images, is generated with software tools developed at the Institute for such purposes.

At present, the texts of the Neo-Sumerian period are being scanned. The scanning of the other texts already has been completed. Work on the compiling of the catalog data has commenced.

The Archimedes Project: Electronic Resources in the History of Mechanics (joint project together with the Perseus Project at Tufts University, Boston)

Mohamed Abattouy, Peter Damerow, Jürgen Renn, Paul Weinig (Max Planck Institute for the History of Science), Gregory Crane (Tufts University)

As a result of a workshop at Tufts University in December 1997, a joint project has been initiated in order to combine the efforts of both institutions to make sources in the history of science electronically accessible. It is the goal of this project to make available on the Internet ancient, medieval and early modern texts relevant for the study of the origins of mechanics and its development into classical mechanics, to provide tools that facilitate the translation of the texts, and eventually to provide translations if necessary.

PROJECTS OF THE RESEARCH GROUP HEADED BY LORRAINE DASTON (DEPARTMENT II)

The work of the research group of Lorraine Daston for 1996-1997 addresses three major topics: the varieties of scientific experience, the history of demonstration, proof, and test in the sciences, and the history of scientific objectivity. All three projects aim to historicize, by means of specific examples taken from several periods and scientific disciplines, categories of analysis long taken for granted by historians, philosophers, and sociologists of science. These projects take as their departure point that experience, demonstration, and objectivity themselves have histories, which can be reconstructed on the basis of key examples.

PROJECT 1: THE VARIETIES OF SCIENTIFIC EXPERIENCE

Lorraine Daston (responsible), in cooperation with Sonja Brentjes, Rivka Feldhay, Doris Kaufmann, Ursula Klein, H. Otto Sibum, Stuart Strickland

General Goals of the Project

Both the natural and human sciences have been extremely fertile in new forms of experience: clinical observations, laboratory experiments, legal indices, statistical tables, anatomical dissection, field work in natural history and anthropology, introspection, instrumental probes, ideal types, and computer simulations. Some of these forms of experience are as old as Hippocrates; others have emerged within living memory. Each has its characteristic objects of study, canons of evidence and proof, and conventions of literary presentation. All have, until very recently, been lumped together under the rubric “empiricism” by philosophers, and mostly ignored by historians. The project “The Varieties of Scientific Experience,” begun fall 1996 in Department II, has three goals: (1) to construct a refined taxonomy of the forms of scientific experience across a varied sample of disciplines and periods; (2) to trace the history of each of these forms, with special attention to the conditions under which they emerge or disappear; and (3) to investigate the relationships between different forms of experience and corresponding standards of evidence, proof, and description within the sample.

Although the center of gravity for the sample lies within the natural sciences since the seventeenth century, for several reasons it has been considered essential to include some examples both from the human sciences and from earlier periods. First, some forms, like the clinical observation, have a long and continuous, though not static, history that stretches back to antiquity. Second, the current classifications of knowledge that divide the natural from the human sciences diverge sharply from earlier classifications. For example, in the medieval university curriculum, music theory was the near neighbor of astronomy, and astronomy and physics were remote from one another. Third, there are historical affinities and genealogies among forms of experience that cut across even contemporary classifications. It is, for example, difficult to understand seventeenth-century notions of what constituted a scientific fact without careful study of the legal doctrines of evidence drawn from things and witnesses from the early modern period. Throughout the project, the importance of comparisons has been emphasized – between disciplines, periods, and intellectual and cultural contexts.

The study of forms of scientific experience sheds light on two other fundamental issues in the history of science: how certain kinds of objects (and not others) come to qualify as objects of scientific inquiry; and what can and cannot be communicated in the presentation of scientific experience to a community dispersed in time and space. In the first case, there is an intimate connection between what can become a scientific object and what are considered to be legitimate forms of scientific experience. For example, the controversy in psychology at the turn of this century over the legitimacy of introspection as a form of scientific experience – it was empirical but not public knowledge – threatened to eliminate the will and consciousness itself as objects of scientific inquiry. In the second case, there are very special conditions placed upon communications intended for audiences scattered across the globe and even across centuries as opposed to those for an audience addressed face to face, as in the classroom. Certain crucial aspects of scientific experience, for example the elements of bodily skill required to get a capricious experiment to work, may become invisible because they cannot be communicated in words, though they might be learned by example.

In the early phases of the project effort was made to limit cases of scientific experience, specifically, to cases that stretch some aspect of the current conceptions of the empirical almost to the breaking point. These limiting cases unsettle the self-evidence of currently accepted forms of scientific experience by providing concrete alternatives to the choices of what to investigate and how. They also throw into relief the otherwise hidden criteria by which certain forms of experience and description are judged to be legitimate. If, for example, the late eighteenth-century *Seelenforscher* attempted to develop an empirical science of dreams, but psychologists of the early twentieth century rejected the possibility of a science even of waking consciousness, a crucial shift in these criteria may explain the change in attitudes. Similarly, if mid-eighteenth-century physicists discard reports of luminescent phenomena that their seventeenth-century predecessors deemed key to understanding the nature of light, the explanation for this probably lies in a change in criteria of evidence, significance, and even of facticity. Special attention has been paid to hybrid kinds of scientific experience, which usually emerge in contexts of application: for example, the standardization of scientific units and procedures through the creation of an electrification network, the extraordinary pressures on psychiatry to classify and cure war-time mental disorders, or the "paper tools" of tables and formulas manipulated by organic chemists suspended between the laboratory and the factory.

Current Research Activities Related to "The Varieties of Scientific Experience":

Wonders and the Order of Nature

Lorraine Daston (in cooperation with Katharine Park, Wellesley College)

Final revisions on the book manuscript *Wonders and the Order of Nature*, which traces the responses of European naturalists from the high Middle Ages through the Enlightenment to marvels and anomalies in nature, were completed in the summer of 1996. The book will be published by Zone Books. Chapter headings are as follows:

Introduction: Nature at the Limit

Chapter 1: The Topography of Wonder

Chapter 2: The Properties of Things

Chapter 3: Wonder among the Philosophers

Chapter 4: Marvelous Particulars

European-Muslim Scientific Encounters Between the Sixteenth and the Eighteenth Centuries

Sonja Brentjes

The project aims to revise another misconception regarding the history of early modern science both in Europe and in the Muslim world. This subject emerged from a large-scale survey of reports about the Ottoman, Safavid, and Mogul empires written by European gentlemen travelers, diplomats, merchants, and missionaries between the sixteenth and eighteenth centuries. They not only demonstrate that, contrary to current standard historiography, there were scientific communities at work in the different Muslim societies during the period of investigation, but they also illustrate that European scientific endeavors were significantly linked with the Muslim societies of their times. On the European side, this concerns the endowment and enrichment of cabinets of curiosity, botanical gardens, and royal and other libraries. It also applies to astronomical and geographical observations, historical investigations, comparisons of measures, sales of instruments, the composition of general and specialized dictionaries, professional careers, and patterns of patronage. On the side of the Muslim societies, the connection is evident in the acquisition of European books and instruments, including telescopes and microscopes, and in the translation and discussion of geographical, mathematical, astronomical, or medical books by Italian, French, German, Dutch, and other European authors of the sixteenth, seventeenth, and eighteenth centuries. Also relevant were efforts to introduce different types of European mechanical devices in mining, printing, military techniques, or the usage of water as energy.

The project surveys a broad range of sources to establish the scope and types of these European-Muslim collaborative encounters in the sciences.

Its major methodological foundation is the analysis of the cultural patterns which warranted and shaped these encounters.

The Use and Abuse of Mathematical Entities and the Emergence of Early Modern Science

Rivka Feldhay

Departing from the debates on the certitude and scientificity of the mathematical disciplines which erupted in the context of a commentary on the pseudo-Aristotlian *Mechanical Questions,* this book identifies and characterizes two different types of mathematical physical discourses on motion in the sixteenth and seventeenth centuries and follows the development of an ontology of mathematical entities, which was used for purposes of legitimization by one discourse and rejected by the other. Themes of this book were developed in a contribution on Galileo and the Jesuits to the volume *Companion to Galileo*. A paper on “The Cultural Field of Jesuit Science” was written for the conference “The Jesuits: Culture, Learning and the Arts,” which took place in Boston in May 1997. Another version was presented at the department seminar in the Max Planck Institute for the History of Science. Feldhay also wrote a paper (“On the Agony of Knowing”) for a workshop held at the Einstein Forum in June, and participated in the conference, “The Varieties of Scientific Experience,” where she commented on two papers.

The Emergence of Scientific Psychiatry: From Clinical Observation to Social Field Work

Doris Kaufmann

Following up on studies of the relationship between psychiatric discourse, its social context, and cultural representation from the 1850’s to the turn of the century – a period which saw the establishment of a scientific psychiatry emphasizing the physiological basis of psychic phenomena in general and the somatic causes of hysteria in particular – the current project focuses on the disappearance of the latter as a central object of psychiatric interest at the beginning of the twentieth century. Following Emil Kraepelin’s new system of classification of nervous and mental diseases, the psychiatric discourse began to abandon the concept of hysteria as a disease entity by assigning hysterical symptoms to psychosis, which were defined on the basis of cerebral disfunctions. When the First World War presented the mass phenomenon of soldiers answering to the previously unknown experience of technical warfare in the language of hysteria, the psychiatric community once again was forced to address the conceptual and therapeutical question of hysteria. This project analyses the importance of the First World War as a new space for psychiatric experience and the development of new psychiatric definitions for the normal and the pathological. As a result of the First World War, the key question of the psychiatric discourse, namely whether external and social or internal and endogenous causes were responsible for psychic and mental disorders, was presumed to have been resolved. A further consequence was the beginning of the divergence of the disciplines of psychiatry and neurology on the one hand from psychoanalysis and psychotherapy on the other. This process in the 1920's is investigated on different levels: the clinic, the courts, the psychiatric discussion of the new "key" disease schizophrenia, and the non-scientific public language or discourse on the self. A primary focus concerns the distinctions and the common ground between psychiatric and public cultural practice, their impact, and the exchange between these spheres.

Formulas and the Production of Order in Nineteenth-Century Organic Chemistry

Ursula Klein

This project is concerned with the introduction of chemical formulas into nineteenth-century chemistry, the different functions of formulas as models and paper tools in organic chemistry, and, intimately connected to the latter, the transformation of vegetable and animal chemistry into organic chemistry during the first half of the nineteenth century. Chemical formulas in their still familiar algebraic form were introduced by Jacob Berzelius in 1813, but not even Berzelius applied them in the subsequent ten years. This changed starting in the late 1820's, when French and German chemists working in the emerging subdiscipline of organic chemistry began to use formulas. Within a few decades, chemical formulas not only became reified as paper tools accepted by all chemists, but also created a new "paper world" that thoroughly altered the image of chemistry. The widespread opinion on chemical formulas among scientists, philosophers and historians of science is that formulas were a convenient means of representing existing knowledge, mere abbreviations and means of communication. No historian or philosopher of science has considered with sufficient care the manipulative aspects of formula techniques and the power of chemical formulas to produce knowledge when applied as paper tools in chemical research. Although scholars have recognized the link between the fate of chemical formulas and the transformation of vegetable and animal chemistry into organic chemistry, the question as to why this link exists has not been investigated. This conjunction of two different research traditions and their following co-evolution demand explanation.

Detailed analysis of a series of experiments performed from the beginning of the nineteenth century through the 1850's – experiments which may be regarded as "paradigmatic" for organic chemistry – and study of the different functions of chemical formulas within this experimental practice, confirmed the conviction that chemical formulas were indispensable "paper tools" in the transformation of vegetable and animal chemistry into organic chemistry. This part of the project, which includes the analysis of the qualitative and quantitative meaning and of the representational form of chemical formulas is nearly finished. It is based on research reports published in various French and German scientific journals. The second part of the project, currently in progress, embeds this detailed analysis of the interaction of experiments and chemical formulas into the broader cultural changes that occurred in the transformation of vegetable and animal chemistry into organic chemistry. Compared with "vegetable chemistry" and "animal chemistry," "organic chemistry" meant a thoroughly different research culture. The epistemic objects of eighteenth-century vegetable and animal chemistry were natural bodies and natural transformations; the experiments done in these fields were intended to leave the natural state of the bodies as untouched as possible; the classification to a large extent followed the principles of natural history; theories were exclusively articulated in natural language; and conceptions were not based on quantification. In contrast, organic chemistry investigated chemical reactions which did not exist in "nature" outside the laboratory, created a new realm of artificial organic substances, introduced a new taxonomic system based on chemical formulas, and linked conceptions and theories articulated in natural language to chemical formulas which embodied measured quantities of chemical substances. This latter part of the project is based more strongly on the analysis of chemical textbooks, letters, and popular writings than on research reports.

The study addresses epistemological questions about the uses of experiments, and about the interaction of experimentation with symbolic representations, models, and conceptions and theories based on quantification in nineteenth-century sciences. A particular focus is the category of the model and techniques of modeling. The project's approach to "models" investigates their functions rather than their structure, thus embedding them in historically specific epistemic systems. The transformation of vegetable and animal chemistry into organic chemistry sheds some light on another epistemological question: what distinctions did nineteenth-century experimental scientists make between nature and art, and how did they draw the boundary between the natural and artificial? Both kinds of epistemological issues are linked to another large question. Modern science in its current epistemological forms, its specialization, and its abstinence from ethical and social issues was shaped in the nineteenth century. This project is a contribution to historical-epistemological studies which attempt to analyze the particular kind of knowledge and style of reasoning which became prevalent in nineteenth-century sciences, particularly in the physical sciences (including chemistry). It studies prerequisites for the transformation of nineteenth-century physical sciences such as quantification and mathematization, the pragmatic application of non-verbal paper tools, the marginalization of natural language, and links to industrial application.

Experiment, Sensuous Experience and Knowledge Production

H. Otto Sibum

Recent historical research has shown that the practices and representation of experiment differ greatly. This has led to a variety of methods of identifying and interpreting the traces produced by historical actors. Reworking experiments by performing them with replicas of historical objects is a technique developed to enrich our knowledge of historical laboratory events. This performative historiography demonstrates that working knowledge in the laboratory is embodied in human actions and cannot be expressed fully in literary form. These hidden dimensions of knowledge production generally are called skills or tacit knowledge, depending on the kind of scientific inquiry involved. As outlined in the Annual Report 1995, in order to study these neglected dimensions of experimentation and its historical meaning for the development of nineteenth-century physics, this methodological approach is the basis of a broader study of the history of a scientific fact, *i.e.*, the mechanical equivalent of heat. At the time, this was seen both as one of the most important "constants of nature" and as the "golden number of the nineteenth century."

Pursuing this course of research raised another question as to the impact of sensuous experience on the formation of knowledge, and whether this can be reconstructed historically. This project addressed these issues in a two-step approach. Firstly, reworking Joule's paddle-wheel experiment by means of a replica provided insight into the use of both the instruments and the senses of the experimenter. Thermometrical skills were identified as particularly crucial for the performance of the experiment, although these were neither noted in Joule's literary renditions nor existent in the early Victorian scientific community. But it is reasonable to argue that such skills were part of the working knowledge of the historical experimenter. The project argues that instruments in action speak their own "language" and that the "eloquence" of the experiment is given through the actors' performance. This emphasis on the performative led to the notion of gestural knowledge in order to account for the embodiment of knowledge in human actions. Sensuous experience is certainly a constitutive part of the gestural knowledge of the experimenter, according to this dynamic perspective of knowledge production. Notebook entries and publications were important, but they were not sufficient representations of the gestural knowledge which was required to carry out experiments.

Secondly, in order to see how sensuous experience had an effect on the formation of scientific knowledge, the historical context in which this experiment was performed and the necessary gestural knowledge was acquired must be reconstructed. Previous historical accounts of Joule's thermometric experience point to his extraordinary skills, but leave open the question of where they were acquired. The reconstruction of apparently unrelated sites of knowledge production, such as the brewing culture to which Joule also belonged, show that only through his continuous work in the laboratory and at the brewing site was he able to develop the gestural knowledge necessary to perform the experiment. More recent results indicate that this brewers "world of sense" was formative even for Joule's knowledge of the dynamic nature of heat, far from accepted in the scientific community of his time. The results thus far have shown that it is possible to reconstruct the historical process of how changing sensory experiences are formative in the production of scientific knowledge. What conventionally has been called "tacit knowledge," and has often obscured the process of major scientific changes, is not tacit at all, but just those forms of expression of gestural knowledge of the historical actor or research collective which can become explicit only through their performance or partly through the objects themselves.

Ideologies of Self-Knowledge and Dilemmas of Personal Experience

Stuart Strickland

This project is an historical examination of the privileged, yet precarious, position of personal experience within the empirical sciences and of the ideological frameworks within which knowledge of nature became linked with knowledge of the self. While assertions of a perfect fit between an external natural environment and an internal self became increasingly common towards the end of the eighteenth century, these formulations consistently obscured at least two difficulties to which this project is addressed. On the one hand, by portraying nature as a living creature whose visible history corresponded to the life-history of an individual, this ideology conflated knowledge of the body and knowledge of the self. On the other, it tended to exclude an essential third term: the communities within which self-knowledge and knowledge of nature each sought their place. The claim that knowledge of nature led directly to knowledge of the self, and vice versa, must be read in the face of an awareness that the two held radically different status within contemporary scientific communities and within a communally shared body of knowledge.

This project thus is embedded at once in a history of modern subjectivity and in an analysis of how concerns about personal knowledge came to define the parameters of a distinctively scientific public sphere. To put it another way, the project investigates why, at this critical moment in the "structural transformation of the public sphere," the self became an issue within science – and how, within a discourse ostensibly devoted to nature, attention to the self of the scientist helped shape a new conception of individuality.

By focusing on the self-experimentation of Alexander von Humboldt, Johann Wilhelm Ritter, and Jan Purkyne, the study has begun to unpack an early moment in the formation of the ideology of self-knowledge by considering the peculiarities of locating the self within the body of the investigator, a body conceived at once as a laboratory instrument, a metaphor for nature, and a sign of the investigator's individual identity. Historicizing the relationship between the self and the body of the natural philosopher also requires scrutiny of the tensions between solitude and community at the turn of the last century. Those who experimented on their own bodies did so at great personal expense and often under intensely private conditions. Their withdrawal into an internal world of personal and perhaps even idiosyncratic experience may appear to have been an attempt to escape from the political and intellectual turmoil that accompanied the Napoleonic Wars and the demands of an emergent public sphere; but these retreats also presupposed an eventual return to a historically specific community whose reservations about personal knowledge were well known to and often ambivalently shared by those who fled. It is thus essential that this study of self-knowledge attend to the difficulties anticipated and encountered in trying to convey experiences rooted in a particular body to a scientific community that was, for ideological reasons of its own, increasingly coming to esteem general over particular truths.

Related Projects of Visiting Scholars and Research Fellows

Jutta Berger, "Georg Ernst Stahl's Concept of Chemical Processes"; Christophe Bonneuil, "Plant Science in the French Empire, 1870-1940"; Alix Cooper, "Local Knowledge and Natural History in the Early Modern German Territories"; Michael Dettelbach, "Surveying Techniques and Nature-Physiognomy in Humboldtian Science"; Elisabeth Emter, "The Human Corpse and Personal Identity in Germany in the 17th and 18th Centuries"; Martin Gierl, "Eighteenth-Century Numismatics and Scientific Rationalization"; Cheryce Kramer, "The Psychiatry of Gemüth in a Biedermaier Asylum"; Christoph Lüthy, "Atomist Iconography"; Alexandre Mallard, "The Role of Scientific Instrument-Makers Between Science and the Market"; Brian Ogilvie, "Observation and Experience in Early Modern History"; Dorinda Outram, "Scientific Voyages in the Eighteenth Century"; Gianna Pomata, "From Recipe to 'Historia' in Early Modern Medicine"; Annelore Rieke-Müller, "German Research Travels and Travelers in the Eighteenth Century"; Sophie Roux, "Rational Mechanics and Corpuscular Theories of Matter"; Richard Staley, "Inferometers, Experiment, and the Early History of Relativity Theory"; R. André Wakefield, "Cameralism and Useful Knowledge in Germany"; M. Norton Wise, "Muscles and Engines: Hermann Helmholtz in Industrializing Berlin"; Michael Witmore, "Accidents: Unexpected Knowledges in Early Modern England" (see *Activities of the Visiting Scholars and Research Fellows p. 182).*

Project 2: The History of Scientific Objectivity

Lorraine Daston (responsible) in cooperation with Wolfgang Küttler and Annette Vogt

General Goals of the Project

When did objectivity begin? With the first gropings towards a philosophy of nature in the fragments of the pre-Socratics? With the strivings of ancient historians like Thucydides and Tacitus to render an impartial account of the past? With the meditations of Descartes on the possibility of certain knowledge? With the cult of facts established by seventeenth-century scientific societies such as the Accademia del Cimento, the Royal Society of London, and the Paris Académie des Sciences? With the attempts of Enlightenment savants to replicate each other's experiments on electricity, pneumatics, or animal magnetism? With scientific illustrations made by camera obscura – or by photography? With the emergence of techniques and instruments of precision measurement in the nineteenth century? With the invention of statistical techniques of data reduction and inference?

Each of these historical moments, which arc from the sixth century B.C. to the 1940's, reflects a facet of our current notion of objectivity. Truth, certainty, impartiality, facticity, publicity, authenticity, impersonality – these concepts all cluster tightly around objectivity as we know it, as do the practices of photography and statistical data analysis. But a mere inventory of the components and close neighbors of objectivity will tell us little about the meaning of the whole, and still less about its history. Both meaning and history depend not only on the components and associations but also on their interrelationships: how did these elements come to cohere together? The corresponding historical question is not, how and when did each element emerge, but rather, how and when did these components and associations crystallize into a whole?

This project seeks to answer this question by studying both the concrete practices (photography, statistical data analysis, etc.) and the reflective ideals (publicity, impersonality, etc.) of objectivity in historical context. Although seventeenth- and eighteenth-century case studies provide instructive antecedents and contrasts, the focus of the study lies in the period 1820-1950, when the very word "objectivity" and its cognates reappeared within major European languages, and when objectivity replaced truth as the primary goal of the sciences. This transformation of ideals and practices stretched across many disciplines in the natural sciences, from anatomy to geology, and also encompassed human sciences such as history and sociology. Hence, although the project emphasizes the specific cultural and intellectual contexts which made this transformation possible, it aims ultimately at a global account of a global phenomenon that affected many diverse disciplinary and national traditions.

At present, the project consists of three complementary studies, each concentrating on a different aspect of the history of objectivity: techniques of visualization in the natural sciences; the careers of women scientists and mathematicians at Berlin universities and within the Kaiser-Wilhelm-Gesellschaft during the first decades of higher education for women in Prussia; and the role of history within the social sciences at the turn of the twentieth century, emphasizing the work of Max Weber. Each of these studies emphasizes a different moment of scientific objectivity. New ways of making images, particularly photography and global mapping, at once symbolized and constituted new forms of scientific objectivity in the middle decades of the nineteenth century. These images were attempted solutions of epistemological and moral problems at the heart of objectivity. The career possibilities for women scientists in early twentieth-century Berlin shed light on another aspect of the practices of objectivity: to what extent were contemporary ideals of a science blind to personal traits realized in institutions and biographies? Although objectivity may have originated in the natural sciences, social scientists confronted with challenge of political relevance on the one hand and with the threat of political ideology on the other provided some of the most acute and far-reaching reflections on the possibility and limits of objectivity.

Current Research Activities Related to "The History of Scientific Objectivity"

The Images of Objectivity

Lorraine Daston (in cooperation with Peter Galison, Harvard University)

The photograph and the global map: these images were at the core of two new and distinct forms of scientific objectivity which emerged in the middle decades of the nineteenth century, which might be called mechanical objectivity and communitarian objectivity. Mechanical objectivity countered the subjectivity of projection onto nature, including judgment and aesthetic idealization. It was nominalist in its metaphysics, mechanical in its methods, and self-restrained in its morals. Scientific images produced in the service of this brand of objectivity were neither types nor ideals nor averages – all time-honored modes of scientific illustration – but rather representations of concrete individuals. Wherever possible, image-making and observation were mechanized, through photographs, self-registering instruments, and statistical data reduction. In a moral vein, scientists upholding the ideals of mechanical objectivity exhorted themselves and their colleagues to refrain from intervention in and interpretation of phenomena. The unretouched photograph became both the emblem and the substance of mechanical objectivity.

Communitarian objectivity, in contrast, countered the subjectivity of idiosyncracy and parochialism, not only of individuals but also of local research groups. Proponents of mechanical objectivity worried that human intervention might distort natural phenomena; proponents of communitarian objectivity fretted about how anthropocentric scales of time and space might fail to register certain phenomena altogether – the path of a storm system, the shape of an isotherm, the distribution of a species. Communitarian objectivity preferred composites of many observations to representations of individuals, and standardized to mechanical techniques. Whereas mechanical objectivity called for self-restraint in judgment and interpretation in the name of authenticity, communitarian objectivity demanded the equally severe curtailment of individual and/or local autonomy in choice of instruments, methods, and even research topics in the name of solidarity. Its most characteristic visual technique was the global map – of the whole earth or the entire dome of the heavens – composed like a mosaic by a network of farflung observers, each contributing a fragment.

This study traces the emergence and development of both forms of objectivity through atlases of scientific objects, from nebulae to fossils, and through the records of the scientific collaborative projects, such as the Internationales Gradmessungsprojekt and the Carte du Ciel, launched in the mid-nineteenth century. Close attention to the choice of practices, such as choice of instrument or mode of illustration, described and debated in these sources reveals how both forms of objectivity fused methods, morals, and metaphysics into new ways of investigating and understanding nature.

In 1996-97 research was extended in two directions from its nineteenth-century focus: backwards into the eighteenth century and forward into the twentieth century, in order to highlight contrasts with the characteristic forms of objectivity that emerged in the nineteenth-century sciences. A study of eighteenth-century scientific illustration, particularly in botany and anatomy, reveals a different epistemic ideal, that of "truth to nature," which strived for accuracy while permitting idealization, interpretation, and abstraction in depictions of natural objects. In the twentieth century, scientific imaging techniques are increasingly accompanied by calls for judgment by an expert eye – not the genial interpreter of nature of the eighteenth century, still less the mechanical observer of the nineteenth, but rather the trained professional. Close comparison of preliminary sketches of objects – plants, insects, fossils, dissected animals – annotated by both artists and naturalists with published versions shows how scientific objects come into being: an initial rendition, often highly idiosyncratic with respect both to the object portrayed and to the style of portrayal, becomes a type specimen, which stands in for a whole class of objects and serves as a reference for a community of naturalists and artists.

History as a Problem for the Sciences. Changing Approaches Towards History in the Social Sciences and the Humanities in Germany After 1900

Wolfgang Küttler

Activities in the context of the present project focused on two major points. First the project investigated the relation between history, science, and objectivity in Max Weber's work. With respect to all three items, Weber's work and its reception reveal an internal tension between structural and evolutionary issues (*i.e.*, social questions) as well as overarching elementary explanations of cultural motivations of action and systems of values and norms (*i.e.*, general problems of culture).

The issues addressed in this project apply to the peculiarities of empirical research and concept formation in all historically oriented disciplines. An analysis of Weber's concept of value-relation and value-freedom of empirical research on history, of his ideal types, and of his concept of modernization as rationalization and disenchantment will be concluded in spring 1998 and will be published as a monograph. Another important contribution of Weber's approach is his perception of the historicity of nature and of human culture. Therefore Weber's approach to history has particular relevance for the role of science in modern rationalization. This process is seen by Weber not only as technical progress in civilization, but also as an irresolvable contradiction between the technical-bureaucratic increase of *Zweckrationalität* and the internal qualities of lifestyle (*Lebensführung*).

From this context, the interdisciplinary question of cultural history emerged: how are historicity, a cognitive function of science, and cultural value systems interrelated? This issue demands a comprehensive treatment of the basic typology of historical knowledge (involving structure, development, progress, events, actions, and historical alternatives). Weber's investigation of the relationship between religious structures of motivation in different cultures (which also function as formative elements of social structures) and of the ethics of lifestyle, especially of economic ethics (*Wirtschaftsethiken*) provides also a framework for assaying the different conceptions of knowledge, of life practice, and of historical change in these cultures.

In view of the changes to the concept of science and objectivity since the turn of the last century and subsequent decades, further studies have been initiated to investigate Weber's sources in the natural sciences and humanities of the nineteenth century, as well as to examine the reception of his innovative approaches. The hitherto conducted studies will be expanded in a wider framework of comparative studies embracing social and natural scientists in Germany at the turn of the nineteenth and twentieth centuries.

The second set of activities closely linked to the research of the work of Max Weber, now partially completed, focuses on Marx's theory and method and on the Marxist tradition in the historical sciences. Like the Weber study, it addresses the issue of history as a form of knowledge on the one hand, and history as a means of orientation of practical life in modern societies on the other. Marx focuses on how scientific objectivity is linked to the knowledge of internal "objective" coherence in history and how this serves simultaneously both as a basis for theory formation and as a strategy for socio-cultural change. Marx brings together the traditional ideal of developing the historical and cultural disciplines towards the standards developed for the classical natural sciences with very concrete social perspectives. At the same time, he proposes a new concept tailored to the peculiarities of the subject matter of the social and historical sciences. The roots of this innovation lie in the development of the sciences since the end of the eighteenth century. Marx's innovation had lasting but contradictory effects on the disciplines in question, their interdisciplinary relations and, particularly, their political engagement.

Two major studies which related Marx's approach to the development of the sciences in the nineteenth century as well as to the reception of his work in the twentieth century were finished in 1996 and 1997.

Women Scientists at the Berlin University and at the Institutes of the "Kaiser-Wilhelm-Gesellschaft" in Berlin/Germany between 1898 and 1945

Annette Vogt

Work continued on the project of a comprehensive survey of women who graduated from the Friedrich-Wilhelms-Universität Berlin from 1898/1899 to 1945 and of women scientists who worked at different institutes of the Kaiser-Wilhelm-Gesellschaft (KWG) (see the Annual Reports of 1994 and 1995). Initial results were published and further results were reported in various lectures.

In addition to establishing the identities and biographies of this surprisingly large group of women researchers, the study aims to uncover:

(1) What were the reasons for women gravitating to certain institutions and specialities within the natural sciences and mathematics? For what reasons did women find opportunities in some Institutes of the KWG? Where did women have better chances, in the KWG or at the University? When and why did the situation change?

(2) What ideals and practices of early twentieth-century scientific research, particularly those of objectivity, helped or hindered the recruitment and the

participation of women?

(3) What role did changing cultural views of femininity during this period in Germany play in the careers of these women scientists? What were the reasons for changing possibilities for employment of women? Why did the situation for female scientists, especially those working in industrial laboratories, change so rapidly after 1933?

As in 1994/95, archival research in 1996 and in 1997 was concentrated in the archive of the Max-Planck-Gesellschaft, the archive of the University of Berlin and the Archive of the Berlin-Brandenburgische Academy of Science in Berlin. Furthermore, in 1996, the papers of Lise Meitner in the Churchill Archives Centre in Cambridge (UK) were studied and other archives were consulted.

1. The study of the documents about the dissertations of women at the Berlin University from 1899 to 1945 has been finished. A surprisingly large number of 368 theses on natural sciences by women were studied. From 1899 to 1936, all 617 dissertations by women were done at the Philosophical Faculty; among them, 346 dealt with topics in the humanities and social sciences, whereas 271 covered topics in mathematics and natural sciences. From 1936 to April 1945 only 97 theses were submitted by women at the Mathematical-Science Faculty, while 310 theses were completed by women at the Philosophical Faculty.

Careful attention was given to the dissertations based on research performed at the laboratories of Institutes of the KWG. Between 1919 and 1936, at least 32 theses were based on research done at the laboratories of several Institutes of the KWG: fourteen in chemistry, fourteen in biology, two in medicine and two in physics. Between 1936 and 1945 only eleven theses were based on research done at the laboratories of Institutes of the KWG: three in chemistry, seven in biology and only one in physics.

Furthermore, all documents of those women who had completed a *Habilitation* at the Philosophical Faculty (twelve between 1919 and 1932 and four between 1937 and 1945) and at the Mathematical-Science Faculty (only two in 1939 and in 1943) were also studied.

A directory of all archival documents related to dissertations and *Habilitationen* by women, with a brief introduction to the theme and with preliminary results, was prepared for print and published as preprint no. 57 of the Institute (in April 1997).

To answer the questions mentioned above, further studies about the possibilities of the employment of women with a doctoral degree are necessary. Biographical research on women scientists who achieved a *Habilitation* at the University was begun in 1996 and continued in 1997. Furthermore, all documents of those women who worked as an assistant in the Institutes of the Philosophical Faculty and the Mathematical-Science Faculty were studied in 1997.

2. The biographical research on women scientists who worked in several Institutes of the KWG continued in 1996 and in 1997. In 1996, records of more than 150 women scientists working for the KWG during the period between 1912 and 1945 have been uncovered, to date, a total of over 192 women scientists. It has become apparent that women scientists headed at least eleven departments in Institutes of the KWG. There were large differences between the institutes, with some institutes employing no female scientists and others employing many. The reconstruction of the scientific careers of the eleven department heads at the KWIs, who have been omitted from the official history of the KWG until the present, continues. Initial results about the different places of the women scientists in the different KWIs and the explanations for these differences were published as preprint no. 67 of the Institute (in July 1997).

Expanding the level at this study from biography to prosography, the project next must reconstruct the sociological backgrounds of these women, the intellectual affinities governing their choice of a certain discipline or sub-discipline, and the culture of gender relations at the leading scientific institutions of Berlin during this period. In expanding the comprehensive survey of women at the University of Berlin and at the Institutes of the KWG, a special comparison must be drawn between the assistants at the University and the scientific workers at the KWIs on the one hand, and the female *Privatdozenten* at the University and the female leaders of departments at the Institutes of the KWG on the other.

Related Projects of Visiting Scholars and Research Fellows

Francesca Bordogna, “Objectivity and Psychical Research, 1880-1910”; Stéphane Callens, “History of Measure - History of Risk”; Berna Eden, “Psychology versus Logic in 19th-Century Probability Theory”; Morgane Labbé, “History of the Concept of Nationality in Statistics”; Sybilla Nikolow, “The Visual Representation of Statistics”; Libby Schweber, “Statistical Entities and the Creation of New Disciplines in 19th-Century France and Britain”; Zeno G. Swijtinks, “Early Visual Representations of Experimental and Observational Data” (see *Activities of the Visiting Scholars and Research Fellows p. 182).*

Project 3: Demonstration, Proof, Test (1997-98)

Lorraine Daston (responsible) in cooperation with Joan Cadden, William Clark, and Sophie Roux

General Goals of the Project

Epistemology studies how we know and how secure our knowledge is. Historical epistemology studies, *inter alia*, the history of the specific ways devised to make knowledge secure, from the mathematical demonstration to the judicial proof to the empirical test. Although the words “demonstration,” “proof,” and “test” in their narrow senses refer to very different aims and procedures – contrast, for example, the demonstration, which seeks to circumvent an induction over cases, with the eminently inductive test of a hypothesis or a machine – their histories and current usages are closely intertwined in the major European languages. This project is dedicated to posing philosophical questions about how knowledge, both theoretical and practical, becomes trustworthy in a concrete, historical vein: what are the forms of argument, the techniques, the procedures that guarantee various kinds of knowledge, and how did they emerge and become authoritative? Although the project takes mathematical and scientific knowledge as its departure point, it follows the broader disciplinary and practical traditions of the words “demonstration,” “test,” and “proof” in including theological, medical, legal, and technological cases as well. Particularly revealing are examples which treat (1) prototypical forms of argument that become models for all other forms of secure knowledge (*e.g.*, Euclidean geometry, or scholastic arguments for the existence of God); (2) procedures and standards that migrate from one disciplinary context to another (*e.g.*, the application of legal standards of evidence to early modern civil and natural history, or the adaptation of proofing techniques to assess the gold content of coins for chemical analysis); (3) the introduction of novel methods to prove or test (*e.g.*, the polygraph in the cross-examination of witnesses, or double-blind trials in medical research); and (4) the convergence and conflict of different methods for securing knowledge about the same objects (*e.g.*, bodily tact versus instruments, or computer simulations versus physical experiments).

UPCOMING PROJECTS:

1998-99: "Scientific Personae"

1999-2000: "The Moral Authority of Nature"

Projects of the Research Group Headed by Hans-Jörg Rheinberger (Department III)

The work of Hans-Jörg Rheinberger's research group is divided into three overlapping areas of investigation: (1) the history and epistemology of experimental practices; (2) the history of objects and spaces of knowledge; (3) the historical pragmatics of concept formation and the uses of theory in the life sciences. Most of the individual projects are situated in the context of the biological and the medical sciences from the eighteenth to the twentieth century. The overarching historical question is: What are the conditions conducive to scientific innovation?

Each of these three areas of investigation will be the subject of a major international conference, the first of which will be held in 1999.

1: History and Epistemology of Experimentation

General Goals

Over the past three centuries, the study of living beings has changed from a classificatory *historia naturalis*, an anatomy of visible structures, and a physiology of apparent body functions, to a highly stratified investigative endeavor adapted to its similarly diverse research objects. These objects range in scale from biodiversity through the social behavior of organisms to macromolecules. Each of these levels of organization and investigation has developed a corresponding phenomenology, set of analytical approaches, and methods of determining its object. In history of science 'from the top down,' these developments are often seen as a social process through which scientific disciplines became differentiated, or as a succession – evolutionary or revolutionary – of theoretical paradigms. Complementary to the history of disciplines and the history of ideas, and in accordance with the recent 'practical turn' in the history of science, the perspective of this investigation is 'from the bottom up.' It inquires how fields of research, and ultimately disciplines, aggregate around a cluster of practices and technologies, methods, concepts, and theoretical conjectures to become relatively stable configurations. Such aggregation appears to be socially as well as theoretically underdetermined.

Serious consideration of this empirical horizon of the life sciences demands that historical assessment start not with the reconstruction of the development of biological theory according to a perceived immanent logic, but rather with the reconstruction of the practical contexts in which particular theories gained momentum. Here, the importance of experimental arrangements for the genesis of concepts and generalizations in the modern biological sciences moves center stage. Our analyses proceed from the assumption that experiment itself is a historically variable practice that has undergone decisive shifts of structure and content. These shifts can be illuminated best through broadly conceived comparative studies. As early as the seventeenth century natural philosophers experimented with living things; but in what sense? The demonstrative experiment of the seventeenth century differs significantly from the eighteenth-century idea of an experiment as a more or less systematic extension of observation. In the nineteenth century, conversely, observation itself becomes dependent on experimental exploration in many areas of science. In accordance with these changes, the practice of experimentation has taken on different forms and has become greatly diversified. These forms of experiment deserve systematic assessment.

Of particular relevance to the life sciences of the nineteenth and the twentieth centuries is a close examination of what we call ‘experimental systems.’ On the one hand, experimental systems can be viewed as comparatively robust, if transient, embodiments of concepts. On the other hand, they represent the most basic, integral, social realizations of scientific activity. As François Jacob once put it: “In biology, any study [begins] with the choice of a ‘system’.”

This state of affairs, synchronically and diachronically, calls for an epistemology of experimentation. A comparative study of the forms of experimentation is an important element of a historical epistemology of the sciences. Such an epistemology of experimentation lies beyond those modes of philosophy of science that have relegated to the experiment the trivial function of testing hypotheses. The case studies that are needed to realize this project require new methodologies. In addition to the analysis of published texts, they include the systematic evaluation of laboratory notebooks and of oral history documents, the study of historical laboratory structures and of other microstructures of scientific practice, and, finally, the virtual reconstruction of historical experiments.

Current Research Activities Related to "History and Epistemology of Experimentation"

Experimental Systems in Molecular Biology

Hans-Jörg Rheinberger

Hans-Jörg Rheinberger's recent book *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford University Press, 1997) contains a detailed investigation of the history of protein biosynthesis research between 1945 and 1965. Central to the story is an 'in vitro system' for the incorporation of radioactive amino acids into proteins. The establishment of this system is followed closely and its various elements are analyzed. This historical case study in experimental systems concomitantly elucidates the roles and functions played by cancer research and biochemistry in the development of molecular biology. On the basis of this historical material, several epistemological concepts are developed both in order to understand experimentation in twentieth-century life sciences and to contribute to a general epistemology of experimentation. These include 'experimental system,' 'epistemic thing,' 'representation,' and 'conjuncture.'

A Virtual Laboratory for Physiology (VLP)

Sven Dierig (in cooperation with Jörg Kantel)

Based on digitized illustrations, texts, and other historical records taken from scientific journals and handbooks, catalogues of scientific instruments, administrative documents, correspondence, and laboratory notebooks, the goal of the Virtual Laboratory for Physiology is to provide an electronic research tool for historical studies on the development of instrumentation and experimentation in nineteenth-century life sciences. The database aspires to a complete collection, classification, and integration (through hyperlinked documents) of representations of experimental practices, instruments, and technical tools used in the production of knowledge and in teaching in the nineteenth-century physiology laboratory. The Virtual Laboratory for Physiology will be presented on the World Wide Web. It will include a virtual library with all relevant journals, allowing visitors to conduct online literature searches and to evaluate statistical and geographical distributions (landscapes of experimentation). Newsgroups and other Internet-related forms of communication will be established to provide a forum for discussion and information exchange.

Related Projects of Visiting Scholars and Research Fellows

Sarah Jansen, "'Population' as an Object of Experimental Systems: Ecology and Related Fields in Germany, 1850-1950"; Ohad Parnes, "The Origins of Microscopical Biology, 1760-1850"; Henning Schmidgen, "Pendula, Noematographs, and Chronoscopes: The Origins of the Reaction Time Paradigm in Nineteenth Century Psychology" (see *ACTIVITIES OF THE VISITING SCHOLARS AND RESEARCH FELLOWS P. 182).*

2: HISTORY OF OBJECTS AND SPACES OF KNOWLEDGE

General Goals

This area of investigation is based on the assumption that a decisive aspect of scientific innovation lies in choosing, shaping, reshaping, and sometimes in abandoning certain objects of study. The mere examination of the history of these objects presupposes that they take on various forms in the different research contexts in which they acquire their epistemic value. Embryos, brains, mice, and bacteria are not epistemic things by themselves; they are things that become epistemic insofar as they locate monsters, memory, oncogenes, and messengers in a cluster of practical and theoretical relations. The projects in this area of investigation focus on three central aspects of the history of scientific objects in the life sciences: first, the choice of organism, or of part of an organism; second, the spaces in which these organisms or parts function as objects of epistemic interest; and third, the 'mental culture' of the scientist who lives in these spaces and investigates these objects.

The choice of organisms has always played and continues to play a decisive role in the life sciences. Since the end of the eighteenth century, the meaning of key biological concepts has been shaped by the availability of particular model organisms. Late eighteenth-century vitalism, for example, was by no means a purely speculative endeavor; it is unthinkable without the frog as a model and emblem of bioelectricity. Similarly, the eighteenth-century conception of epigenesis relied on the polyp as a model of organic regeneration. The history of genetics, to take another example, can be portrayed as a succession of model organisms: from humans to peas to flies to molds, bacteria, viruses, and back to higher organisms. Alternatively, experimental medicine has been characterized since its beginnings by a debate as to what animal models are best suited for the study of human diseases and the testing of pharmacological substances. A closer analysis of such examples shows that the uses and scientific 'careers' of certain organisms are bounded by a complex set of conditions. These include technical specifications such as utility, disposability, suitability for laboratory work, and ease of manipulation; ethical and financial considerations; forms of everyday life; and theoretical presuppositions. These conditions may include the natural and cultural histories of organisms, of diseases, or even of entire environments. Here the cultural, social and epistemological aspects of the investigative enterprise are tightly interwoven.

A natural object can become interesting for many reasons, but it only becomes epistemically relevant if it fits into real and symbolic spaces that have taken different forms in history. Such spaces of knowledge include natural cabinets, botanical gardens, agricultural experiment stations, laboratories, the 'field' of the anthropologist or the naturalist, and computer simulations. Every space of knowledge is characterized by its own particular material culture. Spaces of knowledge mark the boundaries of epistemic objects and connect them to larger cultural settings, forms of everyday life, forms of art and architecture, and especially forms of scientific communication. In turn, these spaces receive their particular shapes from the chosen objects of study. Such mutual dependence of objects and spaces is characteristic not only of the microworld of experimental systems, but also of natural histories, anthropological and clinical classifications, and multidimensional scientific accounts of mass phenomena such as epidemics.

Finally, to any particular material culture there corresponds the scientist's 'mental culture.' In fact, 'the scientist' is itself a figure displaying historically conjugant configurations of explicit and tacit knowledge, skills, bodily and mental discipline, and gestural repertoires. These include such elements as the mastering of instruments in a given experimental situation and the training of the senses in subjective sensory physiology. The concept of mental culture encompasses not only the above aspects, but also the virtues, passions, mentalities, and idiosyncrasies of the researcher. Thus the scope of mental culture ranges from the importance of sensibility in late eighteenth-century life sciences and the role of heroism in romantic self-experimentation to attempts to include or exclude the participating observer in twentieth-century anthropology. The assumption is that such mental culture, in combination with material cultures, helps to explain the relationship between scientific activity and more general cultural and social ideas, practices and values. Notions such as epistemic objects, spaces of knowledge, and mental cultures will allow the development of a framework to overcome the traditional dichotomies of internal *vs.* external factors of scientific development, of experiment *vs.* observation, of basic vs. applied research, and of scientific method *vs.* bricolage.

Current Research Activities Related to "History of Objects and Spaces of Knowledge"

From the Organ of the Soul to the Brain

Michael Hagner

Michael Hagner's recent book *Homo cerebralis. Der Wandel vom Seelenorgan zum Gehirn* (Berlin Verlag, 1997) describes the transformation of brain research in the years around 1800, from 'the organ of the soul' to the brain. In the early modern period, the organ of the soul served as a material medium between the body and the soul. It permitted an understanding of man which combined metaphysical and religious aspects with medical and natural historical approaches. The reconceptualization of the brain as an organ, in which various mental qualities were housed equivalently among each other, marked an epistemic rupture. The previous conception allowed for the categorical differentiation between body and the soul, and between reason and passions, in accordance with an enlightened, yet strictly hierarchical view of man. The new development of brain research represented a science of man, whereby the former categorical differences were now localized in the brain. The brain emerged as the epistemic field for various attributes and differentiations that became fundamental for modernity – such as man/woman, madness/genius, wilderness/civilization, and sense/

sensibility.

The study covers the period from the late Enlightenment to the 1870's, when the foundations of modern experimental brain localization were established. A major focus of the book is the new role of the brain in early nineteenth-century phrenology and romantic *Naturphilosophie*. Although these movements often were regarded as obstacles to scientific progress, both were essential in establishing this new approach, providing a number of assumptions, models, and practices which became central to modern localization research in anatomy, experimental physiology, and clinical research.

Mental Cultures

Michael Hagner

In the context of collaboration with Lorraine Daston, Dorinda Outram, and H. Otto Sibum on the conference project *"Varieties of Scientific Experience,"* (*see p. 258*) Michael Hagner has started a book-length study of the history of 'mental cultures.' To this end, he has focused on the histories of vertigo and of attention as an element of self-experimentation. Scientists' understanding of attention underwent a fundamental transformation in the course of the eighteenth and nineteenth centuries. These conceptualizations were linked to the role of the scientist as subject and as object in self-experiments, as well as to the establishment of attention as a fundamental virtue. The ambiguous character of attention lay in the dual role which it occupied as both an experimental tool and object of investigation. Similarly, until the eighteenth century, vertigo was regarded as a merely pathological phenomenon and thus a subject of interest only to physicians. In the late eighteenth century, however, empirical psychologists came to regard vertigo as a disturbance of the regular activity of the soul and thus began investigating it more closely. Henceforth the concepts of vertigo and attention became polarized. While the latter was defined as a state of orientation, vertigo was understood as disorientation. As a consequence, the history of these two phenomena became inseparably intertwined. This connection will be illustrated through three examples: late enlightenment self-observation, Romantic self-experimentation, and psychophysical research in the 1860's. These case studies may well show that the formation and the transformation of categories such as attention and vertigo became crucial for establishing new criteria of scientific experience. As a consequence, these categories were seen as essential for understanding and investigating the self as a 'mind-body' unity.

Urbanization, Industrialization, and the Place of Experiment in Nineteenth-Century Physiology

Sven Dierig

Laboratories, along with the researchers, organisms, instruments, and experiments associated with these places of investigation, are not isolated from the world beyond their physical and institutional boundaries. Both laboratories and cities in which they are embedded are subject to change, as was most dramatically apparent in their dynamic and far-reaching transformation during the Industrial Revolution of the nineteenth century. Using the example of Berlin and the institutionalization of experimental physiology by Emil Du Bois-Reymond (1818-1896), this project analyzes the interrelations between urban transformation and the laboratory revolution in physiology during the second half of the nineteenth century. The fundamental aim of the project is to understand how cities and laboratories form spaces of knowledge and cooperate in the production of scientific novelty. A main emphasis is to demonstrate how ongoing changes in urban life and society, industry, economy and technology entered Du Bois-Reymond's workplace and became part of the social and material culture of experimental physiology in Berlin. Rather than following a strict chronology, the study focuses on several themes which illustrate the effects of urbanization on laboratory life. These include (1) the networked city: the connected laboratory and the increasing dependence of experimental work on urban technological systems (water, gas, electricity); (2) city building and the establishment of scientific working places; (3) the city as a disruptive factor: public transportation and precision work in the laboratory; (4) the industrial city and labor: scientific instruments, the power of machines, and the evolution from manual work to mass production in the laboratory; (5) the nervous city and changes in public values: utilitarism, the American spirit, and the end of Biedermeier science; (6) the iron city and urban life style: sports, art, and the aesthetics of human bodies, machines, and experiments.

History of the 'Epidemic' as a Scientific Object

Andrew Mendelsohn

Epidemiology is among the oldest fields of scientific inquiry. Yet while much has been written about the history of public health and the social history of disease, relatively little attention has been paid to epidemics as objects of knowledge. Epidemiology is rich in traditions: historico-geographical, environmental, statistical, bacteriological, mathematical. Yet the focus of this project is less on these traditions as such, or on epidemiology as a discipline, than on the history of the 'epidemic' as a scientific object at the intersection of myriad nineteenth and early twentieth-century institutions, technical practices, and fields of knowledge. The project asks in particular how the ancient entity 'epidemic' was transformed by the rise of bureaucratic states, statistics, and that new object, population; and how epidemiology figured in the emergence of population sciences (ecology, genetics, evolution) after 1900. A paper completed in 1997 as part of the project (see bibliography) suggests that quantitative understanding and graphical analysis of the dynamics of epidemics preceded such an understanding and analysis of other biological mass phenomena. The late nineteenth-century epidemiologists' construction of population as a thing of changing densities and rates of interaction would appear to bridge the social statistics of the nineteenth century and the population sciences of the twentieth. A second focus of the project is on the way in which politics and culture shaped methods of investigating epidemics and theories of causation, and, conversely, how the subsequent development of those very techniques of inquiry into mass phenomena of health, disease, and death helped give such categories as the 'social' and the 'environmental' their modern form.

Robert Koch and the Genesis of Bacteriology in Germany

Christoph Gradmann

This project focuses on the 'founder' of medical bacteriology, Robert Koch. Questions concern both the development of German bacteriology in the late nineteenth century and the biography of its central figure. One problem addressed is the extent and nature of medical research on bacteria prior to Koch's identification of the anthrax bacillus in 1875-76. Another issue concerns triangular relations between the Prussian Ministry of Culture, the pharmaceutical industries, and bacteriological laboratories, and the significance of these relations for Koch's career and for the early development of German bacteriology. One of the principal builders of the microcosm of bacteriology displayed a distinct desire for the macrocosm: among Koch's most notable biographic features is his enthusiasm for world travel. Another subject is the impact of bacteriology, apart from the etiological content emphasized in most studies, on contemporary pathological thinking. The project relies on source materials located in many archives, libraries, and other institutions in Berlin.

The project will result in a series of biographical studies of Koch. One aim is to confront the standard biographies of Koch with a more open concept of a historical personality which should not be treated as a given unity, but as an assembly of differing roles that vary in their degree of individuality.

Related Projects of Visiting Scholars and Research Fellows

Berna Eden, "The Mind as an Epistemic Object, or Why Did Psychology and Anthropology Become Dangerous to Logic?"; Peter Geimer, "The Photography of Invisible Phenomena around 1900"; Karlheinz Lüdtke, "Virus Research from the End of the Nineteenth Century to the 1960's", Jutta Schickore, "Investigating the Constitution of the Retina in Nineteenth Century Sensory Physiology" (see *ACTIVITIES OF THE VISITING SCHOLARS AND RESEARCH FELLOWS P. 182).*

3: PRAGMATICS OF CONCEPT FORMATION AND THE USES OF THEORY IN THE LIFE AND MEDICAL SCIENCES

General Goals

The general aim of this incipient study, outlined only tentatively here, is to assess the specificity and role of the 'theoretical' in the investigation of living things. Concept formation and the function of generalizations in biology will be analyzed from a number of different perspectives: the relation between physical and life sciences; the organizing function of concepts, especially over the *longue durée*; the heterogeneity of biological discourses; and the historicization of analytical categories such as reductionism, holism, and mechanism. Special emphasis will be placed on the pragmatic aspect of how concepts and generalizations work as tools in various historical contexts and on how they become embodied. Examples are the concept of species, from taxonomy to evolutionary biology to genetic engineering; the concept of information in the history of molecular biology; the concept of hereditary units in the convoluted history of genetics (see the book project of Peter Beurton in the research group of Jürgen Renn, p. 93). It is the recent 'practical turn' in the history of science itself that makes the question of the theoretical once again interesting and investigable from a new perspective.

The relation between physical and life sciences has been a crucial problem since at least the seventeenth century. In each epoch the boundary between the realm of the living and that of the non-living was drawn differently, as the result of a negotiation that in itself is a first order problem for the history of science. Natural history and physiology in the eighteenth century drew this boundary in a distinctly different manner than romantic biology around 1800, or the biological disciplines of the nineteenth century such as cytology, sensory physiology, and evolutionary biology. Today, the realm of the organic is conceived as being the unique product of an evolutionary process and therefore irrevocably shaped by history. This may be an underlying reason for the fact that the history of bioscience since the late nineteenth century has not allotted as significant a role for 'theoretical biology' and 'theoretical medicine' as the history of physics has for theoretical physics.

Within this general framework, the role of organizing concepts is addressed, paying special attention to their stabilities and instabilities, and to their long-term appropriations and transformations. Two examples will be given in the projects listed below. One deals with the notion of 'regulation' and its impact on the formation of molecular biology. The other traces such concepts as complexity, equilibrium, whole, system, and the 'biological' itself as they came to pervade twentieth-century interwar scientific medicine. Such concepts appear to work without being firmly embedded in an overall theoretical framework, and their fruitfulness often appears to be bound to a lack of strict definition.

Another perspective on the problem of the theoretical derives from the complexity of the living as it has emerged fitfully in different fields since the creation of biology in the nineteenth century. As a consequence of this complexity, conceptualization of the living takes place on many different levels of organization. Access to, and therefore definition of, such levels has depended to a great degree on technologies which generally developed independently of the biological sciences. This adds a further dimension to the question as to how these levels of epistemic activity are connected. We suspect that the connections are largely *ad hoc*, due to historical contingencies. Heterogeneity of discourses results. Instead of joining the perennial quarrel over reducibility – of biology to physics at large, and of one level of analysis to another – projects in this field offer an investigation of the historical dynamics of such heterogeneity in its own right.

Current Research Activities Related to "Pragmatics of Concept Formation and the Uses of Theory in the Life Sciences"

The Complexity of the Body, 1900-1940

Andrew Mendelsohn

This project identifies a 'biological transformation of Western medicine' in the overshadowed, allegedly stagnant period before molecular biology. In this transformation, simpler 'medical' understandings of immunity, hereditary disease, infection, allergy, deficiency, cancer, and perhaps other concepts and entities gave way to what contemporaries called 'complex' biological, ecological, populational, quantitative ones. The aim is to produce a narrative of scientific medicine in the first half of this century complementary to the story of the path to the double helix. In so doing, the project should help to answer the question as to how, after the Second World War, certain fields of medical science were so suddenly reconstructed – for example, when immunology, which had been dominated by a narrow immunochemistry, yielded the 'immune system.' The participation of 'narrow medical men' in those interwar trends which historians of biology have tended to call holistic also points to a wide context of change in the culture of life science – a change which perhaps has less to do with holism and organic metaphors *per se* than with quantitative conceptual structures (although often expressed in qualitative form: "equilibrium") and styles of causal explanation developed in the physical, social, and biological sciences alike. Three papers written in 1996-97 (see bibliography and list of lectures) confirm that contemporaries were at least as concerned with complexity – a concept whose own history will have to be charted – as with unity. The papers suggest, moreover, that standard categories of analysis, such as holism, mechanism and reductionism, fail to capture what changed conceptually during this period. Moreover, their definition, use, and applicability to particular domains of knowledge deserve investigation as a historical problem.

A History of the Notion of Genetic Regulation

Denis Thieffry

The project endeavors to trace some of the main conceptual shifts that occurred in the transition from experimental embryology at the beginning of the twentieth century to contemporary developmental biology. The focus is on the roles of the notions of 'regulation' and 'regulatory network.'

The notion of regulation occupies a central position in most fields of contemporary biology. Accordingly, several authors have addressed its history, especially with respect to the development of the concept of 'regulatory gene' in the context of the rise of molecular genetics in the 1950's. However, the notion of regulation is clearly of much older origin and involves a wide variety of disciplines, including chemistry, physiology, and embryology.

Accordingly, one focus of the present project is on the notion of regulation in the work of experimental biologists in the first half of this century, such as Hans Driesch, T.H. Morgan, Hans Spemann, C.H. Waddington. Versions of the concept are then elucidated in conjunction with related embryological concepts such as 'induction,' 'field,' 'epigenesis,' 'canalization,' up to recent interpretations of embryonic development in terms of a spatio-temporal control of gene expression.

In the shadow of the new molecular biology, most of these embryological concepts went through a partial eclipse in the 1960's and 1970's, all but disappearing from embryological textbooks and mainstream publications. However, some of them ('gradient,' for example) continued to inspire the research of such theoretically inclined biologists as Lewis Wolpert and Hans Meinhardt as well as the research of some experimentalists working on regeneration (Alfred Gierer) and insect development (Klaus Sander).

More recently, some of these concepts, notably ‘gradient’ and ‘epigenesis’, were redefined in molecular terms and reintroduced into the description of cell differentiation and embryonic development, while others, such as ‘canalization,’ remained marginal.

Aiming to understand how the uses and successes of these concepts relate to specific experimental settings, model organisms, disciplines, and local cultures, this study emphasizes polysemy and shifts of meaning. The historical reconstruction will highlight the ways in which the study of embryogenesis was redefined and became integrated into the molecular framework.

Related Project

Christina Brandt, “Linguistic and Informational Metaphors in the History of Molecular Biology” (see *ACTIVITIES OF THE VISITING SCHOLARS AND RESEARCH FELLOWS P. 182).*