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Regimes of science production and diffusion: towards a transverse organization of knowledge

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ABSTRACT

This article is a contribution to the critical sociology of science perspective introduced and developed by Pierre Bourdieu. The paper proposes a transversalist theory of science and technology production and diffusion. It is here argued that science and technology are comprised of multiple regimes where each regime is historically grounded, possesses its own division of labour, modes of cognitive and artifact production and has specific audiences. The major regimes include the disciplinary regime, utilitarian regime, transitory regime and research-technology regime. Though each regime is autonomous, they are simultaneously closely interlaced. In science and technology, autonomy is not antithetical to interdependence and reciprocity. This study demonstrates for the four specified regimes of production and diffusion that differentiation is not contrary to interaction. In science, differentiation and interaction comprise two sides of the same coin. All regimes exhibit a measure of transversality.

Keywords: Regimes of science and technology production and diffusion. Disciplinary regime. Utilitarian regime. Transitory regime. Research-technology regime. Transversality. Pragmatic universality.

Introduction

It is essential to ask whether Pierre Bourdieu's "scientific field" (cf. Bourdieu, 1975, 2001) is better understood as science in its entirety, as a way to distinguish science from other realms of social activity, or instead as reference to a particular discipline or some other cognitive or technical unit within science. The issue here is thus the dilemma of science versus the sciences. The answer to this question is central. To reply that science is to be grasped as a unity demands a reductionist valuation. Herewith lies the imperative to identify and defend a principle that integrates the multitude of historical and practical desiderata that fall under the label of science – no trivial task indeed. Certainly the disunity of science comprises a more likely landscape than the unity perspective in view of science's manifest differing and sometimes even apparently diverging formats and ways of doing and representing (cf. Hacking. 1983). The various manifestations of science captured by terms like the life sciences, physical sciences, laboratory sciences, field sciences etc. suggest the inherent problem in reducing science to a unity principle, or at least a fundamentally invariant unity principle.

On the other hand, if one opts for a pluralistic perception of the organization of science, it becomes necessary to identify the components constitutive of science. What are they? From whence do they derive? What are their characteristics? What distinguishes the different expressions of science from one another? Does a pluralistic perception of science force the science observer into a position where it becomes necessary to speak not of "science", but exclusively of the "sciences"? Stated otherwise, does pluralism demand the abandon of an appreciation of science as a system, even though an articulated, self-referencing system? We believe that the correct response to this question is negative. Thus, perhaps most important, what links the components together to form our conspicuously multi-fold and pluralistic system of science? While a pluralistic structure of science permits specifications of its numerous historical developments, modes of production and markets of diffusion, it similarly offers an opportunity to explore mechanisms that hold the sub-systems together, that allow circulation and communication between them, and that promote transverse intelligibility. In effect, if science is pluralistic, on what is grounded the claim to the universality of science? While this paper raises these crucial issues and proposes a series of hypotheses and propositions, the authors are manifestly conscious that in all too many spheres it is merely an opening gamut and that combined effort on the part of many others will be called for before more complete and solid answers can be derived.

This perception of multi-fold, pluralistic science revolves around three fundamental principles. First, borderlands are essential to distinguish between science and other forms of social activity. The concept of "borderland" leaves boundaries intact. The borderland between two spaces is that strip of land adjacent to each side of a borderline, often imprecisely established, where two people can communicate from the safety of their separate homelands. A borderland lies at the periphery of a territory. Speaking from a borderland one can cooperate with others without endangering the identity and habitus of the base referent.

Second, borderlands are necessary to distinguish between the local expressions that comprise science. They demarcate differences between groups, between what different groups produce and how production is carried out, and borderlands allow us to distinguish between forms and operations of organizations, and between systems of product diffusion (cf. Abbott, 1995, 2004). The various expressions of science, which compose its whole, demarcate the specificities of particular forms of training and certification, designation of tasks, modes of work, validation criteria, reward systems, career trajectories, modalities of products, the form and extent of markets, and the linkage between production and distribution.

Trans-borderland communication, collaboration and synergy is central to the pluralistic view of science. Borderlands do not isolate entities, they instead compose a necessary region of transfer and exchange. Mechanisms such as trans-borderland communication offer one form of intra and trans-regime cognitive and technical circulation. In science, ideas, instruments and men engage in selective borderland dialogs. Trans-boundary exchange is paramount to the operation and vitality of pluralistic science. It comprises the mode of cross-fertilization. It is also sometimes the vehicle for the generation of fresh configurations.

Historicity is the third essential ingredient of multi-fold, pluralistic science. The pluralistic view of science stresses that expressions of science are products of historical circumstances. They are the children of specific events occurring at a particular moment in time marked by observed intellectual, institutional and cultural events. Over time, fresh historical configurations and pressures emerge, and these require the adaptation of the pluralistic expressions of science. Nevertheless, the foundational expressions retain their original historical signature. While adapting, they sustain a self-referencing format and trajectory. Simultaneously, history too introduces unprecedented change, which in turn have in the past, and will surely today and in the future, give rise to novel additional expressions of science in the pluralistic science framework. While historicity modifies relations between existing expressions, it may also enrich the topography of the multi-fold science territory. This perspective, however, remains an empirical question for future generations of historians and sociologists.

Four regimes of science and technology production and diffusion will be presented here (cf. Shinn, 1993, 2000a, 2000b) – the disciplinary regime, the utilitarian regime, the transitory regime, and the research-technology regime (cf. Joerges & Shinn, 2001; Shinn & Joerges, 2002; Shinn, 2008). The genesis of each regime corresponds to the cognitive, political, and economic environment of a historical epoch, to the cultural dimensions of a given time. Each regime also possesses its specific division of labor, organizational framework, internal rules and hierarchy, universe of employment, forms of product output, clientele, and its particular system for circulation between production and market. It is this complex ensemble of factors that establishes the differences between regimes, and on which their respective borderlands and boundaries are grounded. The most crucial issue to be treated here is convergence, circulation and communication between regimes, and emergence of a form of universality that stretches across all regimes. This issue corresponds to activities transpiring in the research technology regime and to its output and effects on fellow regimes. It will be argued below that the products of the research-technology regime participate in curtailing some of the otherwise fragmenting consequences of multi-fold, pluralistic science. The research-technology regime provides a kind of common language to the whole of science and offers a form of universality in the guise of practical universality. The claim is certainly not that this gives rise to the unity of science. Transversality instead suggests a federative system of science characterized both by boundaries and by boundary crossing, and capped by transversality. Science can thus not be viewed as united in the strongest homogenizing sense. "Unity" here instead implies relative territorial autonomy of regimes, where regimes are structurally, functionally, and historically inter-connected by dint of the passage of concepts, materials, instrumentation and men.

1 The disciplinary regime

The disciplinary regime became fully established during the 19th century, and continues to expand today in the 21th century. However, changing technical, cognitive, organizational and market arrangements have impacted the form of many disciplines, particularly during the last sixty years: the operations of what we here refer to as the "new disciplinarity" is incontestably deeply rooted in earlier disciplinarity, which remains the referent, yet certain features of earlier disciplinary orientations and strategies have evolved (cf. Marcovich & Shinn, 2011a). Additional disciplinary specialties are intermittently added to the official union list of disciplines. Solid-state chemistry was recently officially recognized as a discipline in 1972 (cf. Teissier, 2007). Contrary to affirmations from certain quarters, the era of disciplinary science is not yet closed, and seems indeed far from closure. While there is much rhetoric about the death of disciplines and their substitution by interdisciplinarity (cf. Gibbons *et al.*, 1994; Nowotny *et al.*, 2001) and often considerable science policy talk and programming in favor of interdisciplinarity,[1] the substance and stability of disciplines do not appear to be in peril. They are indeed so very central to science. The specificity of three of the four regimes here discussed have disciplines as their point of reference. They appear to be pivotal to practitioners of science, to science's institutions, and to the historian, philosopher, sociologist and anthropologist of scientific knowledge (cf. Shinn, 2000a, 2000b, 2008; Heilbron, 2004).

While Robert Merton (1970) places the birth of modern science in the late 17th century and locates it in puritan England and at the London Royal Academy of Science,

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[1] While there exists a huge and growing amount of written literature, documentation and policy papers dealing with interdisciplinarity, the quasi-totality of this writings merely publicizes its alleged benefits rather than demonstrating whether it exists, how it operates, and establishes its alleged advantages (cf. Weingart & Stehr, 2000). Moreover, inter-disciplinarity is now so favored by those who formulate the public research agency programs on which practitioners of research depend for project finance, that scientists too sometimes themselves employ the language of inter-disciplinarity, tongue in cheek and critically – yet necessarily for purposes of obtaining needed finance.

Shapin and Shaffer (1985) convincingly demonstrate that at that historical period, natural philosophy was still embryonic. Scientific learning did not take the form of a discipline. The relevant struggle then lay between metaphysics, speculation and legitimacy through authority, as represented by Hobbes on the one hand, versus observation, experimentation, instrumentation, debate and expertise, represented by Boyle on the other. Disciplinarity was not at issue here. In the apt language of Shapin and Shaffer, what was at stake was the "scientific way of life" *per se*. The birth of science may instead be identified with the relevant factors of economic expansion that called for enhanced technology, acting as a spur to both craft and more advanced and formal forms of learning. It may equally be identified with cultural change in the form of Puritanism that elevated the status of learning and promoted its diffusion. Learning about the things of God's natural world thus became identified with the pursuit of religion and worship of God. While the explanation of the drive toward modern science offered by Merton centered in 17th century England, may prove geographically too local and his ascribed causality too restrictive, the fact is that in the late 17th century, scientific enquiry was spreading across much of Europe, and disciplinarity had not yet emerged as the intellectual or organizational framework for work, community or communication.

To suggest a date for the origins of disciplines in science and to localize and chronicle their appearance as such, proves difficult. For present purposes, suffice it to say that mineralogy, botany and zoology figured among the initial quasi-structured, organized and acknowledged corpus of learning. Chemistry followed as did physics, and within physics specialties like mechanics, thermodynamics, optics and acoustics quickly emerged. By the early 19th century, a handful of disciplines and sub-disciplines were recognized as such. This contrasts sharply with the cognitive positioning of the 17th century natural philosopher, when Newton was a mathematician, man of astronomy, of optics, and a man who dealt with chemical matters including alchemy as well (cf. Westfall, 1980). In the 19th century, practitioners were identified with a discipline both with reference to their individual expertise and to the position they occupied in an increasingly institutionalized and organized framework. A man like Louis Arago (1786-1853) could never be seen as a zoologist or mineralogist. In the new discipline-based science of the 19th century, Joseph Fourier (1768-1830) could not be seen as a chemist. Perceptions of practitioners were henceforth linked to a particular regime of production and diffusion, and in this instance to the disciplinary regime, and their intellectual and professional trajectory were conditioned by disciplinary components and constraints. This disciplining was not exclusively the consequence of a need to narrow activity because of increasing volume of learning in each field and a need for specialized skills, it was similarly connected with transformations in the institutional and occupational matrix of science itself. Disciplines are a product of modernity, and modernity is accompanied by bureaucratized channels of authority, hierarchy, work, production, distribution and rewards/sanctions.

The German model of the Humboldt University serves as an illustration of the 19th century traditional disciplinary science production and diffusion regime. The university was divided into faculties, one of which served purposes of training and research in the sciences. These science institutes were in turn sub-divided along disciplinary lines – mathematics, mechanics, optics, inorganic chemistry, electricity, magnetism, organic chemistry, acoustics, and later experimental psychology etc. (cf. Ben-David, 1960). A profound conceptual, technical organizational and professional gulf frequently separated these disciplines. The same disciplines arose in France, where one readily documents the emergence of history and sociology in disciplinary form. It is again important to stress the dual character of the disciplinary regime – to reproduce knowledge in the form of teaching, where the output is students bearing diplomas; and to produce original knowledge in the activity of research, which takes the form of publications.

Starting in the 19th century, and still today, universities are structured along disciplinary lines, with departments in physics, chemistry, biology and boasting a myriad specialties such as fluid mechanics, solid state physics (cf. Hoddeson *et al.*, 1992), quantum mechanics and more recent sub-disciplines like biophysics, biochemistry, molecular biology (cf. Abir-Am, 1993; Kay, 1993, 2000), cell biology (cf. Bechtel, 1993), physical chemistry (cf. Nye, 1993), cognitive science and the discipline of computer science (cf. Lenhard *et al.*, 2006; Shinn, 2006). Each discipline, with its attendant department, insists on its portion of autonomy. The point here is that the disciplinary regime of science and diffusion is soundly and historically grounded in the university. Such began around the early 19th century when nation states designated the production and reproduction of knowledge to a new form of organization, both coupled to the state and battling for independence from political and state intervention, and systematically striving to avoid linkage to short-term practical economic-driven demands. Disciplines had as their primary and privileged referent the discipline itself; its principal purpose was to forward its endogenous disciplinary learning. In some instances it was linked in parallel to extra-disciplinary, practical problem solving, and the impact was sometimes of utmost economic or social importance. However, this was neither the capital function nor market of the disciplinary regime.

The disciplinary regime is strongly defined by its self-referencing orientation. As regards research topics, they are drawn from within the discipline, and relate both to disciplinary history and inertia and to where disciplinary practitioners perceive the future of their discipline to lie. The discipline similarly sets its internal criteria for the evaluation of its research results. Along the same lines, it decides what must be learned by students, and to what extent in establishing the certification of achievement in the form of diplomas (cf. Lemaine *et al.*, 1976). The disciplinary regime itself constitutes its own market. Practitioners are the consumers of their own productions. Research output is directed to peer disciplinary colleagues. Disciplinary peers hence evaluate the quality of output and consume the cognitive products generated by other disciplinary fellows. The regime is in many respects circular in logic. It feeds on itself – both generating and absorbing its productions. Distribution of production, and the eventual subsequent assimilation of production are achieved through journals whose content is controlled by the discipline. Thus the circulation of knowledge too transpires inside the confines of the discipline. Passage from the production function to the consumption function is direct, entirely unmediated by exogenous forces. It is fair to say that the disciplinary regime constitutes a largely, if not entirely, closed cognitive economy. While in times of crisis, such as war, disciplinary practitioners historically move beyond their disciplinary referent and become engaged in larger ventures, on the whole, once the crisis is passed, the disciplinary regime again becomes predominant. The fact that many disciplines established two centuries in the past carry on and that new bodies of knowledge struggle to become officially recognized as disciplines, thereby conforming to the regime's intellectual, functional, market requirements, suggests the stability and importance of this framework in modern learning. This does not imply that nothing changes in the disciplinary regime, but the amount of change, such as attempts to introduce economic/entrepreneurial components, pails when compared to the apparent strength and autonomy of the disciplinary regime which is both plastic when seizing state, military or industrial opportunities and steadfast to its own self-referencing agenda and structure (cf. Shinn & Lamy, 2006).

1.1 The new disciplinarity

Looking backward, during much of the 19th century the birth, implanting and institutionalization of successive disciplines was not unproblematic. Discipline creation and discipline multiplication were not the norm. Financial, organizational and professional space and legitimacy were contested both inside academia and beyond as regarded the introduction of new learning. It is safe to say that cognitive, organizational and institutional defensiveness were paramount during the 19th century (cf. Ben-David, 1960). Disciplines were inward looking. The bulk of communication occurred inside disciplines. Practitioners worked to protect their terrain and there existed almost no trans-borderland contact. At this historical moment, it may be considered that the notion of boundaries between disciplines was more adequate than borderland. Disciplines husbanded their intellectual and technical resources. They were uninclined to share or even communicate with others, and even less to elaborate joint projects. In many instances high walls were constructed to distinguish those who were like from the otherness of outsiders (cf. Abbot, 1995). As will be shown below, however, the centrality of the discipline as referent with specific training, expectations and standards transcends both the new and old disciplinarity.

What we term "the new disciplinarity" is a product of the 20th century, and particularly the latter half of the century. The foundational self-referencing of disciplinarity is sustained, yet additional features such as project collaboration have introduced elasticity into discipline operations, that was previously infrequent. As will be demonstrated, the rise of this new disciplinarity is a consequence of a rapid growth in the quantity of knowledge (cf. Marcovich & Shinn, 2011a);[2] of new interlacing forms of technology, of the complexities both technical and cognitive in the research, and a consequence of a growth in the flow of communication.

Since World War II, the amount of research has rocketed. The number of researchers has grown over one hundred fold; the number of objects and forces being explored have multiplied; the spread of laboratories and their number has risen; etc. To take but two examples: molecular biology that was at its infancy in the 1950s, is today a major research discipline (cf. Kay 1993, 2000). The innumerable objects of nanoscale research were poorly identified and only slightly understood before the 1980s, and nanoscale research is now a huge domain involving many disciplines and generating tens of thousands of publications annually (Marcovich & Shinn, 2010, Mody, 2006).[3] This increase is in part the fruit of technology. New instrumentation can explore fresh horizons; older instrumentation is capable of yielding findings at ever faster rates. During the 1950s and 60s, decades were required to collect, calculate and interpret the hundreds of thousands of individual X-rays Fourier diffraction points necessary to determine the structure of a single protein molecule (Nobel Prize Lectures by Max Perutz and John Kendrew 1962) . Today this task can be carried out in minutes (cf. Cambrosio, Jacobi & Keating, 2006).

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[2] In numerous fields of research the number of publications has grown one hundred fold or even many thousand fold. In almost all domains, one observes a rise of over ten times. It can be argued that growth in the number of articles is often the publication of studies in multiple small bits versus a mega article, or it may constitute many printings of much the same message. This is certainly in part the case. However, in countless instances one observes massive publication associated with objects that were unidentified (like neutrinos) in the past, or associated with "artificial objects" made by man and whose physical characteristics draw intense attention. These claims are based on data available on the Thomson ISI Web of Science.

[3] The number of articles dealing with carbon nanotubes and fullerenes rose from 5 in 1990 to 2411 in 2000, and 12361 in 2010, publications focusing on nanodots increased from 54 in 1990 to 6730 in 2010.

The maintenance of a strong disciplinary referent constitutes a foundational signature of both the old and new disciplinarity. It is still the discipline that issues the differentiating emblematic questions and topics that demarcate its territory. The discipline continues to perform the key functions of training and certification of fellows. It allocates research grants according to internal priorities and intellectual standards. Even in interdisciplinary bodies where scholars from various fields meet and deliberate about funding, it is usually the spokesperson from an applicant's discipline whose voice is prominent and often decisive (cf. Lamont *et al*., 2006).

The very mass of new knowledge, its sometimes heterogeneous character, and the resulting complexity entailed in analysis and understanding has in recent decades introduced dual zones inside many disciplines. The nucleus of a discipline, its heart, consists of "standard models", cognitive cannon in the form of what counts as subject matter and appropriate questions. This constitutes the yardstick and the defining locus of the discipline. The increasing complexity of learning means that there exist additional questions whose association with central concerns and information is less direct. This research often stands a distance away from the disciplinary nucleus – it is located in a peripheral zone. We suggest that though practitioners reside in the nucleus, many others circulate between periphery and the discipline's hub. This cognitive and technology-driven circulation comprises one salient characteristic of the new disciplinarity (cf. Marcovich & Shinn, 2011a).

What is here termed "project" is a second key characteristic of the new disciplinarity. A project is a crystallization of a research question that cannot be satisfactorily addressed solely from a single disciplinary referent. It is indeed often the incremental complexity of learning that requires the scientists of a discipline to join forces with practitioners from a different discipline.

It is essential to see that projects do not entail abandoning of the disciplinary referent. They are not prejudicial to disciplinary integrity. The findings therein developed can indeed sometimes reinforce a discipline's hub cognition. Projects are thus today crucial to the transverse extension of learning as well as to disciplinary evolution. Scientists communicate from the safety of their home discipline, addressing one another across the borderlands. The borderland allows the preservation of cognitive and community-institutional identity and the possibility of collaborations over questions whose complexity is vast. Projects prove to be temporary matters, whose duration is limited to the time needed to solve the specific question. In the language of Peter Galison, they may comprise a kind of "trading zone" that develops in a particular domain and where people from different horizons fruitfully gather (cf. Galison, 1997). In the context of the new disciplinarity, during the 1930s and 40s, areas of biology and chemistry occasioned the emergence of what became important projects (cf. Kay, 1993).

Participation in projects introduces an open, outward looking psychology and set of practices. Unlike the structures, expectations, politics and practices of the disciplinary behavior of the 19th and early 20th century, current disciplines are far less closed and defensive in posture. Practices, organization and institutions now comprise steady landmarks on the cognitive and social map, allowing scientists a sense of security and permitting them to gaze with assurance beyond their home borderlands. This means that they can, from the stability of their home geography, develop a broader visit than had historically been the case.

Movement between a discipline's periphery and borderland and its hub illuminates a third underlying characteristic of the new disciplinarity; namely the existence of two temporalities. Engagement in a project usually occupies relatively short intervals of time. Projects are conceived, designed, organized and executed. Questions are generally defined having precise objectives, and collaborations are in the main set. Of course, new cooperations may arise during work, but horizons are relatively established. On completion of a project, practitioners travel back toward the discipline's hub where they conduct research for a long temporality. It is this long temporality versus punctuated moments involved in projects that enhances disciplinary stability and continuity. Nevertheless, when scientists participate in a sequence of projects, where parallel projects are occurring, practitioners can repeat short temporalities in the context of the emergence of a new sub-discipline. In this scenario, they are detached from the initial base disciplinary referent.

Elasticity comprises the final characteristic of the new disciplinarity. It is a structural entity conveyed in part by movement of practitioners toward and away from the borderland as they focus on projects and subsequently regain the disciplinary hub. Elasticity is similarly expressed in the two temporalities. More foundationally, it is related to an enhanced reactivity of disciplines to their broader environment. It may be best seen as the possibility of a discipline to auto-transform within certain limits to the extent that change does not compromise foundational disciplinary lines of enquiry, methodology, standards of evaluation, etc. The presence of elasticity is an important signature of the new disciplinarity, and it offers a guarantee of adhesion to and measured participation in the circulation processes and practices of said transversality.

2 The utilitarian regime of science and technology production and diffusion

The principal tasks of the utilitarian regime are three in number – building, repairing, and destroying (cf. Pickstone, 2000). Unlike the disciplinary regime, the major goal is not the production of knowledge. More precisely, when new knowledge is produced, learning is directly or indirectly subservient to technology of goods or their manufacture. While the disciplinary regime deals mainly in propositional knowledge, the utilitarian regime instead focuses on things (artifacts). Utility is the goal of the utilitarian regime, as indicated by its very name.

The institutional base of this regime resides for the most part in engineering schools. Early engineering schools, specialized exclusively in building, mending and destruction, were established in France starting in the 18th century, with the *École Navale*, and the number expanded over the century with the *École des Ponts-et-Chaussées*, the *École de Génie Militaire*, the *École des Mines*, and the *École Polytechnique* (cf. Shinn, 1980). France led in this formalization of utilitarian learning, yet parallel efforts also arose in neighboring countries through the introduction of structured craft schools in the German states and in England (cf. Fox & Guagnini, 1993). In the early and mid 19th century, craft schools were reinforced and transformed into industrially important *Mittelhochschulen* comprising an impressive network (cf. König, 1993). Again in Germany, the more technologically advanced engineering schools, the *Technikhochschulen*, were introduced near the end of the 19th century in response to Germany's expanding and increasingly technology demanding industrial growth. By 1900 these new institutions had become so central and influential that they, like the older Humboldt University, received government ministry authority to grant a doctoral degree to advanced graduates. In the United States the utilitarian regime was institutionally based inside universities, yet set aside from the disciplinary regime. Most major American universities developed schools of engineering beginning in the late 1890s. These became intimately connected to the nation's industrial structure, leading at the turn of the century to the establishment of an exceptionally influential industry/education lobby – The Society for the Promotion of Engineering Education. Its goals consisted of entrepreneurial authority over the orientation and curricular content of engineering schools, and in some instance tailor-made training for specific firms or industrial sectors (cf. Noble, 1997).[4] Thus, the introduction of the utilitarian regime was connected to a par-

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[4] In a comprehensive, wide-ranging article Jean-François Auger has written extensively on the emergence of the *Montreal Polytechnique* as emblematic of the utilitarian regime of science and technology production and diffusion. He points to the extent to which teaching came to serve often narrow industrial objectives, how school staff

ticular set of historical and political conditions, and it arose and began to flourish over half a century after the birth of the disciplinary regime, and its maturity occurred one century later than disciplinarity.

Over the last four decades attempts at convergence between engineering institutes and university disciplinary departments has occurred. This is the result of three factors. First, as technological artifacts have come to incorporate ever more discipline-based knowledge, devices/instruments and components, pressures toward a move toward the science regime by engineering schools has grown. Second, engineering knowledge is increasingly formalized and mathematized, and these are the signature of disciplinary practice and learning. Lastly, for many years the professional status of science was superior to that of engineers. In an attempt to enhance their standing, practitioners of the utilitarian regime adopted strategies to bring them where possible into line with some disciplinary elements. Among these, publication was foremost. It became an increasingly important strategy for members of the utilitarian regime to circulate their output in professional journals, in-house bulletins, public reports and the like.

As suggested above, one focal point of such disciplinary/utilitarian convergence is to be seen in the installment within the university of a new sort of knowledge/professional unit – material science (cf. Bensaude-Vincent, 2001). These departments are central to what is known in France within the *Centre National de la Recherche Scientifique* as "*la science de l'ingénieur*". *La science de l'ingénieur*, or "engineering science" is sometimes connected with the new and strongly emerging domain of the design and synthesis of unprecedented man-conceived and manufactured materials. This is sometimes carried out in close connection with the science regime, as in the case of nanoscience (cf. Johnson, 2006; Shinn, 2008; Marcovich & Shinn, 2010, 2011b).

The aims and epistemologies of the disciplinary regime of science research and diffusion and the utilitarian regime contrast significantly. While the disciplinary regime seeks propositions of a universal order that transcend time, space, culture, and particularisms of all forms, the productions of the utilitarian regime are rooted in the local and practical. Its parameter is the solution to specific and short-term problems. Work is guided by a well-defined set of requirements. Products frequently correspond to clientele demands of having a very specific character. The construction of dams, bridges, buildings etc. are subject to local topography, legislation and other exogenous constraints. The schedule of work is imposed. Accuracy and validity are measured in

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vehicle the same purposes, indicates the careers paths followed by graduates, the forms of work carried out by graduates and suggests the nature of the transmission between the production of student and utilitarian learning inside engineering schools and their assimilation within enterprise or related utilitarian organisations (cf. Auger, 2004, 2006).

terms of durability, ergonomic measures. Economic consideration figures foremost. If the results of the utilitarian regime are technologically exceptional but exceed the potential for reaping profit, the results become unacceptable. Of all of the regimes of scientific and technological production and diffusion, the utilitarian regime appears the most contingent-laden and relativistic. Performance is dependent on space, time, the vicissitudes of clients and demand, and economic factors.

Unlike disciplinary practitioners, the practitioners of the utilitarian regime hence do not address themselves – this is no self-referencing community. Its members do not comprise the regime's market. On the contrary, the professional scope of the utilitarian regime is vast. They serve as technicians and engineers in the main. However, they may also often find their way into managerial positions. They occupy a multitude of professional niches. The utilitarian regime serves industry, the service sector of the economy: it is frequently associated with technical work in the public service. Here practitioners undertake narrowly technical tasks, coordinate the efforts of others, or manage. The utilitarian regime is equally present in the military. Expertise and consulting are today becoming an expanding market for the diffusion of utilitarian regime learning and technical competence.

Client and market are paramount in the epistemology of the utilitarian regime. The very selection of the work object is not a self-referencing entity, yet instead an artifact for which there is an intended client and where market conditions will permit client access to the product. Design is central here. Phenomenological design guarantees material performance. Yet it entails considerations not merely of efficiency, and must also ensure considerations of safety, norms and standards. The mind set of the utilitarian regime practitioner needs to incorporate properties of "over design" to establish robustness and to guarantee safety. This necessitates reflection on the context of use – the conditions, ordinary and extra-ordinary of the artifacts implantation or utilization. Hence the introduction of over-dimensioning is a frequent characteristic of much USA engineering.

Design also enters in utilitarian epistemology with reference to product utilization. Engineers generate artifacts that correspond to their usage in terms of their functional application, the environment of application, and implicitly of usage. Design aesthetics play an increasingly central role. This element powerfully impacts the science and technology of the regime, since practitioners must dimension and locate technical components within the aesthetic cadre, and this is often a difficult task as tight fit electronic or/ and magnetic components often affects performance, reliability and robustness.

Negotiation lies at the heart of the utilitarian regime, and must be counted as part and parcel of its epistemological composition. Negotiation over schedule, over dimensions, over what represents reliability, over security and safety in use of the artifact, over cost etc. The utilitarian regime combines human and material elements in a fashion totally absent from the disciplinary regime. While the disciplinary regime emerges as relatively autonomous because it self references and constitutes its own market, the contrary is true of the utilitarian regime which exhibits an economy of production and diffusion grounded largely on exogenous factors versus disciplines that are rooted largely on endogenous considerations.

There is a final epistemological consideration that marks an important contrast between the utilitarian and disciplinary regimes. The methodology of engineering is often one of trial and error, where margins of error always lie foremost and problems of accuracy and failure emerge *post facto* – after the observation of malfunction or catastrophe. Theorizing is frequently nugatory in the utilitarian regime. While modeling may be as current in this regime as in the disciplinary regime, models are normally not themselves objects of investigation and sources of understanding, but instead easy formulae for functional solutions.

The territory of the utilitarian regime is demarcated by two preoccupations – control and contingency. Control assumes two forms: on the one hand, practitioners' work is grounded on the effort to control physical objects and forces in order to obtain wanted technical effects. Control, functional effects and product are a mantra of the utilitarian regime. The other form of control is social. The utilitarian regime no longer exists in the absence of external demand for its output. Attempts to control potential markets for technical goods is paramount here. For this regime, control over social inputs and outputs is just as fundamental as issues of the aforementioned work at physical control. The second specificity of the utilitarian regime is the centrality of contingency. Contingency too exhibits two expressions. Technical contingency is often ubiquitous. Because techniques are increasingly complex and hence subject to unpredicted and ill-controlled component interactions, no one really knows how materials will function in peculiar circumstances. Contingency can kill a technology and its associated products. Economic, political or social contingency similarly strongly impacts the internal dealings of this regime. Economic disruptions can curtail promising engineering research. Projects have no intrinsic value; their value is measured entirely in terms of monetary profit. The voice of money is far louder in the utilitarian regime than in any of the other regimes.

In the case of the utilitarian regime, it is epistemological issues, contingency and control that demarcate its practitioners from alternative regimes. The utilitarian regime is, in important ways, separated from other regimes by its work processes, objectives and values. As will be shown below, while many factors differentiate the disciplinary, transitory and the research-technology regimes, they nevertheless share, under different banners, the high worth that they accord to cognition and the technologies designed to extend cognition. Overarching the consideration of control and contingency, and by dint of the fact that the involvement of the utilitarian regime with learning is often largely opportunistic and not intended to advance cognition *per se,* this regime owes its differentiation. The regime clearly possesses its specific institutions (schools, professional associations, journals, lobbyists etc.). But perhaps the most decisive border between it and other regimes is its mentality, and said mentality-based activities.

3 THE TRANSITORY SCIENCE AND TECHNOLOGY REGIME

To what does the "transitory regime" refer? It refers to circulation of scientists from a disciplinary framework into an entrepreneurial environment, and the subsequent migration back to the disciplinary referent. Under what circumstances does this movement occur, and what does it imply for disciplinarity? Does it constitute an expression of technoscience? We suggest that a cognitive phenomenon that we term "respiration" occurring inside disciplines often provides the dynamics preparatory to circulation, and it similarly contains the logic that motivates the return to disciplinarity after experience in the entrepreneurial environment (cf. Marcovich & Shinn, forthcoming).

The transitory regime is a little explored segment of the science and technology production and diffusion system. A profile vaguely akin to it was not uncommon during the Renaissance and during the following two centuries. Its centrality declined with the institutionalization of the disciplinary and utilitarian regimes. While some individuals continued to work along lines that one can solidly identify with the transitory regime, due to the preponderance of discipline and utility, the endeavor and systemic aspects of actions in the transitory frame were difficult to detect and to analyze. It would seem that the importance and visibility of the transitory regime is today on the rise. It is interesting to see the recurrence of this regime as a returned form of action from a semi-forgotten past.

Prior to the 19th century introduction of the disciplinary regime of science production and diffusion, many practitioners occupied with classification of objects and with the description and analysis of phenomena, also engaged in the production of material artifacts. It was an age best described as that of the scholar/inventor. While many of the artifacts contributed to an understanding of the natural world in the form of scientific instruments, such was far from the rule. Other artifacts possessed a dual character, both advancing research and serving a practical purpose. The telescope represented a huge leap forward in instrumentation for study of the heavens. It also contributed to advances in optics. The device similarly proved crucial to military practice.

Not least of all, the optical learning derived from the telescope became incorporated in an extended range of other apparatus. Maurice Crosland's comprehensive study of the Paris Academy of Science clearly shows that particularly before the 19th century, but also afterwards, a large portion of Academy competitions and awards were associated with the solution of very practical, applied problems by France's top scholars (cf. Crosland, 1992). In many instances the boundary between achievement in grasping the natural world and accomplishment in invention was blurred or inexistent. The division of labor was minimal or absent.

This is linked to two considerations. The quantity of learning required for the mastery of a subject was not yet vast, highly complex, and fully differentiated from other domains. Effective research did not yet require full-time commitment, as later became the case. Moreover, the scale of the scholarly community remained rather circumscribed. Only slowly did there develop a sizable growth in the number of scholars by the introduction of many new rigorously defined spheres of scientific inquiry. Hence, a sizable research oriented intellectual group and an adequate market for purely cognitive production reached critical proportions only during the 19th century, therewith forming a differentiated, inward-looking, autonomous community. Stated differently, one here observes new conditions of possibility associated with the emerging disciplinary regime that consisted of a division of labour, specialized institutions, a well-defined reward system and an internalized and autonomous market for narrowly cognitive endeavors that no longer invited practitioner investment in extra-cognition projects, and that sometimes unofficially yet effectively even sanctioned participation in them. Hence the former pre-disciplinary system where there existed spaces favorable to simultaneous, undifferentiated contributions to scholarship and an open-ended concern with devices slowly declined. This is certainly not to suggest, however, that some individuals did not continue to operate at a very high and prestigious level in the domains of disciplinary production and artifact innovation. Those who did so, moved from a discipline into enterprise and engineering, and then back to the disciplinary context.

Two key elements underpin this transitory regime of science and technology production and diffusion. First, trans-border movement is generally circumscribed. It tends to comprise an important yet infrequent component of the practitioners professional trajectory. Most individuals cross the disciplinary frontier into enterprise and then back into their home discipline but once or twice. Repeated and regular circulation and border crossing is absent. Structural transversality is not part of this regime. The primary referent remains the disciplinary regime. While successful in industry, the academic is often contested, despite frequent effective technological contributions leading to commercial success. Second, despite such success, legitimacy of the individual, and his principle place in the historical chronicle is discipline bound. The practitioner identifies himself with his discipline and strategically seeks to be linked to it. Technology is important, yes, but it is the disciplinary regime that constitutes the key standard.

There are two reasons for this. The disciplinary regime stands at the cultural and professional apex versus industry. This continues to be the case, despite political, journalistic and entrepreneurial discourse to the contrary. When given a choice between academia and industry among individuals who have for various reasons opted for enterprise, most regret their move across the frontier from the disciplinary regime and into enterprise (cf. Shinn & Lamy, 2006). They regard enterprise as the lesser path even in the face of representations of innovation-driven globalization as an inevitable and desirable cultural horizon. Another consideration is structural. The disciplinary regime of science production and diffusion is characterized by self-recruitment, the self-selection of research questions, of methodology, self-determination of quality criteria, and it constructs through peer citation and through internal attributions of prizes and other rewards, its own system of compensation. In effect, it forms a relatively autonomous closed-economy.

The cognitive and professional trajectories of William Thomson, Lord Kelvin, can be taken as emblematic of the transitory science and technology regime (cf. Smith & Wise, 1989). William Thomson (1824-1907) was professor of physics for over 50 years, mostly based at Cambridge University. He is sometimes described as among the most brilliant 19th century physicists. For a part of his long career, Kelvin also worked closely with industry, crossing the disciplinary-enterprise boundary both in the context of trans-oceanic telegraph laying technology and instrument making. In connection with the former, he bridged the border between disciplinary and enterprise through involvement in establishment of metrologies, though this is not generally recognized as the heart of his endeavors.

In the disciplinary mode, Kelvin contributed crucially to the study of thermodynamics. He was both a mathematical physicist and experimentalist. Unlike many British scholars of the mid 19th century, he embraced the mathematics of Joseph Fourier (1768-1830). He early demonstrated that using Fourier series it is possible to solve the partial differential equations that describe the conduction of heat. Kelvin's work also focused on the Faraday problem of the relation between electricity and magnetic induction. Kelvin demonstrated that the relation occurs via a dielectric effect and not through some incomprehensible mechanism. But perhaps his most outstanding contribution to physics is his development of the Kelvin scale of absolute zero – the lowest temperature attainable independent of the material involved in the measurement. This is perhaps his most longstanding addition to the corpus of science. Kelvin also explored the connection between light and magnetism. Bridging his disciplinary and engineering efforts, Kelvin also worked in the area of metrology. Here, he participated importantly in determination of the standard unit of current, the ampere. During his long career, Kelvin published over 650 articles, and for much of his life he was acknowledged both within and outside of Britain as one of the world's most far seeing and accomplished physicists.

Lord Kelvin traversed the boundary of the disciplinary regime of science production and diffusion on two principle occasions, turning instead to the utilitarian regime. In 1856, he took work with the Trans-Atlantic Telegraph Company. While persisting in the disciplinary regime, he sustained connection with this firm until 1864, on successful completion of the Trans-Atlantic cable that linked Ireland to Newfoundland. In the 1857 expedition, the cable broke after only 350 miles of emersion. Kelvin studied the stresses exerted on laying a cable from the surface to the ocean floor and suggested changes in the dynamics of the uncoiling. Kelvin was in constant conflict with the company's chief engineers and part of the board of directors on countless technological grounds. First, the chief engineer, Whiteside, believed that electrical strength carried over the immense distances, was dependent on ever-higher voltage. Kelvin demonstrated that signal strength was inversely proportional to the square of the distance of cable length. The solution lay not in greater voltage, but rather in an increased cable cross-section and enhanced insulation. He moreover insisted on the necessity of upgrading the quality of copper used in the cable, thusly improving performance. One can speculate that Whiteside reluctance to adopt Kelvin's proposal issued from a fear of taking technical risk particularly originating in a disciplinary theoretical orientation. The use of lower voltage naturally necessitated more sensitive detection systems. Kelvin calculated that in view of contemporary technology, a maximum emission data rate was one character every 3.5 seconds. He went onto invent a series of apparatus capable of detection of low intensity signals. One of these was the mirror galvanometer. This device was long resisted by the board members and chief engineer of the Trans-Atlantic Telegraph Company. Ultimately, however, Kelvin convinced them that it comprised the most precise technique for signal detection, one that employed a minimum of voltage and current, both capable of damaging or destroying the integrity of the fragile sea floor cable. In combination with the mirror galvanometer, Kelvin also invented the siphon recorder, which translated data bits into usable intelligible information. This too was resisted before gaining acceptance. One clearly discerns here that the logic of the disciplinary regime was continuously challenged in Kelvin's industrial activities. The professional logic and rules, the balance of power, the might of the economy, pragmatic considerations, consumer satisfaction and capitalistic motives all hold sway – considerations largely absent from the disciplinary regime.

Lord Kelvin's second transgression of the disciplinary regime boundary crossing lay in the domain of narrow niche instrumentation invention, and it transpired somewhat later in his career. In 1884, he set up an instrument firm, "Kelvin and James White Ltd". Among Kelvin's innovations, one can count a device using pressure differential to determine water depth. Previous cable reading had proven inaccurate. Kelvin's system relied on mathematical processing of water pressure differential – a huge advance. He similarly developed a highly precise machine for detection of tidal level and tidal timing. He invented a system to neutralize the magnetic deviation generated by the iron increasingly used in ship construction, and by so doing improved the navigational compass. More generally, he introduced improved forms of ampere-meters, including the quadrant ampere-meter, and the Kelvin balance. While not all of the innovations were economically successful, they constituted one important facet of his endeavors, and they represented a second instance of distancing from the disciplinary regime of science production and diffusion. In such ventures, the audience and market were not disciplinary peers. The questions raised, methodology, and validation criteria did not emanate from the disciplinary referent but instead from utilitarian criteria and from the potential of the capitalistic market place – so very at odds with the disciplinary agenda and logic of diffusion. But one thing is certain, Kelvin insisted on his primary identity as a physicist, as a member of the disciplinary regime. Though he took pride in his engineering accomplishments, and through them became a rich and famous man, his devotion lay in academia and in fundamental physics research. Throughout the final decades of his life, his major activities and public statements focused exclusively on disciplinary things, and not on events connected with his important yet temporary episodes of extra-disciplinary boundary crossing into enterprise and engineering. He clearly perceived the accomplishments of 19th century physics, and he equally clearly perceived the many domains of failure and where key additional fundamental research was required and urgent. By contrast, there was almost no commentary on industry and engineering, an important but secondary episode in Kelvin's trajectory.

The birth of the model of technoscience, which has experienced considerable success in recent years, may in part stem from a misreading of some historical and contemporary experiences in science and technology that have not adequately taken into account structures such as disciplines, and dynamics such as circulation (cf. Clain, 1995; Stengers, 1997; Brown & Brian, 2000; Idhe & Sellinger, 2003; Hayles, 2004; Pestre, 2008; Bensaude-Vincent, 2009, Bellacasa & Puig, 2011). This myopia has resulted in the conflation of elements that yield a misguided perception that differentiation between the epistemologies of science and technology, and their corresponding organizational frameworks have collapsed inward, resulting in undistinguishable ensembles. To the extent that the frontiers inside and between scientific and technological things collapse and disappear, the very conception and action of circulation become unthinkable and impossible. The rejection of the notion of circulation from the analytic repertory of science constitutes a big step backward both in terms of description and epistemology.

Two principal features differentiate the practices of the transitory regime from the disciplinary and the utilitarian regimes. Practitioners of the disciplinary regime do not transgress the discipline's boundary, as do people identified with the transitory regime. The practitioner of the disciplinary regime possesses uniquely one referent: extra-discipline communication is carried out with scientists working in other disciplines, and not beyond. Communication and collaboration emanates from the terrain of the discipline and is done from the safety of the borderland. To repeat, the discipline's border remains intact! Those steeped in a discipline do not become engaged in the issues of control, contingency and the epistemology of the economy in the way that engineers do. By contrast, the practitioner of the transitory regime experiences two referents. There nevertheless exists a hierarchy where the disciplinary orientation is paramount, providing legitimacy. Second, the epistemology of those engaged in the transitory regime is bifurcated and segmented. The epistemological components and their relations of utilitarian work are highly complex, contingent and changing. Technical endeavor, as all else is unstable. What counts as valid and outstanding on one day, is evaluated as unacceptable the following day (issues of reliability or safety). In the disciplinary regime the epistemology of research is relatively standardized and stable. It resists local drama.

Those engaged in the transitory path adhere totally to the epistemology of disciplinary requirements while working in that regime. Do they symmetrically adopt the control/contingency rooted epistemology while in the utilitarian regime? Are they intellectually ambidextrous? Based on the case of Kelvin and our own on-sight observation of contemporary practice, it appears that they may, to some degree, superimpose some transitory mental operations on a stronger, permanent disciplinary epistemological substrate when engaged in enterprise. They may mobilize selected components of utilitarian epistemology in order to address specific questions of possible entrepreneurial interest that they had dealt with or formulated in the course of earlier disciplinary research. On completion of their enterprise tasks, relevant practitioners travel back to their disciplinary homeland where they comfortably and entirely re-engage discipline epistemology.

However, the essential question for a deep understanding of the specificity and the operations of the transitory regime is how do practitioners of the regime manage both to sustain a strong connection with disciplinarity and to move temporarily beyond the disciplinary base as they circulate into enterprise and then back toward the discipline? What is the specific mechanism that underpins this sequential trajectory?

3.1 Respiration

Respiration is a dynamics which originates inside the disciplinary regime (cf. Marcovich & Shinn, forthcoming). It can be seen as a motor which promotes circulation of certain practitioners between the disciplinary regime and enterprise, and hence as a principle force that underpins the transitory regime.

Respiration is the interval between closing one research project and entering into another, when practitioners take stock of the relevance of their past research work and instruments, and consider what fresh research questions tied to what novel instruments might now be possible. It is time out for reflection about past accomplishments, whether they should be continued, or alternatively, what new paths might be embarked on. In many instances, respiration leads scientists to perpetuate or reformulate research inside their discipline. In other instances, however, a variety of considerations induce them to look beyond their discipline and to envisage participation in a precise entrepreneurial project (cf. Marcovich & Shinn, 2011b). It is important to note that in the latter case, disciplinary practitioners' interest in engagement with industry is based on two considerations. First, they wish to express in concrete terms and explore in an alternative environment (enterprise), the range of possibilities of their earlier disciplinary findings. They may anticipate that by connecting their findings to existing commercial technologies, it may be possible to make the technologies more efficient or allow them to address new problems. Based on precise elements in recent research, the practitioners project the possibilities of their implantation in diversified terrains, and in so doing open their horizon. In effect, it is alternative expressions of extant work and curiosity that represents the faces of respiration. Second, linked to this, this propensity is strongly connected to the existence of a kind of curiosity which is of different nature than the one that propels them in their disciplinary work. It is worth noting that, very surprisingly, the concept of curiosity is often strikingly absent from reflection on the operation of science and technology. Curiosity connected to disciplines is framed in terms of the understanding of self referencing physical objects and forces. In enterprise, curiosity ultimately focuses on applicability of laboratory disciplinary results to concrete situations and markets.

The relevance of our respiration model is that it allows understanding of the motives and mechanisms which are at work in the circulation between the two regimes. There are subsequent respirations in enterprise which most frequently induce practitioners to return to their discipline which remains their primary referent. This anchors scientists' work in cognition and disciplinary referents and excludes the idea of a mixed and undifferentiated configuration of the sort proposed by technoscience. In the case of the trajectory of Lord Kelvin, there are two episodes. One which entails respiration and that corresponds to the transitory regime and a second where respiration is absent and that does not adequately coincide with the transitory logic. In the case of the telegraph example, Kelvin's participation was demand-driven, that is to say, it was prompted by a request coming from industry which demanded expertise, and was not an expression of Kelvin's earlier disciplinary efforts. The exogenous stimulus for work and its disconnectedness from discipline are the decisive feature. By contrast, Kelvin was engaged in a transitory episode when he designed and built his various metrology. These were based in disciplinary efforts and were offered as gifts to enterprise which could develop them as appropriate.

4 The research-technology regime

Each regime is the product of its particular historical circumstances, and this fundamental fact emerges with outstanding force in the case of the research-technology regime of science and technology production and diffusion. It arose in Germany during the last third of the 19th century, a conjunction of military, governmental, industrial, instrument maker and to a lesser extent academic forces. Assertive Prussian ambitions and aggrandisement, the explosive growth of German industry and extension into new chemical, electrical, naval, and infrastructure domains, swift progress in science research, government determination to introduce and impose strong standards and norms on industrial products, and keen interest among some instrument makers, to compete internationally with the French and British and to transform the fundamental logic of their craft combined to forge a new regime of science production and diffusion (cf. Joerges & Shinn, 2001; Shinn & Joerges, 2002; Shinn & Ragouet, 2005; Shinn, 2008). German culture thus became the nexus for the rise of the research-technology regime.

The foundational concept, at least among some government thinkers, military figures, captains of industry, and above all Berlin instrument makers, was the generation of an absolutely novel form of technology capable of addressing a diversity of applications in a broad range of disciplinary and industrial domains. The goal was in fact to establish an original epistemological matrix. Rather than deliberating on the laws of nature, the new regime instead proposed to explore the laws of instrumentation. Mastery of the laws of instrumentation could in turn lead to development of generic devices. A generic device would express fundamental principles of instrumentation that could subsequently be integrated into specific technological functions and tasks through proper adaptation. A generic instrument would thus, according to an extended group of Berlin instrument making firms and then firms in other German cities, embed basic very general instrument concepts that would allow for open-ended flexibility, and multi-functionality. The generic principle would permit aspects of the device to be effectively re-designed for local niche application without disorganizing the technological logic and division of labor within the variety of environments in which it operates. Adoption through adaptation through re-embedding of generic instrument laws comprised the underlying logic.

A range of small Berlin companies became committed to this project in the 1870s, 1880s and 1890s, most active being the Hench Company. Government policy insisted on its institutionalization and spread. A huge compendium by Leopold Loewenhertz (1847-1892) published in 1880 pressed home the need to generate generic devices, which could subsequently lie at the heart of convergence between many technologies and diverse domains of science research (cf. Loewenhertz, 1880). This new sphere, labelled "research-technology" began to be perceived as a transverse mechanism for extending technical and science work and for introducing order into what was increasingly viewed as a fragmented arena of learning, skills and technology. Something had to be undertaken to introduce convergence, and research-technology's generic instrument artifacts was viewed as one such key mechanism (cf. Shinn, 1993, 2000a, 2000b). In effect, research-technology comprised one antidote against excess mental and material segmentation.

Instances of generic instruments from the late 19th century through the 20th century include, for example, the stereoscope of Carl Pulfrich (1858-1927). This device incorporated unique three dimensional-producing optical arrangements. The generic three-dimensional optics was quickly adapted by users for undertakings in naval gunnery, precision diagnosis of problems in architecture, in the study of historic sculpture, in topography and infrastructure work (railway and road construction). Another instance of generic research technology took the form of automatic switching generic principles and artifacts that were used in astronomy research, in the chemical industry and in electrical power regulation. More recent examples include development of the Fourier transform spectroscope by Pierre Jacquinot, Janine and Pierre Connes and Peter Fellgett, the rumbatron by William Henson, the oscilloscope and the laser. In research-technology, genericity sometimes also surpasses purely material artifacts. Genericity can cover non-material purely mental technological apparatus as well. Simulation counts as a contemporary generic device (cf. Lenhart *et al.*; 2006; Shinn, 2006), as does the mathematical Cooley-Tukey algorithm, which is today used in literally hundreds of applications extending from physics and astronomical academic research to informatics, aviation, finance etc. (cf. Shinn, 2008). Cybernetics too is considered by some to comprise a generic conceptual instrument.

The concrete instance of how German instrument makers organized their apparatus helps illustrate the logic that lays behind their generic philosophy. In the material organization of traditional instrument exhibitions, Germany instrument makers, like those of other countries, exhibited their innovations side by side, with no regard to their underlying logic. Electrical devices were arranged together with other electrical apparatus, and the same held for optical, mechanical etc. instruments and devices. This suddenly changed among Berlin instrument specialists in the 1880s, when for the first time generic principles constituted expository practice. A generic instrument law that could find expression in optics, magnetism, and electricity systematically grouped products of all sorts relevant to the underlying instrument law. In this fashion, attention was immediately drawn to the underlying principle and to the myriad adaptations that it could express. In so doing, research-technology emphasized the transverse commonality of what otherwise superficially appeared as fragmented, differentiated forms of knowledge and technology. Through such a redistribution of devices, the federative, or at least the confederative character of science and technology, became visible. This transverse logic was particularly noteworthy in the 1904 Saint Louis Universal Exhibition, where many observers took note of the new logic that stood behind the organization of artifacts, and thereby behind science and technology (cf. Joerges & Shinn, 2001).

Two additional events occurring in the 1880s reveal the specific dynamics of research-technology. Imperial Germany possessed the world's largest science, technology and medicine-related professional organization, numbering over 5000 members – the *Versammlung der Deutschen Naturforscher und Ärzte* was composed of 42 sections, each representing a particular discipline, scientific or technical specialty or profession – for example, astronomy, zoology, botany, mechanics, optics, acoustics, geology, geography, various engineering fields, medical and veterinary areas and the like. The various sections were highly defined, membership depended on training, cognitive domains and profession. The groups were distinct and were jealous of their separateness and autonomy. The *Versammlung* indeed acted as an association, having no confederal or federative ambitions. Beginning in the mid 1880s German research-technologists mounted a vigorous campaign to become part of the association. The effort was at first stiffly resisted. Opposition focused against the plan of research-technologists to introduce a transverse section. Generic instrumentation was intended to straddle the particularities of the other standing *Versammlung* groups. This was initially perceived as a threat to the traditional autonomy of the historical sections. Nevertheless, by 1892 generic instrumentation makers at last managed to be admitted as a kind of semi-recognized renegade section. It never achieved full membership, due to its insistence on a transversalist theme and strategy – an approach to science and to technology intended to form a bridge between sub-groups and to promote systematic circulation of ideas, materials and men across all regimes of science and technology production and diffusion.

Research-technology also figured in the development of the *Physikalisch-Technische Reichanstalt* (PRT) established in 1887. The PTR entailed two sections, one for science and another for technology-related endeavor (cf. Cahan, 1989). While the science section, directed by Herman von Helmholtz (1821-1894), was devoted to fundamental research, the orientation of the technology body remained ill defined. One possibility would involve the introduction and implementation of industry standards and norms. A second option focused on engineering, and more specifically on research associated with engineering education. This path was supported by the mighty German engineering lobby. Research-technology comprised a third area. The goal here would be research on generic devices testing and their dissemination. The aforementioned champion of research-technology, Leopold Loewenhertz was the principal advocate of this line of action. To the surprise of many, it was generic instrument research that prevailed. Loewenhertz became the PTR's technology sections leader for a brief period, after which the institution's technology research tended to become less clear-cut in direction and even to fade. Despite this, for a short moment the research-technology trajectory advocated and practiced by generic instrumentation practitioners held sway and demonstrated its strength.

As will now be shown, when taken together, the trajectory, forms of circulation and synergy, interstitial arena and boundary crossing format constitute signatures of research-technology practitioners, and this signature contrasts singularly with the characteristics of the previously described three other regimes. The production of generic, open-ended, multi-function, multi-purpose and highly flexible artifacts requires operating out of an interstitial arena. Research-technologists work in the open, unoccupied spaces between dominant institutions and organizations – the university, industry, military, state metrology services and the like. At various junctures in their career, they sometimes develop connections with a particular organization, yet subsequently move back to the interstitial arena. This arena provides several key features to research-technology. First, it protects them against short-term demand from clients requiring specific devices to resolve well-defined particular problems. Stated differently, the research-technologist here enjoys a temporal space relatively free from immediate exogenous constraint where he can focus on the underlying principles of instrumentation, as opposed to simply designing or building an apparatus that fits a narrow need. He who works for everyone is the bondsman of no one.

Second, the interstitial arena facilitates abundant boundary crossing opportunities. Research-technologists cross boundaries as they temporarily pass into local niche domains when collecting technical information or looking for problem categories which might be useful in generating a generic device. They likewise engage in boundary crossing when sometimes assisting local users adapt a generic apparatus, or helping extract particular appropriate components, in the complex process of generic instrument adoption. Reverse boundary crossing also occurs when local niche users themselves move out of their habitual organizational industrial, academic etc. space and temporarily transfer into the interstitial arena in the course of contributing to the potential of an existing generic apparatus, thereby making it even more multi-purpose and multi-functional. Research-technology is through such countless boundary crossing and reverse boundary crossing often highly synergistic. Circulation is of foremost significance in this regime.

At this juncture it is important to distinguish between the research-technology regime and the practitioners of the transitory regime who are also involved in boundary crossing. The latter shift between the disciplinary referent and the utilitarian referent to the extent that they operate with reference to enterprise or other beyond discipline organizations and interests. Such boundary crossing, however, occurs infrequently in the case of the transitory regime, as scientists usually only traverse two or three times over a career. This contrasts with research-technologists who routinely move across frontiers, doing so countless times. So in one case boundary crossing remains an exceptional activity, while in the other case, it is normative and abundant. Another foundational difference is that practitioners of the transitory regime are wed to their discipline. Their discipline constitutes the hub from which they operate. It provides identity and legitimacy. With research-technologists, the primary identity and referent is at all times instrumentation and instrument-related endeavors. Genericity and the principles of instrumentation comprise their yardstick of achievement rather than the laws of nature and disciplinary distinctions.

The research-technology regime is singular to the extent to which it fosters the circulation of practitioners, materials and ideas across boundaries within science, and between science and other forms of social action. Through generic instrumentation, communication occurs within academia, and between science, industry, state services, the military and beyond. Research-technology spawns a kind of *lingua franca*. Specific vocabularies, metrologies and images are embedded within a generic device. As the generic instrument becomes re-embedded in a local user niche, part of that particular set of representations is transferred into the local environment and becomes part of users' habitus. Instrument operators from a multitude of diverse domains thus appropriate, through integrating the language of the generic vector, a minimal shared language. The common language enables actors from different horizons to communicate and interact effectively independently of their origins and setting. In this way, research-technology functions as a mechanism that promotes convergence. Research-technology thus partly neutralizes the fragmentation often associated with the contemporary multiplication of sub-groups, sub-functions, and an enhanced societal division of labor. This *lingua franca* is foundational to the linkage capacity that makes this regime consciously transverse. The regime sustains the efficiencies commensurate with differentiation, and at the same time generates strong association. One perceives here that differentiation and interaction are not necessarily contradictory. Research-technology emphasizes and structures the complementarity between differentiation and forms of integration. By serving as a cross road, it generates and amplifies synergy between domains.

The research-technology regime affords an additional element of cohesion, this one based in the practices of instrument operation. As large numbers of generic-device-based apparatus are successfully used by different groups of scientists, engineers, technicians and other operators in vastly different environments, and performing contrasting functions for alternative purposes, confidence in the results yielded by their apparatus develops and strengthens. The sole commonality between the various expressions of the different devices is their generic components and principles. Shared confidence leads to shared belief, itself grounded on the regularity and reliability of instrument output. This instrument output is independent of user, use, function, geography and culture. The generic-ground system produces a form of robustness within science. Through shared experience of operating devices and obtaining comparable findings, practitioners perceive their apparatus as yielding "valid" results. This validation takes on the form of "universality". However the universality born of research technology is not solely the stuff of epistemology. The practical universality of research-technology generic instrumentation contains a social component, rooted in shared social experience by heterogeneous groups. Practical universality is hence partly sociological. It contains elements of communication and collective dynamics and interactions. It also entails a material component, since the robustness of practical universality requires reliable, comparable and standardized instrument products. This triangle of reliability, comparability and standardization is the product of instrument genericity.

5 UNITY AND DISUNITY IN SCIENCE: THE TRANSVERSALIST PERSPECTIVE

If one's criteria for the "unity of science" is an unblemished homogeneous whole, a unity theory of science is inconceivable on historical, institutional, organizational, epistemological and social grounds. The above analysis of the emergence and dynamics of the disciplinary, utilitarian, transitory and the research-technology regimes of science and technology production and diffusion demonstrate the plural aspects of science. Based on structure, output and history, one is compelled to think of "science" simultaneously in terms of a whole and of the "sciences". Each expression of science as a particular regime operates within a specific territory possessing its own form of symbolic and material capital, its characteristic configurations of conflict with their specific rules for judging what counts as a valid or unacceptable output, and distinguished by a highly defined market for its productions. There are hence multiple forms of science, where the corpus of circulation and dynamics of circulation function differently. Each expression of science delimits its particular territory.

The question nevertheless remains whether it is reasonable to speak in terms of "science". If one may speak of science in the singular, what legitimates this representation? The sociologist Andrew Abbott (1995) stresses that boundaries serve principally to identify differences between entities. The social operation of boundary is not to defend or protect, but instead to demarcate differentiations. It is fully justified here to think in terms of an intertwined, transverse science which is demarcated from all other spheres of social activity – art, enterprise, law, government and so forth. Science may better be likened to crystalline structure. The crystal's atomic lattice is periodically aligned, and the crystal entails its internal regularities and characteristics that distinguish it from other crystals and from other forms of matter. Crystals also frequently possess local defects which alter their local geometry. While the crystal remains a differentiated entity, it nevertheless exhibits specific local variations. The relationship between the correspondence between unitary science and the sciences, presents parallels with the complex/paradoxical composition of the logic and geometries of crystals.

A form of intertwined, transverse structure of science, despite its pluralistic features, may be upheld on a second register. The research-technology regime provides apparatus that introduces convergence and coherence between science's other regimes. Generic apparatus, like mathematics, offers data, results, a way of seeing, and intelligibility that transverse boundaries (cf. Shinn, 2000a; Bourdieu, 2001). Generic apparatus also promote the circulation of practitioners among the many territories comprising science. If science is viewed as composed of territories, generic devices federate these vast territories, providing them with a common language in the guise of instrument-based *lingua franca*, and through shared practitioner expectations, experiences and results providing even a form of practical universality. The historical, material, experimental and psychological robustness of the generic factor connects the materials, concepts, predictive capacity and solidity of science. The very transverse aspect of science comprises one of its salient strengths, as there exists a measure of complementarity between its several regimes. The intertwined, transverse territories of science are visible in the growing circulation between its components in the form of cross borderland regime movement.

Finally and surprisingly, genericity and the *lingua franca* of the research technology regime contribute to transversality in a second and rather unexpected fashion by re-enforcing the stability of the other regimes. As generic instruments are adopted in the context of research of each scientific discipline and/or in the context of the different regimes, they are adapted to the necessities emerging from the way they are used there. This adaptation must be considered as a strong element in the consolidation of each territory of science, and disciplines. The circulation and utilisation of a generic instrument contributes in that sense to strengthen the identity and particularity of their users. So, by circulating through the different disciplines, a generic instrument, at the same time, creates the possibility of a link and of exchanges between the different practitioners, and by its very utilisation and adaptation, it contributes to redefine and consolidate the borders between the disciplines. Indeed genericity and universality contribute to keep the frontiers between territories relevant and even necessary for the sake of these different territories of research and of the consolidation of their very referents.

The same reflection can be made about the *lingua franca*. As scientists of different disciplines speak together across the borders of their territory, they adapt their language and try to find common concepts and representations of reality so that they can communicate and perhaps work together. When meeting at the borderland and trying to organize a project together, scientists are taken in a double movement: they assume the use of common language between them in order to communicate, but so doing they continue to keep their own discipline referents. The *lingua franca* must be seen in that sense, as the pidgin that makes communication possible between groups that are strangers to one another, and at the same time as a factor that contributes to reinforcing one's own language, culture and identity where one feels "at home" in a familiar terrain of research.

More generally speaking, one can say that what seems to blur the borders between disciplines, also contributes in fact to maintain the different frontiers between them, between science and technology, and enhances the relevance of each different regime, and the inadequacy of the idea of the emergence of a so called technoscience.

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