concepts and theories in response to anomalies and new research.

In some cases the members of excluded groups do more than replace old research methods and programs with new ones; they also create new research fields based on their identity concerns. A prime example is the work of the African American scientist George Washington Carver. Although best known in American popular culture for finding many new uses for the peanut, Carver's research was embedded in a larger research program that was focused on developing agricultural alternatives to King Cotton for poor, rural, African American farmers (Hess 1995).

4. Conclusions

It is important not to think of the embeddedness of scientific cultures in broader cultural practices as a problem of contamination. The broader cultures of modern science provide a source of metaphors and institutional practices that both inspire new research and limit its possibilities. For example, if evolutionary theory could not be thought before the progressivist culture of the nineteenth century, it cannot help but to be rethought today. Not only have new research findings challenged old models, but the broader cultural currents of complex systems and limits to growth have also inspired new models and empirical research (DePew and Weber 1995). In turn, today's concepts and theories will be rethought tomorrow. The broader societal cultures are not weeds to be picked from the flower bed of scientific culture(s) but the soil that both nurtures and limits its growth, even as the soil itself is transformed by the growth that it supports.

See also: Academy and Society in the United States: Cultural Concerns; Cultural Psychology; Cultural Studies of Science; Culture in Development; Encyclopedias, Handbooks, and Dictionaries; Ethics Committees in Science: European Perspectives; History of Science; History of Science: Constructivist Perspectives; Scientific Academies in Asia

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D. Hess

Scientific Disciplines, History of

The scientific discipline as the primary unit of internal differentiation of science is an invention of nineteenth century society. There exists a long semantic prehistory of *disciplina* as a term for the ordering of knowledge for the purposes of instruction in schools and universities. But only the nineteenth century established real disciplinary communication systems. Since then the discipline has functioned as a unit of structure formation in the social system of science, in systems of higher education, as a subject domain for teaching and learning in schools, and finally as the designation of occupational and professional roles. Although the processes of differentiation in science are going on all the time, the scientific discipline as a basic unit of structure formation is stabilized by these plural roles in different functional contexts in modern society.

1. Unit Divisions of Knowledge

Disciplina is derived from the Latin *discere* (learning), and it has often been used since late Antiquity and the early Middle Ages as one side of the distinction *disciplina* vs. *doctrina* (Marrou 1934). Both terms meant ways of ordering knowledge for purposes of teaching and learning. Often they were used synonymously. In other usages *doctrina* is more intellectual and *disciplina* more pedagogical, more focused on methods of inculcating knowledge. A somewhat later development among the church fathers adds to *disciplina* implications such as admonition, correction, and even punishment for mistakes. This concurs with recent interpretations of discipline, especially in the wake of Michel Foucault, making use of the ambiguity of *discipline* as a term always pointing to knowledge and disciplinary power at the same time (cf. Hoskin in Messer-Davidow et al. 1993). Finally, there is the role differentiation of teaching and learning and the distinction *doctrina/disciplina* is obviously correlated with it (Swoboda 1979).

One can still find the same understandings of *doctrina* and *disciplina* in the literature of the eighteenth century. But what changed since the Renaissance is that these two terms no longer refer to very small particles of knowledge. They point instead to entire systems of knowledge (Ong 1958). This goes along with the ever more extensive use by early modern Europe of classifications of knowledge and encyclopedic compilations of knowledge in which disciplines function as unit divisions of knowledge. The background to this is the growth of knowledge related to developments such as the invention of printing, the intensified contacts with other world regions, economic growth and its correlates such as mining and building activities. But in these early modern developments there still dominates the *archival function of disciplines*. The discipline is a place where one deposits knowledge after having found it out, but it is not an active system for the production of knowledge.

2. *Disciplines as Communication Systems*

A first premise for the rise of disciplines as production and communication systems in science is the specialization of scientists and the role differentiation attendant on it (Stichweh 1984, 1992). Specialization is first of all an intellectual orientation. It depends on a decision to concentrate on a relatively small field of scientific activity, and, as is the case for any such decision, one needs a social context supporting it, that is, other persons taking the same decision. Such decisions are rare around 1750 when encyclopedic orientations dominated among professional and amateur scientists alike, but they gained in prominence in the last decades of the eighteenth century. Second, specialization as role differentiation points to the educational system, which is almost the only place in which such specialized roles can be institutionalized as occupational roles. From this results a close coupling of the emerging disciplinary structures in science and the role structures of institutions of higher education. This coupling is realized for the first time in the reformed German universities of the first half of the nineteenth century and afterwards quickly spreads from there to other countries. Third, role differentiation in institutions of higher education depends on conditions of organizational growth and organizational pluralization. There has to be a sufficient number of organizations which must be big enough for having differentiated roles and these organizations must be interrelated in an ongoing continuity of interactions.

The emergence of *communities of specialists* is a further relevant circumstance. In this respect the rise of disciplines is synonymous with the emergence of *scientific communities* theorized about since Thomas Kuhn (Kuhn 1970). Scientific communities rest on the intensification of interaction, shared expertise, a certain commonality of values, and the orientation of community members towards problem constellations constitutive of the respective discipline. Modern science is not based on the achievements of extraordinary individuals but on the epistemic force of disciplinary communities.

Scientific communities are *communication systems*. In this respect the emergence of the scientific discipline is equivalent to the invention of new communication forms specific of disciplinary communities. First of all one may think here of new forms of *scientific publications*. In the eighteenth century a wide spectrum of publication forms existed; they were not, however, specialized in any way. There were instructional handbooks at the university level, journals of a general scientific nature for a regional public interested in utility, and academy journals aiming at an international public, each covering a wide subject area but with rather limited communicative effects. It was only after 1780 that in France, in Germany, and finally, in England, nationwide journals with a specific orientation on such subjects as chemistry, physics, mineralogy, and philology appeared. In contrast to isolated precursors in previous decades, these journals were able to exist for longer periods exactly because they brought together a *community of authors*. These authors accepted the specialization chosen by the journal; but at the same time they continually modified this specialization by the cumulative effect of their published articles. Thus the status of the scientific publication changed. It now represented the only communicative form by which, at the macrolevel of the system of science—defined originally by national but later by supranational networks—communication complexes specialized along disciplinary lines could be bound together and persist in the long run (Stichweh 1984, Chap. 6, Bazerman 1988).

At the same time the scientific publication became a formal principle interfering in every scientific production process. Increasingly restrictive conditions were defined regarding what type of communication was acceptable for publication. These conditions included the requirement of identifying the problem tackled in the article, the sequential presentation of the argument, a description of the methods used, presentation of empirical evidence, restrictions on the complexity of the argument accepted within an individual publication, linkage with earlier communications by other scientists—using citations and other techniques—and the admissibility of presenting speculative thoughts. In a kind of feedback loop, publications, as the ultimate form of scientific communication, exercised pressure on the scientific production process (i.e., on research) and were thereby able to integrate disciplines as social systems.

This reorganization of the *scientific production process* adheres to one new imperative: the *search for novelties*. The history of early modern Europe was already characterized by a slow shift in the accompanying semantics associated with scientific truth, from an imperative to preserve the truth to an interest in the novelty of an invention. The success achieved in organizing traditional knowledge, as well as tendencies towards empirical methods and increased use of scientific instruments, worked toward this end. In this dimension, a further discontinuity can be observed in the genesis of the term *research* in the years after 1790. In early modern times the transition from the preservation to the enlargement of knowledge could only be perceived as a continual process. In contrast, *research* from about 1800 refers to a fundamental, and at any time realizable, questioning of the entire body of knowledge until then considered as true. Competent scientific communication then had to be based on research in this sense. What was communicated might be a small particle of knowledge, as long as it was a new particle of knowledge. Scientific disciplines then became research disciplines based on the incessant production of novelties.

The link between scientific disciplines and organizations of higher education is mediated by two more organizational structures. The first of these are *disciplinary careers*. Specialized scientists as members of disciplinary communities do not need only specialized occupational roles. Additionally there may be a need for careers in terms of these specialized roles. This again is a condition which sharply distinguishes eighteenth from nineteenth century universities. Around 1750 you still find, even in German universities, hierarchical career patterns which implied that there was a hierarchical succession of chairs inside of faculties and a hierarchical sequence of faculties by which a university career was defined as a progression of steps through these hierarchized chairs. One could, for example, rise from a chair in the philosophical faculty to an (intellectually unrelated) chair in the medical faculty. The reorganization of universities since early nineteenth century completely discontinued this pattern. Instead of a succession of chairs in one and the same university, a scientific career meant a progression through positions inside a discipline, which normally demands a career migration between universities. This presupposes intensified interactions and competitive relations among universities which compete for qualified personnel and quickly take up new specializations introduced elsewhere. In Germany such regularized career paths through the national university system were especially to be observed from around 1850.

This pattern is again closely related to *disciplinary curricula*, meaning that one follows one's disciplinary agenda not only in one's research practice and personal career, but furthermore that there exist institutional structures favoring teaching along lines close to current disciplinary core developments. The unity of teaching and research is one famous formula for this, but this formula does not yet prescribe disciplinary curricular structures which would demand that there should be a complete organization of academic studies close to the current intellectual problem situation and systematics of a scientific discipline. Only if this is the case does there arise a *professionalization of a scientific discipline*, which means that a systematic organization of academic studies prepares for a non-academic occupational role which is close to the knowledge system of the discipline. Besides professionalization there is then the effect that the discipline educates its own future research practitioners in terms of the methods and theories constitutive of the discipline. A discipline doing this is not only closed on the level of the disciplinary communication processes, it is also closed on the level of socialization practices and the attendant recruitment of future practitioners (on the operational closure of modern science see Luhmann 1990, Stichweh 1990).

3. *The Modern System of Scientific Disciplines*

It is not sufficient to analyze disciplines as individual knowledge producing systems. One has to take into account that the invention of the scientific discipline brings about first a limited number, then many scientific disciplines which interact with one another. Therefore it makes sense to speak of a modern system of scientific disciplines (Parsons 1977, p. 300ff., Stichweh 1984) which is one of the truly innovative social structures of the modern world.

First of all, the modern system of scientific disciplines defines an *internal environment* (*milieu interne* in the sense of Claude Bernard) for any scientific activity whatsoever. Whatever goes on in fields such as physics, sociology, or neurophysiology, there exists an internal environment of other scientific disciplines which compete with that discipline, somehow comment on it, and offer ideas, methods, and concepts. There is *normal science* in a Kuhnian sense, always involved with problems to which solutions seem to be at hand in the disciplinary tradition itself; but normal science is always commented upon by a parallel level of interdisciplinary science which arises from the conflicts, provocations and stimulations generated by other disciplines and their intellectual careers.

In this first approximation it is already to be seen that the modern system of scientific disciplines is a very dynamic system in which the dynamism results from the intensification of the interactions between ever more disciplines. Dynamism implies, among other things, ever changing disciplinary boundaries. It is exactly the close coupling of a *cognitively defined discipline* and a *disciplinary community* which motivates this community to try an expansionary strategy in which the discipline attacks and takes over parts of the domain of other disciplines (Westman 1980, pp. 105–6). This was wholly different in the disciplinary order of early modern Europe, in which a classificatory generation of disciplinary boundaries meant that the attribution of problem domains to disciplines was invariable. If one decided to do some work in another domain, one had to accept that a change over to another discipline would be necessary to do this.

Closely coupled to this internally generated and self-reinforcing dynamics of the modern system of scientific disciplines is the openness of this system to new disciplines. Here again arises a sharp difference to early modern circumstances. In early modern Europe there existed a closed and finite catalogue of scientific disciplines (Hoskin 1993, p. 274) which was related to a hierarchical order of these disciplines (for example philosophy was a higher form of knowledge than history, and philosophy was in its turn subordinated to faculty studies such as law and theology). In modern society no such limit to the number of disciplines can be valid. New disciplines incessantly arise, some old ones even disappear or become inactive as communication systems. There is no center and no hierarchy to this system of the sciences. Nothing allows us to say that philosophy is more important than natural history or physics more scientific than geology. Of course, there are asymmetries in influence processes between disciplines, but no permanent or stable hierarchy can be derived from this.

The modern system of scientific disciplines is a global system. This makes a relevant difference from the situation of the early nineteenth century, in which the rise of the scientific discipline seemed to go along with a strengthening of national communities of science (Crawford et al. 1993, Stichweh 1996). This nationalization effect, which may have had to do with a meaningful restriction of communicative space in newly constituted communities, has since proved to be only a temporary phenomenon, and the ongoing dynamics of (sub-) disciplinary differentiation in science seems to be the main reason why national communication contexts are no longer sufficient infrastructures for a rapidly growing number of disciplines and subdisciplines.

4. *The Future of the Scientific Discipline*

The preponderance of subdisciplinary differentiation in the late twentieth century is the reason most often cited for the presumed demise of scientific discipline postulated by a number of authors. But one may object to this hypothesis on the ground that a change from disciplinary to subdisciplinary differentiation processes does not at all affect the drivers of internal differentiation in modern science: the relevance of an internal environment as decisive stimulus for scientific variations, the openness of the system to disciplinary innovations, the nonhierarchical structure of the system. Even if one points to an increasing importance of interdisciplinary ventures (and to problem-driven interdisciplinary research) which one should expect as a consequence of the argument on the internal environment of science, this does not change the fact that disciplines and subdisciplines function as the form of consolidating interdisciplinary innovations. And, finally, there are the interrelations with the external environments of science (economic, political, etc.), which in twentieth and twenty-first century society are plural environments based on the principle of functional differentiation. Systems in the external environment of science are dependent on sufficiently stable addresses in science if they want to articulate their needs for inputs from science. This is true for the educational environment of science which has to organize school and higher education curricula in disciplinary or interdisciplinary terms, for role structures as occupational structures in the economic environment of science, and for many other demands for scientific expertise and research knowledge which always must be able to specify the subsystem in science from which the respective expertise may be legitimately expected. These interrelations based on structures of internal differentiation in science which have to be identifiable for outside observers are one of the core components of modern society which, since the second half of the twentieth century, is often described as *knowledge society*.

See also: Disciplines, History of, in the Social Sciences; History and the Social Sciences; History of Science: Constructivist Perspectives; Human Sciences: History and Sociology; Knowledge Societies; Scientific Academies, History of; Scientific Culture; Scientific Revolution: History and Sociology; Teaching Social Sciences: Cultural Concerns; Universities and Science and Technology: Europe; Universities and Science and Technology: United States; Universities, in the History of the Social Sciences

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R. Stichweh

Scientific Discovery, Computational Models of

Scientific discovery is the process by which novel, empirically valid, general, and rational knowledge about phenomena is created. It is, arguably, the pinnacle of human creative endeavors. Many academic and popular accounts of great discoveries surround the process with mystery, ascribing them to a combination of serendipity and the special talents of geniuses. Work in Artificial Intelligence on computational models of scientific reasoning since the 1970s shows that such accounts of the process of science are largely mythical. Computational models of scientific discovery are computer programs that make discoveries in particular scientific domains. Many of these systems model discoveries from the history of science or simulate the behavior of participants solving scientific problems in the psychology laboratory. Other systems attempt to make genuinely novel discoveries in particular scientific domains. Some have produced new findings of sufficient worth that the discoveries have been published in mainstream scientific journals. The success of these models provides some insights into the nature of human cognitive processes in scientific discovery and addresses some interesting issues about the nature of scientific discovery itself (see *Scientific Reasoning and Discovery, Cognitive Psychology of*).

1. Computational Models of Scientific Discovery

Most computational models of discovery can be conceptualized as performing a recursive search of a space of possible states, or expressions, defined by the representation of the problem. Procedures are used to search the space of legal states by manipulating the expressions and using tests of when the goal or subgoals have been met. To manage the search, which is typically subject to potential combinatorial explosion, heuristics are used to guide the selection of appropriate operators. This is essentially an application of the theory of human problem solving as heuristic search within a symbol processing system (Newell and Simon 1972).

For example, consider BACON (Langley et al. 1987) an early discovery program which finds algebraic formulas as parsimonious descriptions of quantitative data. States in the problem search space of BACON include simple algebraic formulas; such as P/D or P^2/D, where, for instance, P is the period of revolution of planets around the sun and D is their distance from the sun. Tests in BACON attempt to find how closely potential expressions match the given quantitative data. Given quantitative data for the planets of the solar system, one step in BACON's discovery path finds that neither P^2/D nor P/D are constant and that the first expression is monotonically increasing with respect to the second. Given this relation between the expressions BACON applies its INCREASING operator to give the product of the terms, i.e., P^3/D^2. This time the test of whether the expression is constant, within a given margin of error, is true. P^3/D^2 = constant is one of Kepler's planetary motion laws. For more complex cases with larger numbers of variables, BACON uses discovery heuristics based on notions of symmetry and the conservation of higher order terms to pare down the search space. The heuristics use the underlying regularities within the domain to obviate the need to explore parts of the search space that are structurally similar to previously explored states.

Following such an approach, computational models have been developed to perform tasks spanning a full

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