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► Higher Education and Innovation

Teaching as Invention

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Synonyms

Instructional design; Lesson design; Planning lessons

Introduction

The knowledge as well as the beliefs of a teacher influence the way teaching takes place and the results of the teaching process (Pajares 1992; Neuweg 2011). But knowledge and beliefs are not the only factors influencing the teaching process. Since under certain conditions teaching can be described as a problem-solving process, i.e., as an invention process, it seems probable that the creative disposition of the teacher may be another factor that influences the teaching process (Hanke et al. 2011). This contribution describes teaching as a decision process and explains under which conditions it takes place as an invention process which is influenced by the creative disposition of the teacher. As one of these conditions is that enough time is available for processing, it will be shown that above all, designing lessons can take place as a creative problem-solving process, i.e., as an invention process.

Key Concepts and Definition of Terms

Teaching

In order to describe how a creative disposition may influence teaching, it is important to have a look at the process which takes place before a teacher acts, independent whether it is an act of designing lessons or an act of interacting in class. In both cases, this process preceding action is a decision process that results in the decision on how to act. In order to describe this process in more detail, it can to be divided into three subprocesses (Hanke 2011): (1) the subprocess of perceiving the environment, (2) the subprocess of activating possibilities of how to act, and (3) the subprocess of choosing one of these possibilities (see Fig. 1).

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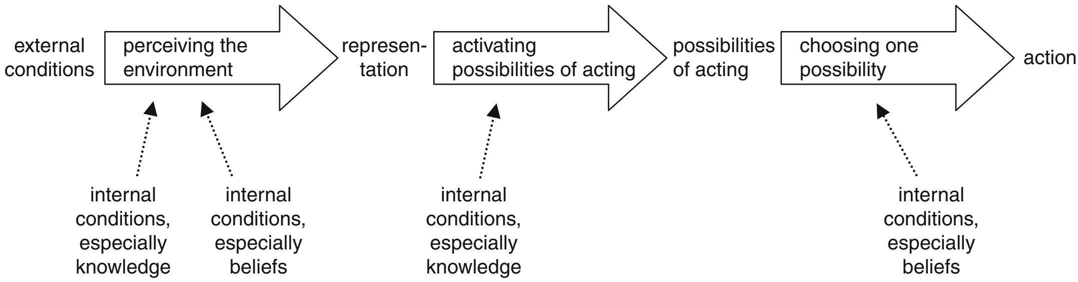

Teaching as Invention, Fig. 1 Subprocesses of the decision process

The starting point of the decision process is to perceive the environment and represent it mentally (subprocess 1). Based on this representation, the teachers realize different possibilities of how they can act (subprocess 2) and finally choose one of them to implement (subprocess 3).

Each of these three subprocesses is influenced by internal and external conditions (see Fig. 1). External conditions are those aspects of the environment that teachers perceive, e.g., location, media available, number of pupils, etc. Internal conditions are the teachers' knowledge (Neuweg 2011), their beliefs (Pajares 1992), their experiences, their emotions (Hascher and Krapp 2009) and motivation (Krapp and Hascher 2009), their skills, etc., and perhaps their creative disposition as well (Hanke et al. 2011).

External conditions are perceived and represented differently by different teachers, depending on their internal conditions. Thus, subprocess 1 is influenced by the external conditions on the one hand and by the internal conditions on the other, which are mainly the knowledge and the beliefs of the teachers which are represented in perception schemata (Berliner and Carter 1989).

Based on how teachers represent the external conditions, they realize different possibilities of how they can act. Which possibilities they realize depends on their representation of the external conditions on the one hand and on their perception schemata on the other hand. It is evident that teachers who have more knowledge are able to activate more possibilities of how to act than those who have less knowledge.

The last subprocess is, in contrast, mainly driven by the teachers' beliefs. Depending on these beliefs, they evaluate the effectiveness and adequacy of the different possibilities and therefore choose different possibilities of how to act.

The decision process described above can take place based on schemata, i.e., based on already existing knowledge and beliefs, as well as a process of mental model construction. In most cases, it is a schema-based process because this way of processing is less exhausting. A mental model is only constructed if the schema-based processing fails (Seel 1991) because of a resistance to process based on an existing schema, i.e., because of a resistance to assimilation as discussed by Piaget (1976). This resistance provokes a mental disequilibrium, which makes a person feel the necessity to accommodate, i.e., to construct a mental model.

As assimilation and accommodation are the basic processes of information processing and therefore take place in every situation, they are also assumed to be the basic processes in the decision process of teaching described above.

A schema-based decision process in teaching is characterized by activation of schemata in the second subprocess and an evaluation based on schemata, i.e., on existing knowledge and experiences in the third subprocess. On the other hand, a decision process that results in a mental model can be characterized as a problem-solving or invention process. In this case, knowledge is activated, but it has to be restructured in order to construct a mental model and with it find a solution for the problem/task. Thus, the second subprocess is not a process of activating schemata, but one of restructuring knowledge and constructing a mental model: it is an invention process.

Based on these assumptions, the decision process in teaching is assumed to be schema-based as long as there is no resistance to processing based on schemata. But a closer look at the different processes of teaching shows the specifics of that act:

The basic assumption is that the decision process described above takes place during the preactive phase of teaching, i.e., while designing lessons, as well as during the interactive phase of teaching, i.e., in class. There is, however, one big difference concerning the external conditions of these decision processes during the two phases of teaching: during lesson design, there is less time pressure than during the interactive phase, where teachers have to act almost immediately, as the learners are waiting for their reactions. For this reason, the decision process during the interactive phase is assumed to be mainly schema-based, i.e., is based on already existing schemata that represent the individual teachers' knowledge and beliefs. Because of time pressure, it is not possible for them to generate new solutions in a problem-solving or an invention process based on the construction of a mental model. They are forced to act based on a schema, even if this schema does not meet the requirements of the situation very well.

On the other hand, there is less time pressure during lesson design. It could therefore be assumed that the decision process during the preactive phase of teaching is schema-based, but turns into a problem-solving process as soon as a resistance to schema-based processing is met. Taking into account that the lessons which teachers have to design are almost never truly identical (at least the conditions of the target audience vary), it seems plausible to assume that the task to design a lesson often provokes a resistance to process based on schemata and therefore turns lesson design into a process of invention. However, findings about scripts and schemata in the lesson designs of the teachers and the way they act in class (Seidel 2011) do not give evidence for this. These findings seem to be an indicator of mainly schema-based processing, even while designing lessons.

For this reason, it is assumed that a task to design a new lesson does, in many cases, not cause a resistance to schema-based processing.

The only condition that may cause the construction of a mental model in designing lessons therefore seems to be a high commitment or dedication to act in an extraordinary way. When teachers have the time and are motivated to put effort into teaching, this may provoke them to construct a mental model instead of designing a lesson based on schemata. In this case, the process of designing a lesson can be characterized as a problem-solving process or an invention process.

It can be summed up that the decision process in teaching in the pre- as well as in the interactive phase is primarily schema-based. Only in cases where enough time is available, i.e., mainly during the preactive phase, and when teachers meet a resistance or are sufficiently motivated, may schema-based processing be inhibited and a mental model will be constructed. In this case, the decision process can be described as a problem-solving or invention process. As is to be shown later, the problem-solving process is the place where creativity comes into play. But beforehand, the concept of creativity has to be defined.

Creativity

Creativity is normally discussed in the context of the characterizations of creative products, creative processes, and creative persons (Funke 2000). Creative products are developed by creative persons in a creative process and are normally (Linneweh 1978; Schlicksupp 1999; Sternberg and Lubart 2002) characterized as new, i.e., different from already existing products and as useful and practical at the same time. As the result of a creative process is a new product, this creative process cannot be based on schemata, but can be characterized as a process of mental model construction, i.e., as an invention or a problem-solving process (Landau 1974), during which the creative person has to solve the problem to create a new but nevertheless practical product (Linneweh 1978). In this sense, the creative process is not an unusual process, but an act of thinking that takes place every day. Nevertheless, it is not the primary way of thinking: as has been described above, there are certain conditions that have to be met in order to inhibit schema-based processing.

As schema-based processing does not result in new products, it is not supposed to be a creative process and is not supposed to be influenced by a creative disposition of a person. On the other hand, a problem-solving process which is supposed to result in a creative product may depend on a creative disposition, as will be shown in the following section.

Theoretical Background and Open-Ended Issues

Creative Teaching

Concerning teaching, a creative disposition may influence the way that teachers act because creativity influences the decision process that precedes action. It can be assumed that creative persons are able to perceive (subprocess 1) their environment differently because they do not rely only on their schemata. Additionally, they will also be able to create new but nevertheless useful possibilities of how to act and do not only activate their existing schemata (subprocess 2). Concerning the third subprocess of the decision process, it is assumed that a creative disposition may lead to a different evaluation of the possibilities and therefore to a different choice of how to act.

The decision process can therefore have the form of a creative process, but nevertheless not every decision process while teaching is creative in nature: as was explained before, in most cases, this decision process takes place as a schema-driven process that is carried out automatically. In this case, the decision process cannot be described as a creative process in the sense of a problem-solving process, because activating schemata is not supposed to be influenced by a creative disposition.

On the other hand, the construction of a mental model as a problem-solving or invention process may be influenced by a creative disposition.

But as elaborated above, certain conditions have to be met before a decision process in teaching makes the construction of a mental model probable: there has to be enough time and there has to be a resistance to perform schema-based processing, or the motivation to put extra effort into teaching. As teachers have to decide under time pressure during the interactive phase of teaching, creative processing is supposed to take place only during the preactive phase of teaching. Thus, teaching as an invention process is always a process of designing lessons.

It may be astonishing that not every process of designing lessons is a creative problem-solving process, because the task to plan a new lesson may seem to provoke a resistance to process based on schemata. But as has been shown, the analysis of lesson designs gives evidence for mainly schema-based processing, even during lesson design (Seidel 2003, 2011; Seidel and Prenzel 2004). Therefore, the task of constructing a new lesson design does not always provoke a resistance to assimilate and therefore does not automatically inhibit processing based on schemata.

For this reason, it is believed that creative processing in designing lessons is met when teachers are willing and motivated to put effort into it.

This is the reason why the subjects in one of the rarely existent studies about creativity and teaching (Hanke et al. 2011) were explicitly asked to design creative lessons. In order to investigate the effect of a creative disposition in lesson designs, this was necessary to make sure that the subjects constructed mental models and did not activate schemata, because schema-based processing does not even have the potential to be influenced by a creative disposition. In this study, the subjects (students enrolled in the "Instructional Design" Bachelor program at the University of Freiburg, Germany) had to create two lesson designs with different specifications. Their resulting lesson designs were then rated by their degree of novelty and practicability. In addition, the lesson designs of each person were compared, in order to investigate if more creative persons create more structurally varied lesson designs. The results of this quite small study ($N = 44$) showed no clear evidence for an effect of a creative disposition measured by the V-K-T (verbaler Kreativitätstest/verbal creativity test, Schoppe 1975) on the lesson designs. But an in-depth analysis gives first evidence that participants with a creative disposition create more structurally varied lesson designs (Hanke et al. 2011).

Conclusion and Future Directions

The explanations above show that teaching processes can usually not be characterized as invention processes because creativity does not show up under time pressure. For this reason, creative processing in teaching can only take place during the preactive phase in the process of designing lessons. But as the less exhausting and therefore "usual" way of processing is schema-based, and the task to design a new lesson does not cause the necessary resistance, even the process of designing lessons does not usually take the form of a creative invention process. The only situation when designing lessons becomes an invention process seems to be when the teachers are motivated enough to put extra effort into designing a lesson. However, since there are almost no studies about the role of creativity in teaching, the explanations above can only be treated as tentative hypotheses. There is a need for significant additional research in order to be able to describe the relation between processes of teaching and creativity.

Cross-References

▶ Creative Behavior
▶ Creative Pedagogy
▶ Creativity Training in Design Education
▶ Divergent Thinking
▶ Divergent Versus Convergent Thinking
▶ Teaching Creativity

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Teaching Creativity

► Promoting Student Creativity and Inventiveness in Science and Engineering

Teaching Problem Solving

► Inventive Thinking Skills, Development

Teaching Thinking

► Inventive Thinking Skills, Development

Techno-Globalization and Innovation

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Synonyms

Innovation internationalization; Research; Technology

Techno-globalization denotes a global pervasion in generating technological knowledge and exploiting innovations with a technological content. It also claims that globalization has been shaped and advanced with the help of technology. With regard to research and development (here *R&D*) and innovation, the term in its most modest use is shorthand for the fact that generation, transmission, and diffusion of technologies is increasingly international in scope. A fundamental typology of Archibugi and Michie (1995) differentiates between global technology exploitation, global technological cooperation, and global generation of technology. Techno-globalization subsumes different internationalization aspects: firstly, the international exploitation of domestically generated new technological knowledge on foreign markets, either embedded in innovative products or process technologies (exploited by trade or offshore production) or nonembedded (by license agreements); secondly, the internationalization of sourcing new technological knowledge by founding or buying R&D facilities abroad or through international R&D subcontracting and outsourcing (and, conversely, the selling of R&D services to foreign customers); and, thirdly, international R&D cooperation in generating new technological knowledge through joint R&D ventures, cooperative agreements, or alliances and collaborative R&D projects, where each participating partner typically retains its formal independence. The main actors of techno-globalization are commercial companies looking for business opportunities and technological competition head start at an increasingly global scale. Industrial and technological standards play a major role in favoring or preventing entrepreneurial activities in creating or penetrating specific markets. Increasingly public research organizations engage themselves in the field of international R&D pushing international R&D *cooperation* as a subphenomenon of R&D internationalization to become a distinct field of science and technology (*here S&T*) policy. Research about techno-globalization, however, is still confronted with methodological shortcomings, insufficient data, and data comparability.

Background and Drivers of Techno-Globalization

Techno-globalization is both a result and a driver of new forms of economic organization and division of labor, fortified by sociopolitical (e.g., integration of the European Union, *here* EU) and sociocultural (e.g., "global village" and web2.0) changes. Among its main characteristics are:

- A wide application of new technologies to organize global transactions (information and communication technologies; logistics, packaging, and transport technologies)
- Multinational enterprises (*here* MNEs) as major agents and promoters, which – next to technology trade and technology exploitation – increasingly undertake R&D at locations outside their home countries and which are implementing new management practices to (out)source R&D internationally (e.g., open innovation)
- A worldwide tendency toward market deregulation, diffusing from the triadic countries (the USA, Japan, the European Union) to emerging economies and beyond, accompanied by global and sub-global diffusion of standards and norms
- An increasing mobility of production factors, especially capital, but also of (codified) knowledge, accompanied by an emergence of efficiency-oriented education systems, capable to produce human resources to manage the global exchange of goods, services, capital, information, and knowledge, not only in economically advanced post-industrialized countries but also in emerging economies with considerably cheaper labor costs
- Rising public awareness on global challenges, which do not stop in front of national borders

Economic growth and technological change, defined as the extension of knowledge in way of new products, production, and organization technologies, are increasingly relying on innovation relevant knowledge. The competition for new innovation relevant knowledge has reached a global level. Technological progress has both an endogenous as well as an exogenous dimension. Positive exogenous spillover (e.g., by means of technology transfer) can only develop if the knowledge-receiving company (or institution) has the ability to make use of it and to enhance it through own contributions. For the development of absorptive capacities, the quality of educational institutions (e.g., universities) and science and technology policy (through an efficient allocation of resources) play a major role. National economies which do not invest in knowledge production might in the long term not be able to master the speed of progress of knowledge-based economies (and societies).

Internationalization of Business R&D

Techno-globalization is not a new phenomenon. Although it might reach back decades, it became widely recognized in the academic discourse end of the 1980s and early 1990s. This was caused by a strong growth in the 1980s by companies' propensities to trade and to exploit their inventions and innovations internationally. Also, global technological cooperation of companies experienced a major boost during that time (Mowery 1992), however, confined to few, but crucial fields (e.g., information and telecommunication technologies), and with a very selective regional focus on the "classical" triadic countries (Japan, but especially on the USA and Europe). A more recent development is that companies increasingly also undertake R&D at locations outside their home countries. The location of R&D production has always been regarded as most "sticky" among all business processes, in a sense, that it was perceived as least transferable to other locations or countries. Only 20 years ago, Patel and Pavitt (1991) concluded that R&D is an important case of non-globalization. Today, a vast amount of evidence draws a different picture. Internationalization of R&D has become an important trend that shapes the national innovation system of all OECD countries. Foreign-owned firms already account for around 20% of total business R&D in France, Germany, and Spain; between 30% and 50% in Canada, Hungary, Portugal, the Slovak Republic, Sweden, and the UK; and more than 50% in especially smaller countries such as Austria, Belgium, the Czech Republic, or Ireland (Dachs et al. 2012).

Howells (2008) contextualizes the new wave of R&D globalization as an ongoing process of increasing spatial division of R&D where, besides the geographical widening, a deepening of R&D activities is occurring too. Business R&D is widely considered a production-related activity as input into the innovation process and a knowledge-generating activity as input into the transformation of manufacturing-based economies into knowledge-based economies. In more general words, *"R&D either follows production"* or *"R&D follows excellence*." In the first mode, the so-called adaptation mode, companies need to perform some R&D in foreign markets to adapt to local tastes and requirements and/or to take advantage of cost arbitrations in the global division of scientific labor. In the second mode, the augmentation mode, companies are driven by the search for excellent R&D conditions, particularly access to quality and scale of human resources and to a developed public research base.

Especially the first of these two modes was decisive for the emergence of the so-called BRICS countries (i.e., Brazil, Russia, India, China, and South Africa) as R&D locations of foreign companies. In part, the BRICS are also emerging as hotspots for R&D excellence, but the notion of "R&D following excellence" is still predominately a core issue of intra-triadic exchange with a few new smaller high- or post-industrialized countries catching up, such as Israel or Singapore. According to Dachs et al. (2012), foreign-owned firms in the USA spent around EUR 30 billion on R&D in 2007. The corresponding amount for Germany is EUR 11 billion and EUR 9 billion for the UK. The R&D expenditure of US firms in the EU (considered as one entity, not taking intra-EU relationships into account) and of EU firms in the USA taken together account for two-third of R&D expenditure of foreign-owned firms in manufacturing worldwide. In absolute terms, overseas R&D expenditure of US firms in the EU more than doubled between 1994 and 2008, but in relative terms, the rise of Asian countries as R&D locations for US firms has led to a dramatically declining share of US overseas expenditure in the EU (from around 75% in 1994 to around 60% in 2008). Brazil, Russia, India, and China are not only host countries for R&D activities of foreign-owned firms, but a few of their companies are also increasingly setting up R&D activities in the EU and the USA.

R&D expenditure of foreign-owned firms concentrates on R&D intensive, high-technology or medium-high-technology sectors. Thus, techno-globalization predominantly takes primarily place in pharmaceuticals, machinery and equipment, electrical and optical equipment, information and telecommunications (here *ICT*), motor vehicles, and other transport equipment. Some sectors offer better preconditions for a decentralized organization of R&D because their knowledge base is less cumulative with fewer size advantages in R&D or allow also an easier exchange of knowledge. This is the case for ICT, but also for business services as important non-manufacturing sector for instance in Israel or the UK. The lowest degrees of internationalization of R&D are found in low- and medium-low-technology sectors such as textiles and clothing, wood, paper, rubber and plastics, or basic metals and metal products. Though data is scarce, the existing evidence suggests that service industries tend to be characterized by lower levels of R&D internationalization compared to manufacturing industries (paragraph based on Dachs et al. 2012).

Major motives for firms to locate R&D activities abroad are:

- The size of the host economy, which promises superior market potentials and sales prospects conducive to R&D efforts of foreign-owned affiliates, especially in light of specific market and customer preferences and requirements
- Rising costs of R&D in knowledge intensive industries, which lead to international R&D allicances, mergers and acquisitions
- The accessibility and quality of a developed public research base (including technological infrastructure)
- The quality, cost, and size of skilled workforce, which is important for any research endeavors
- Subsidies incentives

However, R&D internationalization is still heavily influenced by geographic proximity and low cultural barriers, that is, factors which are conducive to reduce transaction costs.

From a country's inward perspective, R&D expenditure and labor productivity of foreign-owned affiliates seems to be positively related to labor productivity of domestic suppliers, especially if incentives for spillover and competition effects are promoted by the host country's industrial and innovation policy (Edler 2008). Sometimes, local content measures, including funding of collaborative R&D projects, are in use to enforce a connection of the MNEs' R&D with domestic partners to avoid a Janus-shaped industrial organization, where productive MNEs are not integrated in domestic chains of economic value added and where local companies, thus, do not benefit from productivity spillovers and remain less efficient and profitable. From an outward perspective, home countries may benefit from the global expansion and from reverse knowledge spillovers and reverse technology transfer. Although hollowing-out effects are possible, today's empirical evidence still suggests that overseas R&D activities are usually not (yet) a substitution for similar domestic activities.

Internationalization of Science and Technology Policy

The role of S&T policy for R&D internationalization has long been regarded primarily as an accompanying "enabling" or – at least – "preventing" framework. Although academic science has been international in scope almost since its inception, public R&D expenditure remained rooted in the national context. The enabling function of internationally oriented S&T policy comprises the development of stimulating incentives or support programs, while its preventing function primarily concerns the protection of intellectual property at international scale. Above all, however, the main task of national S&T policy toward internationalization of R&D is to keep the own house clean, that is, to be an attractive place for conducting R&D and, thus, for attracting R&D inflows from abroad.

In the last couple of years, S&T policies actively started to deal with internationalization of R&D, not just to let it happen but to support it and even to direct it. Examples for this proactive understanding are incentives to attract inward corporate and institutional R&D; to establish and to participate in cross-border research programs; to invest in joint R&D labs abroad; to support the mobility of researchers; and to promote political cooperation, dialogue, and trust eventually leading to coordination of R&D internationalization policies toward third countries.

Basically, two different sets of S&T internationalization objectives can be distinguished: an intrinsic dimension, which puts goals into the center of public S&T policy that directly aim to substantiate S&T (e.g., through enabling R&D cooperation among the best researchers globally or to find joint solutions for large-scale R&D infrastructures which cannot be financed by a country at its own) and an extrinsic dimension, which puts goals into the center that are meant to support other policies (e.g., facilitation of access to foreign markets through standard settings or research for development to assist technical development cooperation). The main addressees of interventionist approaches of S&T policy toward R&D internationalization are public R&D organizations and agencies.

The major motives of public R&D organizations to participate in international R&D cooperation are to access and to utilize excellent and complementary knowledge available abroad, to secure international funding, and to build up reputation through international visibility. For universities, further motives are to gain solvent students, to branch out colleges to commercialize their educational activities, and also to bolster their prestige in international rankings. Branch campus offshoring is a rather new phenomenon, connected particularly to American universities, with an initial concentration on the Middle East and a very recent shift to the Far East.

The main objectives (Sonnenburg et al. 2008) that drive R&D internationalization from an S&T policy perspective are:

- The quality acceleration and excellence objective
- The market and competition objective
- The resource acquisition objective
- The cost optimization objective
- The global or regional development objective
- The science diplomacy objective

Different rationales are guiding these objectives: the rationale behind the *quality acceleration and excellence objective* is primarily an intrinsic one that assumes that international R&D cooperation improves the domestic science base, leads to faster and improved scientific progress as well as enhanced, or even superior, scientific productivity, and is also supportive for the professional advancement of the involved researchers (e.g., trough joint publications in acknowledged international journals). The rationale behind the extrinsic *market and competition objective* is to support the market entry of domestically produced technologies/innovations abroad as well as to support the access to and a quick uptake of technologies produced abroad within the domestic economy. The rationale behind the *resource acquisition objective* overlaps partly with the two major objectives mentioned before. The access to information, knowledge, technology, and expertise as well as to singular equipment/facilities and materials is in the focus. But resource acquisition is not limited to different codified and tacit dimensions of technology transfer but extends to brain gain, gaining of solvent students, and increasingly also gaining research funds from abroad or from multilateral or international sources. The *cost optimization objective* from a public S&T policy focus does not primarily mean to use cost arbitrages of other countries (e.g., lower wages abroad) as might be an argument of the business sector but rather focuses on cost-sharing approaches to create critical mass in a certain S&T arena, for example, to establish large-scale research infrastructures, and it also includes the rationale of risk sharing. The assumption behind the *global or regional development objective* is the comprehension that many risks have no frontiers (e.g., infectious diseases or climate change) or cannot be solved without international cooperation and solidarity (e.g., Millennium Development Goals) and, thus, have to be tackled through international R&D collaboration (e.g., research for development). The main rationales underlying the *science diplomacy objective*, which often refers to global challenges and to development cooperation agendas, are to support other policies through R&D cooperation (e.g., nonproliferation of mass destruction weapons through keeping former weapon researchers busy with civilian R&D projects) and, secondly, to promote the national science base abroad in support of other objectives already mentioned above (e.g., to attract "brains" or to promote a general quality trademark like "made in Germany").

Public S&T policies toward R&D internationalization have both a strong "inward" dimension, which is to reinforce the domestic S&T base through attraction of and connection establishment to foreign resources (e.g., human resources, knowledge, or foreign funds), as well as a strong "outward" dimension in linking domestic actors to foreign markets and to knowledge produced abroad (Boekholt et al. 2009). An important channel for absorption, extensively taken up by the European Commission, is to integrate foreign actors into cooperation programs. The most recent communication of the European Commission (here *EC*) on internationalization puts the issue of excellence through competition (or better *co-opetition*) in the forefront: "*Excellence in research stems from competition between researchers and from getting the best to compete and co-operate with each other. A crucial way to achieve this is [. . .] to work together across borders"* (European Commission 2008, p. 4). This stems from the belief that the EU does not claim to be a self-sufficient entity in the realm of S&T and innovation, but that both Europe's knowledge resource (e.g., human capital) and its role in the global economy will be increasingly shaped by its ability to source knowledge internationally and to adapt it for its own use.

Further Aspects: Sub-Global S&T Integration, Technological, and Industrial Standards and R&D Internationalization Indicators

This integrative approach, which cumulated in a general opening of the 7th European Framework Programme for Research and Technology Development (2007–2013), the world's largest single R&D program, toward third countries, is a further aspect of the most ambitious international S&T policy integration process ever experienced sub-globally, namely, the creation of a single European research area (here *ERA*). With ERA, a harmonized, mutually open intra-European R&D arena of free movement of knowledge, researchers, and technology, with the aim of increasing cooperation, stimulating competition, and achieving an optimized allocation of resources, should be created by 2013. Less advanced subcontinental integration policies in the field of S&T can be witnessed in other important regions of the world too, such as in MERCOSUR, the Common Southern Latin American Market, here especially between Argentina and Brazil, or in ASEAN, the Association of Southeast Asian Nations. Regarding the latter, the ASEAN Committee on Science and Technology has been established back in 1971 with the objective to increase the competitiveness of S&T in the ASEAN region by supporting intra-regional R&D cooperation, partly supported by the ASEAN Science Fund established in 1989.

A further important aspect of integration policies is to reduce regulative barriers preventing a diffusion of economically relevant technological activities, including knowledge generation and innovation exploitation, across national borders. After technology, regulation and standard-setting has played an important role in making globalization a reality. In order to facilitate global communication, telecommunication technology – for instance – depends strongly on industrial and technological standardizations. Also, environmental standards and codes with more or less technological implications (e.g., passive energy buildings and 3-l motors) can be either encouraging or discouraging to global transactions. Typically, the standard setter has both an accumulative and first-mover advantage against the standard adopter. Triadic industries, and contemporarily also increasingly China and Russia as well as other emerging economies, have a long history in competing standards for the sake of promoting own industries globally, respectively, of preventing the intrusion of foreign companies at domestic markets. Early set standards can help to focus investments, but they can also subvert vivid innovation competition and might result in technological trajectories with too early dead end. Industrial and S&T policy increasingly aims to push international standard setting by establishing lead markets or pre-commercial innovation procurement, but often industrial standards are settled by market forces. A classical example of a standard war was that of the Video Home System VHS (developed by JVC) versus Betamax (developed by Sony) about video cassettes.

Compared to economically wasteful standard wars, open technical standards developed under appropriate patent policies can generate significant public benefits. Competition within an open technical standards framework, however, depends crucially on the proper functioning of industry standards setting organizations. An often citied example is that of GSM, the global system for mobile communications, which is in use in 200 countries, covering around four-fifth of all mobile communication clients. In order to avoid a similar fragmented situation as the one referring to analogous mobile communications in Europe, the *Groupe Spécial Mobile* was established in 1982 to develop a uniform intra-European standard for digital mobile communications, which later pushed other standards, for example, in the USA, aside and became a global industrial standard. In 2000, next generation GSM standard activities have been transferred into the "3GPP" consortium, which includes relevant authorities from the EU, the USA; Japan, Korea, and China as partners.

The measurement of techno-globalization differs significantly with respect to the observed phenomenon. Indicators are usually well developed at the level of supranational and international organizations, but poor when it comes to binational or multinational programs or the participation of foreign companies or research organizations in national programs. Patent statistics can provide a number of meaningful throughput indicators for approximating business-relevant knowledge interactions at global and international level, while academic publication databases, such as Scopus or Thomson Reuters Web of Science, enable insights in international co-publication activities which are globally on the rise. Although there are a series of reports on international R&D flows, published data is frequently neither complete nor fully comparable. Among other issues, published data on sources and origins of R&D expenditures reveal methodological differences, data gaps (especially concerning specific regions), timeliness in reporting, and high levels of aggregation, preventing in-depth analysis to observe the often subtle changes in the character and content of internationalized R&D. The situation is even worse when it comes to R&D activities of public funding organizations and research organizations. Governments do often not precisely know themselves what share of national budget is spent for foreign actors or how money allocated to domestic actors is spent abroad or in international cooperation (Verbeek et al. 2009).

Conclusions and Future Directions

Since the industrial revolution the importance of technological change for economic development has not been questioned. Access to scientific and technological knowledge can be seen as what divides the "haves" and the "have-nots." One of the highest-value business functions in terms of its value-added contribution is R&D. For this reason, internationalization in general, and in particular of high value-added activities such as R&D, is an issue of political debate. There are first signs that in contrast to the early years of foreign direct investments in R&D in emerging economies, an investment in those countries could be more likely to be accompanied by a disinvestment in the triadic core regions. This shift in R&D locations might be amplified by a larger supply of skilled and more cost-efficient S&T workforce in emerging economies, which will shape the global R&D landscape in the future. While a lot about empirical trends and motives of firms is known and the measurement of internationalization of research organizations has just begun, there is still considerable lack of knowledge as regards the effects of techno-globalization on home and host countries, not only in terms of economy but also in terms of impact on the social fabric and cohesion as well as on the individual experience in the everyday world.

In fact, under techno-globalization, more can be understood than only different aspects of R&D internationalization or the diffusion of technology for the sake of economic activity or academic progress. Future research on techno-globalization will have to take also noneconomic and non-R&D processes into account. The globalized impact of basic technical infrastructures, such as the internet on political developments (e.g., the Arab revolution in 2011), or the presumably borderless use of "social" software on the design and diffusion of sociocultural trends and social innovations will probably broaden the focus of research about techno-globalization in the future. Furthermore, global sustainability, justice and governance aspects of technology, its unequal distribution, and use in view of its contribution to induce global problems but also to mitigate global challenges will have to be readdressed. Effects of technologies induced in region "A" might have intended or unintended impact on region "B" (e.g., spatially differentiated effects of the emission of chlorofluorocarbons [*CFCs*] on the planet's protective ozone layer) and can even create global dependencies (e.g., the use of genetically manipulated seeds in Africa). This calls for more effective international cooperation and appropriate sharing of burdens and benefits in order to protect the global "commons" and the world's public goods, but what constitutes effective governance of international cooperation in STI to meet global challenges is not yet clear (OECD 2012).

Finally, the question about winners and losers needs to be reassessed. While globalization in general seems to have created a system which has benefitted the more developed countries, it also seems that globalization trough technology, as a whole, has not only brought preponderant negative impact on the developing countries. In fact, while some developing countries have profited enormously through techno-globalization, others lack certain factors preventing them to take active part and to gain benefits.

Cross-References

► Knowledge Society, Knowledge-Based Economy, and Innovation
► Multi-level Systems of Innovation

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Technological Entrepreneurship and Asymmetries

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Synonyms

Actors management; Technological innovation management

The concept of asymmetries is adapted to the technological innovation, process aimed to create a new sustainable business based on a new couple of technology related to a targeted (created) market. The entrepreneurial team which leads this process is facing an important challenge while developing the technology up to the ninth Technology Readiness Level (TRL) corresponding to the market certification. Asymmetries, between the entrepreneurial team and the other actors among the different stages corresponding at the various levels of the TRL scale while progressing on it, are identified and described in this contribution (first sales and market issues are not addressed hereby). Newly identified asymmetries (Paun 2011) in the innovation process occurring on different risk, cultures, and time scales are introduced together with the classic one (information asymmetry) (Stiglitz and Weiss 1992), occurring from different possessed information (particularly related to the technology gap in this described case). These asymmetries could induce barriers to the technological development process. Finally, examples of collaborative tools developed to compensate or reduce these asymmetries are proposed (Paun 2011).

Notion of "Technological Entrepreneurship"

This contribution identifies the eventual barriers occurring between the entrepreneurial team (or individuals) and the other actors while carrying technology-based innovation projects.

Technological Entrepreneurship

Regardless of the new idea sourcing approach, provided by a promising new emerging technology (technology push) or by the identification of an existing expressed need in the market (market pull), the successful exploitation of such a new idea will be possible only when the technological development chain will take end by the introduction in the market of a new product or service. The technology development process, by creating new technologies or by adapting existing ones up to a new product or service, is thus a fundamental process related to any technology-based innovation. The commonly used tool for measuring the progression of the technology development process is the Technology Readiness Level – TRL scale (first definition by Mankins 1995). This scale is proposing nine levels, starting from level 1, meaning fundamental research, and finishing at level 9 related to the market certification and sales authorization, passing through TRL levels 3–4 related to laboratory demonstration or proof of concept and through TRL levels 6–7 related to operational conditions demonstration or industrial prototype.

The success of such a development process is partially given by the ability of the entrepreneurial team (or individuals) to define, identify, obtain, and manage the appropriate capabilities able to provide technology progression relative to the TRL scale, and this regardless of their socioeconomic environment (individuals, company employees, state agents. . .).

At each level, the actors are changing and their characteristics too. Up to the level of TRL 3–4, the work will be carried by scientists; between TRL 3–4 and TRL 6–7, by industrial R&D offices competencies types; and beyond, by industrial process designers. The decisions will be made on thinking patterns adopted by R&D directors, then by design offices, marketing directors, and production and supply chain managers. The investments will be driven from business angel to venture capital thinking patterns while progressing on the TRL scale.

All these actors are different, and the entrepreneurial team will need to understand, negotiate, and work with all of them using and being adapted to their specificities.

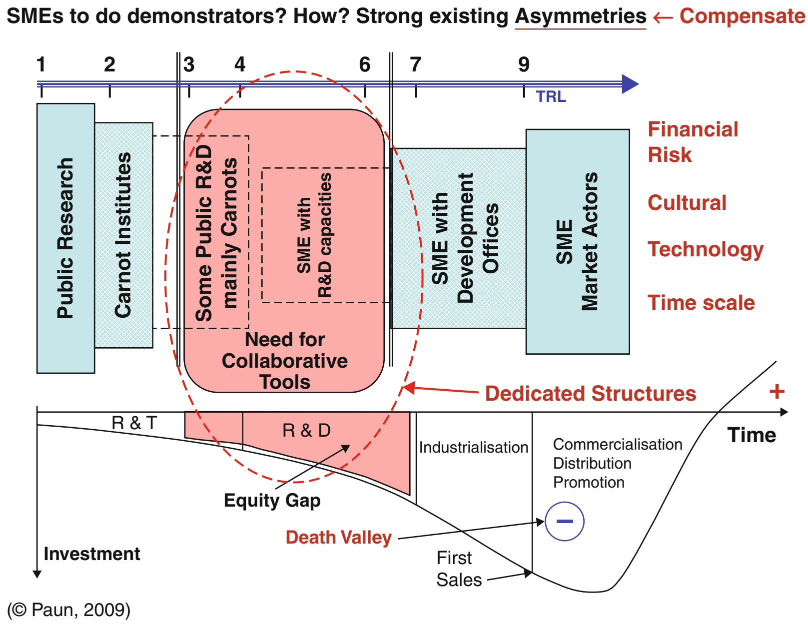
Notions of "Asymmetries"

Certain barriers for the technological entrepreneurship are mostly related to the various existing asymmetries between parties and could be reduced, for the information asymmetry, or compensated, for the risk, cultural, and time scaling of other newly identified asymmetries (Paun 2011) specific to the technological entrepreneurship, with specific collaborative tools.

Asymmetries Definition and Identification-Induced Barriers

Some of the actors involved in the technology development process (identified like a fundamental process inside the technological entrepreneurship), who will collaborate along the TRL scale stages with the entrepreneurs, will be highlighted and analyzed.

What about the characteristics of scientists, industrial researchers and developers, design engineers, industrial process executives, and marketing, financial, or supply chain managers? Or about business angels or venture capital partners, who will invest in the particular case of a technology-based venture? Are they thinking and behaving in the same way? Do they have the same type of competencies? Obviously no.



Technological Entrepreneurship and Asymmetries, Fig. 1 Information (from technology perspective) asymmetry showcased on the TRL scale between public R&D laboratories and small and media enterprises

Does the entrepreneurial team (or individuals) involved in a given technological entrepreneurship posses all these specific competencies? It is impossible and not necessary. Are all of these actors different and specific? Yes, and it is good like this because they all have complementary skills. Do the entrepreneurs need to collaborate and work with them? Yes.

The differences between the various actors are defining the existing asymmetries. These asymmetries will create value and will lead to the successful exploitation of the new idea if well coordinated and managed.

The specificity of the technological entrepreneurship is thus the one of being a highly collaborative process (Paun 2011). If it is well proposed by Stiglitz theory that the information asymmetry (Stiglitz and Weiss 1992) in a transactional relation could create value, it has to be acknowledged that, within a collaborative relation, asymmetries must be compensated (sometimes even reduced) in order to avoid barriers otherwise impeaching the agreements.

The ***information asymmetry*** related to the technological entrepreneurship could be identified as the difference existing between the scientist competencies, operating between TRL 1 and TRL 4, and the industrial process designers, operating between TRL 7 and 9 (see Fig. 1). They need "technological translation" between them, and this specific role could be assumed by developers from both sides or by appropriate training. For example, if the entrepreneur is a scientist, he will need to learn what industrial process means at least to a sufficient level to be able to understand an appropriate specialist.

A scientist is minded on a "workshipman" instinct as Veblen described it (Veblen 1914). An entrepreneur is mostly a "predator" type for Veblen. This strong ***cultural asymmetry*** could lock the process if not compensated, and it is generally acknowledged by various practitioners that working with a scientist "is not so easy." This is coming from this newly conceptualized cultural asymmetry (Paun and Richard 2009). They also need specific compensation tools (e.g., "translators") activated between them in order to be able to understand each other while the scientist will be interested by the knowledge progress and the entrepreneur by the prototype design.

Other important asymmetries are occurring while an entrepreneurial team is contracting R&D works with a laboratory. The value of the

R&D contract could represent an important percentage of the financial resources in the case of a small enterprise and very few for an important R&D laboratory.

This ***financial risk asymmetry*** (Paun 2011) has to be compensated while working together in order to guarantee for the execution of this type of contract the same importance for both parties, especially if the R&D laboratory is working with main industrials on important R&D contracts which could get a priority to the small enterprise one.

In addition to compensating for risk and technological asymmetries between the two parties, this contract has also subsequently proved to be a good tool for reducing transactional information asymmetries (Akerlof 1970; Stiglitz and Weiss 1992) between the start-up partner and its investors. Indeed, at the time of the phase of "due diligence" between the creators of the start-up partners and the business angels, the shared risk development contracts (Paun and Richard 2009) yield paramount information on both the product and the target market, and on the technological developments and their costs.

The ***time scaling asymmetry*** (Paun 2011) could occur in the same phase of contracting R&D works between an SME and an important R&D laboratory which are used to work with main industrial or state agencies. Indeed, in this case, some laboratories are programming their activities on a yearly base (eventually revised once or twice per year) while the SMEs are expecting actions and acting themselves on a monthly base (sometime even faster). This asymmetry could be accepted for eventually the negotiating stage of an agreement but will endanger the SME in the case of eventual delayed works (due to a monthly scale against a yearly one).

Example of Collaborative Tool as Asymmetries Reduction or Compensation Mechanism

To compensate and equilibrate the various described asymmetries occurring between a small enterprise (or a start-up) and an important R&D laboratory, a new type of R&D contract is being observed in practice recently (Paun 2011). Based on a negotiated business plan for the new product or service proposed for a targeted market by the entrepreneurial team, the R&D laboratory could invest in its own work to be carried for developing the needed technology. The financial risk taken by the laboratory is sufficient enough to prioritize the negotiated contract between the parties and give the same importance of succeeding the technological development to both parties. The various other asymmetries will be compensated by the strong managerial support inside the R&D laboratory provided on this type of ***risk and benefits sharing development contract***s.

Technological demonstrations that result in innovation can arise in any of the market sectors in which the SME receiving the technology can itself control the innovation process completely (until the successful introduction of the new product to the market). For example, some niche markets will be accessible, even in the aerospace sector (green aviation, small-scale drones, leisure, etc.). Once the technology is demonstrated, there are strong chances that the large aerospace groups will integrate this technology as a tested module into the systems they are designing (Mouchnino and Sautel 2007).

Conclusion and Future Directions

Succeeding the technological entrepreneurship implies to correctly identify, obtain, and manage the appropriate capabilities (Paun et al. 2012) able to provide the successful exploitation of a new technology (or a new couple of technology crossed with a market). Obtaining the capabilities will be a matter of rightly identifying and compensating (Paun 2011) through collaborative tools the various asymmetries existing between the different actors who posses these capabilities. The sum of competencies and capabilities then gives a figure for "capacity," as in building capacity both external and internal resources need to be meshed together (Paun et al. 2012).

Many authors have identified, in the various studies of the conditions and mechanisms of financial support for innovation and their impact on economic growth, that information asymmetry (Akerlof 1970; Stiglitz and Weiss 1992) is one of the major factors influencing the financial risk taken to generate innovations in our societies.

The generalization of this type of collaborative tools will no doubt mean the constitution of a better business angels culture and venture capital in France, and especially the appearance of new investors because of the reduction in financial risk as a result of the reduction of information asymmetry between the SMEs (or start-up partners) and investors.

As a transition to the macroeconomic level, an important perspective could directly impact the development policies of regionally specialized clusters, as with the national strategies for innovation. The R&D laboratories will adapt their behavior by intensively using asymmetries compensation/reduction mechanisms in their relationship with the regionally specialized SMEs, but also with other SMEs, not regional or acting in other domains.

Thus, the regionally specialized clusters (supposing there is more than one present in the same region) will be interconnected through direct collaborations occurring between some of their "provider (R&D labs)" and technology "consumer (technology adopter SMEs)" members. They will also be interconnected with other non-regional clusters. These types of interactions, driven through either market-pull or technology-push (or hybrid) approaches, will exchange technology inside and outside their related clusters, with no more monitoring by clusters authorities. To upgrade this type of a possible multiply embedded innovative system, mainly based on TT between providers and consumers of technology, the smart grid models could be an appropriate approach (Paun 2011).

Cross-References

▶ Business Angels
▶ Clusters
▶ Informal Venture Capital
▶ Innovation Systems
▶ Open Innovation
▶ Organizational Behavior
▶ SME
▶ Technology

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Technological Innovation

▶ Invention and Modification of New Tool-Use Behavior

Technological Innovation Management

▶ Technological Entrepreneurship and Asymmetries

Technological Innovation Systems

▶ National Innovation Systems (NIS)

Technological Invention of Disease

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Synonyms

Ailment; Discovery; Illness; Innovation; Sickness

Disease and Technology

Traditionally, diseases are considered to be entities in nature that are revealed by the health sciences. In short, diseases are discovered in nature. However, our view on nature is dependent on technology, which changes ever more rapidly. Diabetes has been a disease of the nervous system, of the liver, of the kidneys, and of the Langerhans islets of the pancreas. In 1763, Sauvage classified all 2,400 known diseases in his *Nosologia methodica*, and in the WHO's International Classification of Disease (ICD-10) of today, there are 45,000 disease codes. This development is not only a result of improved knowledge of nature but also of invention, innovation, and entrepreneurship.

There is unanimity that technology plays an important role in the development of medical theory as well as clinical practice. Technology has become the driving force of medical development. It has changed medical knowledge as well as its practice. The detection of bacteria, the development of penicillin, and the elaboration of the diagnostic and therapeutic armamentarium (as in the case of ECG, X-ray, MRI, endoscopy, genetic and pharmaceutical products) have all played an evolutionary role in medicine over the last two centuries.

There are many ways in which technology may influence health care in general and the concept of disease in particular. Firstly, according to a common account, technology has eradicated many diseases, reduced the prevalence of others, and improved the health of the human race. Technology has great potential for reducing disability and avoidable death, improving the quality of life and prolonging lives of good quality. That is, technology alters the occurrence of disease. Secondly, it has been argued that technological development alters the physical and social environment of man, creating new diseases. Life in modern urban societies causes man to develop new diseases. Thirdly, modern medicine has become dependent on and altered by the technical armamentarium it applies (Hellerstein 1983; Tymstra 1989; Jennett 1994; Mitcham 1994, 1995; Davidson 1995; Fischer and Welch 1999). It has changed the content and configuration of its knowledge. Both in theory and in practice, technology appears constitutive of medical activity and its basic concepts. As the two first perspectives are trivial, only the third perspective will be addressed here, as it represents the strongest claim: Technology provides the basic phenomena defining disease and generates and forms medical knowledge and action. Hence, there is an essential relation between technology and the concept of disease.

What Is Technology?

Before entering the detailed discussion on how technology constitutes the concept of disease, it will be important to clear what is meant by *technology*. A plausible definition of technology might be that it is the complex of devices, methods, and organizations applied in human purposive activity. Both in terms of devices, methods, and organization, technology today is integrated in modern medicine. A defibrillator (heart starter) is not just a box with wires, electrodes, and electronic components (*device*). It is a defibrillator on behalf of the *methods* of medical resuscitation applied in an *organization* of health care. This definition of technology stresses the significance of technology for different levels of health care, and accordingly, the term "technological medicine" emphasizes the constitutive role of technology in modern medicine.

What Does It Mean to *Invent* Disease?

The term invention denotes that diseases are not mere discovered in nature but that disease entities are framed by technological practices: Diseases are defined by its tools on three levels: ontologically, epistemologically, and practically (see below). This hinges on an intimate interaction between science, invention, and entrepreneurship which has been particularly visible since the British industrial revolution (Freeman 1997; Hessels and van Lente 2008).

After what has been called the empirical turn in the philosophy of science, the traditional divide between science and society has withered. Science does not live an isolated life in laboratories delivering results to society, but science and society continuously interact in negotiating and renegotiating the phenomena, the methodologies, and the assessment of its result in new modes of knowledge production. Hence, the traditional distinctions between science and technology and between discovery and invention (innovation and entrepreneurship) tend to lose relevance.

The Technological Constitution of the Entities Defining Disease

The central phenomenon of disease is given by technology. Technology provides the entities and events that are applied in defining diseases both in diagnostics and in treatment, in clinical practice and in research. The pathological morphology, chemical substances, biochemical agents, and biomolecular sequences studied in research, detected in diagnosis, and manipulated in therapy are grounded in technology. Light microscopy establishes basic structures, such as the cell, whereas stains and cultures constitute viral and bacterial agents, and electron microscopy and functional magnetic resonance imaging machines (fMRI) define a range of diseases.

The QRS complex, the echo-Doppler image and its corresponding indices, the scintigram and angiogram, establish a wide range of cardiac diseases which are generated by technology such as the electrocardiograph, ultrasound machine, gamma camera, and X-ray modality. Entities like *Helicobacter pylori*, *urea*, *cholesterol*, and *deoxyribonucleic acid* (DNA) are basic to the definitions of diseases such as *peptic ulcer*, *renal insufficiency*, *cholesterolemia*, and *Huntington's disease*.

Evans argues that technology constitutes the etiological agents that define disease (1991). For example, the technology which cultivates and identifies bacterial culture has led to the discovery of most bacteria causing diseases: The development of fluorescent antibody resulted in the discovery of *M. pneumoniae*, and the etiology of infectious mononucleosis. Furthermore, the growth of human B and T lymphocytes in suspension cultures led to the discovery of several important groups of viruses. In this manner, technology constituted a number of disease entities.

Correspondingly, the phenomena constituting *epilepsy* were in antiquity conceived as being humoral and spiritual (*the sacred disease*). Through technology, for example, electroencephalography and fMRI, the constitutive phenomena of epilepsy have come to be the electrical activity of the brain and the paroxysmal function of cerebral nerve cells.

Furthermore, we do not perceive entities like Helicobacter pylori and DNA directly, but they are provided by technology. We have no access to the time delays (T1 and T2) constituting the magnetic resonance image except through the MRI machine. The electrocardiogram (ECG) providing the signs of various cardiac diseases does not exist independently of the electrocardiograph. They are constituted by the armamentarium itself.

Hence, the basic phenomena and entities applied to define many central diseases are provided by technology. However, technology also influences the way we detect, identify, and interpret these phenomena. That is, technology strongly influences the content and formation of medical knowledge to be investigated in the following section.

The Technological Knowledge of Disease

Technology constitutes medical knowledge in several ways: It establishes the signs, markers, and end points that define the (epistemological) entities of disease. Furthermore, technology strongly influences the explanatory models of disease and the way medical knowledge is organized (its taxonomy).

Signs of Knowledge About Disease

Modern medicine relies on paraclinical signs for defining and detecting disease. For example, blood pressure and venous plasma glucose concentration define diseases such as *hypo-/hypertension* and *diabetes*. A variety of cardiac conditions are defined by specific ECG patterns, ultrasound Doppler flow and tissue stress measurements, and radiographic morphology. Paraclinical signs that define disease might be abnormalities of morphology, physiological aberrations, biochemical defects, genetic abnormalities, ultrastructural abnormalities, and etiological agents.

Such paraclinical signs are detected with chemical analyzers, X-ray modalities, ultrasonic devices, hemodynamic monitors, and CT, MRI, and PET scanners. Furthermore, they are manipulated by dialysis machines, lasers, diathermy, anesthesiological devices, and drugs of various kinds. In this manner, technology founds the paraclinical signs that define disease.

One important reason for the constitutive role of these paraclinical signs is their reproducibility. Technology makes the previously subjective and unreliable signs of disease dependable. Clinical signs earlier investigated by manual means are now tested by technology, and clinicians trust the results from instruments more than their own judgment. Reading the oxygenation in the color of the blood in a wound has been substituted by oxygenation measures, for example, pO_2 and SaO_2.

Moreover, success of technology in the generation and formation of knowledge in medicine has led to the application of technological tests in the detection of symptomatic diseases and syndromes as well. In fact, technology has become the gold standard for assessing and evaluating such conditions. *Lung infarction* is one example where pulmonary angiography and lung scintigraphy have been applied as a standard for diagnosing this symptomatic disease.

Furthermore, the set of technological tests is constitutive of how physicians conceive the symptoms of the patient. Chest pain of a certain kind immediately implies an ECG with a focus on the ST segment. In medical practice, the symptoms are transformed into paraclinical signs and tests. Symptoms gain significance only as projections of signs. Technology directs their significance and the way they are interpreted and acted upon.

Hence, technology influences the conception of symptoms in two ways. Firstly, technology is developed to detect symptoms. Secondly, the subjective experience of the patient is projected onto paraclinical signs and tests.

Markers and Risk Factors of Disease

In many cases, the signs that define diseases are not accessible (directly). However, various markers are applied to detect and identify them. For instance, changes in DNA are markers or risk factors for breast cancer and Alzheimer's disease. For such diseases, neither signs nor symptoms are detectable early in the development of the disease. However, genetic markers might indicate a disposition to them. Such markers are applied to identify and distinguish disease entities. As with paraclinical signs, disease markers are provided and founded by technology. Advances in technology facilitate the identification of new markers that will be treated as disease.

Thus, the technological constituted signs and markers are basic to the demarcation of disease. They define disease entities and are applied to recognize disease in the particular case and as such provide a technological semiology of disease.

Technological End Points

The signs and markers of disease also represent the measure of what is to be altered in order to make the patient healthy again. The general belief, in the existence of basic phenomena such as cells, calcium and potassium concentrations, or signs like ST segment displacement and markers like trisomy 21, causes physicians to try to influence and manipulate them. They become end points of medical treatment. The end point of the treatment of *hypertension* and *cholesterolemia* is the blood pressure and the level of cholesterol in the blood. The aim of genetic engineering is to repair or exchange defective DNA sequences, for example, in persons showing markers of *Huntington's disease*. Hence, technology defines the signs and markers to be detected, studied and manipulated in medicine, and thereby, it also constitutes the end points of medicine. In this, technology moves the attention away from patients' experience, as they do not feel high levels of cholesterol or Huntington genes (see below).

Technological Explanation of Disease

Important conceptual ties between different forms of causal thinking and conceptions of disease are widely recognized. Throughout history, disease has been conceived as an imbalance of the humors (Hippocrates, Galenus), as a disturbance of the morphological structure of the elements of the body, such as its organs (Morgagni), tissues (Bichat), or cells (Virchow), and as an error in the base pair sequence in deoxyribonucleic acid (DNA). Hence, the *explanatory language* of medicine is constitutive of the concept of disease. In addition, as argued, this language is today formed by technology, and it is technology that constitutes its expressions, measures, and aims. In other words, the causality of disease is limited by its frame of reference which is in turn technological methodology. The explanatory models of disease and its causality are constituted by technology (Engelhardt and Wildes 1995).

Moreover, technology has not only constituted the models of disease. It has influenced the models of man himself. The application of technology in medicine, successfully detecting, identifying, and treating disease, has made it a model for human physiology: The ear has been compared to an audio system, the eye has been viewed as an optical CCD system, and the brain that Descartes viewed as a hydraulic network has been modeled as a computer hard disk.

Technology is not only constitutive of the models of health and disease. It provides also for their metaphors. Furthermore, with the application of artificial organs such as pacemakers, cochlear implants, and advanced limb prosthesis, technology becomes a part of man's physical existence, that is, there is a fusion of man and technology. Hence, technology constitutes the explanatory models of disease and its symbolism, in addition to establishing the signs and markers that define diseases.

Technological Taxonomy

Furthermore, the organization of medical knowledge is influenced by technological innovation. Progress in science and technology changes the classification of disease. This is explicitly stated in the introduction to the International Classification of Disease. Since the time when technology began to impact on medicine, the number of disease entities has increased coherently with technological development which, while typically gauged by qualitative judgments, is generally believed to follow an exponential curve.

The influence of technology on medical taxonomy has been commented on in various ways. Jensen already long ago claimed that classification does not result from the nature of disease but from the apparatus of treatment (1983). Wulff correspondingly argues that the development of treatment strongly influences the classification of disease (1997). As will be argued later, technology is constitutive of medical treatment. Hence, a medical taxonomy founded on existing treatment must be influenced by technology.

According to Feinstein, the classification of diseases seems to follow three main organizing principles (1988). Firstly, diseases are classified according to clinical manifestations. Secondly, they are classified according to entities causing these manifestations. Thirdly, diseases are classified according to patterns and events following

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the clinical manifestations. The main argument so far is that the manifestations, the causal entities, and the resulting patterns and events are constituted, detected, and identified by technology. It follows from this that the organization of medical knowledge is also established by technology.

The influence of technology on the classification of disease appears in several ways. Firstly, technology creates new disease entities. Secondly, it changes existing disease entities. Thirdly, technology differentiates existing disease entities.

New Disease Entities

There are numerous examples of new disease entities generated by technological innovations. Only a few examples will be discussed to illustrate the point. It has been argued that the invention of the sphygmomanometer established *hypertensio arterialis* and that the *electrocardiograph* revolutionized the analysis of heart diseases, resulting in several new disease entities. For example, the clinical entity *atrial fibrillation* was established by the electrocardiogram (ECG).

The case of electrocardiography can be applied to illustrate another important aspect of the technological generation of new disease entities. It also constituted conditions such as *silent ischemia*. The electrocardiograph revealed that many patients had similar changes of their ECG under stress testing as patients with angina and that such changes predicted an increased risk of heart disease. In this way, the technological method established disease without the patient feeling ill. Hence, it was the technological test that defined and detected disease and that initiated medical activity and not the subjective experience of the patient.

In this way, technology has replaced the traditional meaning of disease, for example, bodily pain (*dolor corporis*), suspension of joy (*intermissio voluptatum*), and fear of death (*metus mortis*). Disease has become independent of the subjective experience of the person, and technology has endorsed a new range of disease entities: asymptomatic diseases. The development of molecular biology is a clear example of this. A great number of new disease entities are based on genetic abnormalities. A variety of genetic tests can detect diseases where the person tested does not feel ill.

How technology has made medicine less dependent on the subjective experience of the patient will be discussed in further detail later. Here, it has been argued that technology constitutes the classification of new disease entities and a wide range of them are asymptomatic diseases.

Technological Change of Disease Entities

When development in technology changes the phenomena that are used to define disease and the explanatory models of medicine, this correspondingly affects the classification of disease entities. Hence, disease entities alter with the advances of technology. Hence, people suffer and die from other diseases than before, for example, the introduction of the electrocardiograph (ECG) made people die of myocardial infarction rather than indigestion.

Disease terms such as “diabetes,” “epilepsy,” and “dropsy” have been applied in medicine since ancient times. Their meaning and extension, however, have changed. The name “dropsy” was replaced with “Bright’s disease,” which was exchanged with “nephritis” and lately with “end-stage renal disease” (ESRD). Changes in conceptual framework, for example, the prevailing entities, theories, and tests, result in alteration of disease entities. For example, diabetes has been conceived as a condition caused by excessive salt (Paracelsus) and excessive food, sex, or alcohol (Amatus Lusitanus), as a disturbance of the nervous system (Cullen), as a disturbance of the nutrition of the liver (Bernard), atrophy of the pancreas (1788–1910), and hydropic degeneration of the islets of Lagerhans (Opie). Today, diabetes is partly considered to be the result of infectious agents. Similarly, *infectious diseases* were earlier classified according to their respective organs. Today, they are classified separately. The technological detection of viral and bacterial specimens establishes the category *infectious diseases*.

Hence, technological development in medicine changes the definitions and taxonomy of disease entities.

Differentiation of Disease Entities

A third way in which technology has contributed to the development of disease entities is through the differentiation of existing entities. What was once reckoned to be one disease entity has through the development of technology evolved into a multitude of different diseases, for example, what was once called *acute respiratory disease* developed into many different infectious and chronic disease entities. One way both to differentiate and properly detect the various entities was by the use of proper laboratory technology. Diseases, previously diagnosed in only a vague manner, have now been rendered less ambiguous by technological means and can thus be clearly differentiated.

For example, angiography, echo-Doppler, tissue velocity imaging, and blood analysis have resulted in an extended classification of *myocardial infarction*. The application of the tank respirator in the 1950s established the differentiation between intercostal and bulbar polio. In the case of intercostal polio, the treatment with a respirator had an effect, but not in the case of bulbar polio (Rothman 1997).

So, technology has altered medical taxonomy: It has constituted new disease entities and changed and differentiated existing entities.

From Subjective Symptoms to Objective Signs

Technology has thus become constitutive in defining, classifying, and identifying disease entities. It has been argued that technology makes diagnosis and treatment objective and reliable. It facilitates direct access to the disease. This, however, has reduced the epistemological importance of the individual person for the concept of disease; it has reduced the importance of the subjective experience of the patient.

Before the eighteenth century, medicine was based on the patient's narrative of the symptoms. In addition to this subjective portrait of the illness, the physician observed the patient's appearance and behavior as well as any signs of disease. During the eighteenth and nineteenth centuries, medical instrumentation enabled and extended the physical examination of patients which made the physician less dependent on subjective narration. With the stethoscope, the physician could "listen to the disease directly." Measuring blood pressure gave an "objective account" of the internal conditions in the patient. The introduction of machines such as the ECG, X-ray, and chemical laboratory analyzers during the nineteenth and twentieth centuries further enhanced the objectivity of medicine. Technology enabled the physician to translate the language of symptoms and tests into the language of physiological processes. In this, the symptoms often had to be ignored in favor of underlying physiological or biochemical processes given by technological devices.

In addition to removing the errors introduced by subjective patients, technology also reduced the risk of error in physicians' judgments. Technology freed medicine from the subjective, the individual, and emotional, which confused the conception of "the real objective disease." Whereas the physician earlier was dependent on narration and clinical signs, he has nowadays come to rely on pathogenetic and etiological signs. Technology has guided medicine from basing its knowledge on symptoms to basing it on clinical signs, and from them to paraclinical signs and markers.

Technology has provided a detachment from the suffering of the patient. The capacities of technological medicine have replaced the individual patient as the epistemological basis of the disease concept. This has urged critics to maintain that medicine has become a "stranger medicine" and that technology has altered the patient's experience of being ill, for example, that the X-ray image becomes part of the patient's illness.

The Technological Gaze of Disease

One way to epitomize how technology has influenced the content and formation of medical knowledge is by the notion *technological gaze*. As argued, technology constitutes the signs, markers, and end points that define disease entities; it strongly influences the explanatory models of disease, and the way that medical knowledge is organized, that is, medical taxonomy. Hence, technology provides medicine with a new and radically different semiology.

Technology constitutes the categories of the medical gaze. It translates the physiological events into "the language of machines." Medical technology creates what the physician, the technician, or the researcher sees. And they see what they are looking for: *disease*. "The technology mediates between the seer and the seen and what is seen becomes largely constituted by technology. This is why practices change with the development of new technologies" (Cooper 1996). As argued, technology even transforms subjective symptoms into the realm of paraclinical signs.

The way we perceive diseases, name them, and talk about them is dependent on technology. Technology has become constitutive of the medical gaze and added to medical language. The change in medical gaze can be recognized in medical language. In pace with the technological development, the question of chest pain changed to the question of coronary heart disease, which is changed to the question of coronary artery disease.

Before the nineteenth century, *dropsy* was characterized and recognized by symptoms such as diminished urine and swollen legs. During the 1840s, patients with the same symptoms came to have *Bright's disease*. The technique of detecting albuminuria had, together with the recognition of different textures of autopsied kidneys, established a new disease entity. Furthermore, the application of the light microscope and cryoscopy during the 1850s established the disease entity *(glomerulo-) nephritis*. In the 1970s, the development of the dialysis machine and the method of transplantation established the *end-stage renal disease* (ESRD) as a disease entity.

Each new technology represented a new perspective and a new language which were distinctively different from the perspective and the language of the patients. Technology changed the physician's perception and made disease the physician's property, but at the same time removed him from it. There was an increasing electronic narration of disease.

This technological gaze in medicine has been criticized because it fits the illness of the patient to the skills of technology. As H. Spiro, a Yale professor in medicine, remarked:

> The worst problems come when the doctor fits the patients to his skills, something which is true for all professions. A woman comes to a gastroenterologist and gets a sigmoidoscopy, a barium enema and a high fibre diet. Going to a gynecologist, she runs the risk of laparoscopy and of losing her uterus if she continues to complain. . . . "I know that the minute I see the x-rays of the patient, before looking at the patient or before working on him, I will fit the patient's story into whatever the x-rays or other images are showing me." Here cited from Wolf and Berle (1981).

Altogether, medical knowledge is constituted by technology: Technology constitutes the signs, markers, and end points that are applied to define disease entities; it strongly influences the explanatory models of disease and the way that medical knowledge is organized. Hence, there is a *technological gaze* in medicine.

The Practical Formation of the Disease Concept

In addition to this crucial role of technology in the formation of medical knowledge and the constitutive role of technology to the (physiological, biochemical, biomolecular, and morphological) entities that are applied to define disease, there is a pragmatic influence on the conception of disease. The concept of disease is defined by its use, and the use of the term "disease" is constituted by the application of histopathological and chemical analyzers; CT, MRI, and PET scanners; and (radiation) therapy machines, surgical devices, and pharmaceuticals. Hence, technology does not only constitute the concept of disease by its subject matter and by medical knowledge, but also through medical practice. This practical formation of the disease concept will be investigated in the following sections.

The Technological Constitution of Medical Action

Conceptualizing disease is motivated by the purpose of medicine: to help the patient. The concept of disease is formed by the physician's capacity for action involving an obligation: Calling a set of phenomena a disease encompasses a medical commitment. And conversely, the need for medical intervention causes certain conditions to be perceived and classified as disease. The perspectives of the medical gaze and the concepts of medical language have an aim: medical action.

Diagnosis

The practical importance of technology is well illustrated in diagnostics, where ever more significance is attached to evidence provided by technology. The diagnostic methods give access to the signs and markers that define the disease entities. They provide the means to recognize the entities in clinical practice. The diagnostic methods of modern medicine are founded by technology, which ties the concept of disease even closer to technology.

In this way, technology comes to constitute an *operational definition* of disease where the concept of disease is defined with reference to a particular operational test. "Disease" is a term that applies to all those cases where a given technological test yields a specific outcome. *Diabetes mellitus* is defined as a fasting glucose concentration of the blood plasma above a given level. The practical identification of disease is given by the technological test.

Furthermore, it has been argued that the practical ability to detect phenomena in the human body has changed the meaning of these phenomena. Detectable phenomena, such as the electrical activity of the heart disclosed by ECG, gained importance by their correlation to various pathologies. The electrical activity was already known to a certain extent at the end of the nineteenth century but had no pathological significance before the development of the electrocardiograph.

Correspondingly, disease entities that earlier were detected using one technological method alter diagnosis with the emergence of new technology. *Myocardial ischemia* was earlier detected by angiography but was later diagnosed by ultrasound Doppler and tissue stress measurements, as well as blood troponin level. A change in diagnostic method has altered the conception of the disease.

It might be argued that there are a vast number of disease entities where there are no technological tests. Hence, technology cannot be constitutive of the definition and diagnosis of the disease entities. Even "new" disease entities, for example, whiplash and fibromyalgia, have (so far) no corresponding technological tests. These examples, as with other symptomatic diseases, do not, however, weaken the argument for the technological diagnosis of disease. On the contrary, these are controversial cases classified as syndromes much because they do not have a technological test. Nontechnological disease entities are low-status diseases precisely because they are not technologically testable and treatable (Album and Westin 2008).

Treatment

Practically, the fundamental role of technology in relation to the concept of disease is not limited to diagnosis. There is also a therapeutic constitution of disease. It has been claimed that a technological treatment of disease is the result of a technological conception of disease. A mechanically or technologically structured concept of disease requires a mechanically or technologically structured therapy.

However, the relationship between technology and treatment might also be conceived in a reverse mode: Technological treatability itself constitutes disease. It has been argued that it is not the concept of disease that decides whether something is treated or not; it is the treatability that makes something a disease. The success of technological medicine has made technology the criterion for the demarcation of treatment. The methods of technological medicine determine what is treatable and thereby set a precedent for what is to be treated. That is, medical technology has become the measure of what is to be treated and not, and hence, what is diseased and what is not.

Therapeutically, the technologies of corrective surgery, regulating blood pressure, and artificial fertilization have caused health care to treat these conditions as diseases: *hypoplastic left* *heart syndrome*, *hypertension*, and *infertility*. Decisions and prognosis have come to be based on technology. Furthermore, the possibilities of dialysis and transplantation of kidneys established *ESRD* as a disease entity.

However, treatability has not only changed the concept of disease by establishing new disease entities. It has also altered existing entities. For example, advanced surgical procedures tend to turn type 2 diabetes mellitus from being a metabolic disease to a surgical disease. The ability to detect and treat disease on an early stage has changed the symptoms that patients normally experience and the signs that the doctors relate to the disease. As pointed out earlier, with some diseases, the patient never experiences any symptoms at all. Hence, technological treatment alters the course of the disease (perceived by physicians) and the way patients experience it. In this manner, technology itself introduces new signs and symptoms that come to constitute the disease. Whereas patients with *nephritis* earlier experienced diminished urine, swollen legs, nausea, and headache, a patient with ESRD is subject to complications of dialysis treatment, such as dialysis-introduced cramps, clotting and infection of catheters and shunts, chronic anemia, renal bone disease, and aluminum toxicity.

Thus, technological treatment influences the concept of disease in a variety of ways. Whether technological treatment is a result of a technological conception of disease or technological treatability strongly influences the concept of disease, the conclusion is the same: Technological treatment is basic to the concept of disease. In the former case, the technological concept of disease is established by the pragmatic concern for diagnosis. One applies a technological concept of disease to be able to detect the phenomena of disease. In the latter, the concept of disease is founded by treatability. However, both diagnosis and treatment are established by technology.

The technological influence of diagnosis and treatment can also be recognized in the way medicine is organized. Disease taxonomy affects the centralization and specialization of medicine. This is displayed by the emergence of diagnostic departments, such as in radiology, nuclear medicine, and neurophysiology, and in centers for single technologies such as ultrasound and genetics. Correspondingly, there are therapeutic departments like chemotherapy, anesthesiology, and dialysis. Hence, there is a technological organization of diagnosis and treatment of disease.

Accordingly, disease is defined by the methodology of medicine, and that this is constituted by technology. Technology has become the *definiens* of disease. Due to this constitutive role in medical action, technology has become the paradigm method in medicine. This has influenced the status of disease, which will now be investigated.

The Technological Status of Disease Entities

In practice, technology has become the general method in medicine. Disease can now be measured using objective instruments, and technology has become the norm for detecting, identifying, and treating disease. The success of technology has extended the general belief in technological medicine, enhanced its status, and strengthened its paradigmatic position. Technology has become the criterion for the demarcation of what is "real medicine" and what are "true diseases."

In this way, technology has not only influenced the concept of disease but also the status of the disease entities. Acute high-tech diseases, for example, *myocardial infarction*, enjoy a higher status than chronic low-tech diseases in the same way that heart and brain surgery gain a higher position than geriatrics. *Malaria*, *tuberculosis*, and *cancer* are conceived as clear cases of disease, whereas color blindness, senility, and depression are vague cases. Thus, there is a technological influence on the status of the disease entities (Album and Westin 2008).

Sensitivity, Treatment Threshold, and the Technological Expansion of Disease

Technology has not only influenced the concept of disease by expanding medical knowledge, as discussed earlier. In practice, technology has also expanded the conditions qualifying for a disease entity. It has defined the normal values and increased the sensitivity to the paraclinical signs and markers. Hypertension and hypotension, hypercholesterolemia, polycythemia, and anemia are now recognizable and subject to quantitative assessment.

This methodological increase in sensitivity seems to be rich in its consequences. It expands the range of conditions qualifying as disease. More (and milder) cases are detected, which is conceived of as a success. One example is CT for pulmonary emboli which in areas has doubled the number of patients that got the diagnosis (but without any better treatment results). Dissection of craniovascular arteries has been diagnosed three to ten times more frequent after the introduction of MRI. Thus, technology increases the sensitivity and enables lower limits of disease. In this manner, the technological improvement of medical methods increases the prevalence of disease, that is, *technology generates disease*.

The increase in sensitivity combined with improvements in therapeutic capacity results in a lowered treatment threshold. This results in an apparent improvement in patient outcome and has made technological methods appear highly successful. This subsequently enhances the constitutive role of technology in defining, recognizing, and treating disease.

Concluding Remarks and Future Directions

All in all, it has been argued that technology is constitutive of concept of disease. Firstly, technology provides the physiological, biochemical, biomolecular, and morphological entities that are applied in defining diseases. Secondly, it constitutes the formation of medical knowledge. Technology constitutes the signs, markers, and end points that define disease entities, and it strongly influences the explanatory models of disease and medical taxonomy. Thirdly, technology establishes how we act toward disease: Thorough diagnosis and treatment technology establish the actions that constitute disease. Furthermore, the practical capability of technology increases the sensitivity and lowers the treatment threshold, resulting in an increased occurrence of disease.

Hence, medical technology has become the measure of all things, a kind of *ars mensura*. It has become the *technê metriké* of the modern age, the measure of what is good and bad, what is to be treated and not, and hence what is diseased and what is not. This can be entitled *the technological invention of disease*. What, then, are the consequences of such a "technological concept of disease"?

If the concept of disease is constituted by technology, this must be of relevance to the philosophy of medicine. The fundamental role of technology will be essential to the debate on the ontological and semantical status of the concept of disease. Furthermore, it will be of great importance to the debate on the value-ladenness of the concept of disease. The evaluative status of technology will be of relevance to whether disease is a value-laden concept. Hence, the status of technology is highly relevant to the debate on the concept of disease.

Moreover, the analysis illustrates the importance of paying attention to technology in the general discussion of medicine and health care. Technology has become crucial to understand modern health care, as it constitutes its basic concepts, its knowledge, and its actions. That makes technology essential to understand crucial challenges of modern health care such as medicalization, somatization, paternalism, and patient autonomy. For example, it has been argued that a mechanical conception of disease contributes to paternalistic medical practice due to the reduced role of the patient.

Furthermore, it is worth noting that the analysis does not presuppose a particular conception of technology. The argument that technology is constitutive to the concept of disease does not depend on a determinist view of medical technology, a phenomenological position, a social constructivist stance (Bennett 1977), or on the value-neutral dictum. Although perspectives from the science and technology studies are relevant, this analysis does not hinge on any particular perspective. The point here has been to argue that within any of these positions, technology is constitutive for the concept of disease: Technology has become the measure of disease. However, further research based on specific theories can clarify the technological invention of disease and should be encouraged.

Acknowledgment This entry is a revised version of Hofmann (2001). More references can be found here and in Hofmann (2002).

Cross-References

- ▶ Actor-Network-Theory and Creativity Research
- ▶ Analogies and Analogical Reasoning in Invention
- ▶ Directed Evolution® Technology
- ▶ Epistemic Governance and Epistemic Innovation Policy
- ▶ Invention Versus Discovery
- ▶ Levels of Invention
- ▶ Mode 1, Mode 2, and Innovation
- ▶ Mode 3
- ▶ Patterns of Technological Evolution
- ▶ Quadruple Helix
- ▶ Quintuple Innovation Helix and Global Warming: Challenges and Opportunities for Policy and Practice
- ▶ Technology Push and Market Pull Entrepreneurship
- ▶ Triple Helics

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Technologies

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Technology

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Technology Evolution

► Technology Life Cycles

Technology Impact on Innovation

► Semantic Technologies in Knowledge Management and Innovation

Technology Life Cycles

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Synonyms

Competitive dynamics; Nonlinear growth models; Technology evolution

The Dynamics of Technology-Based Growth

Most of innovation economics is cast in a static framework. Studies of cross-sectional relationships between inputs such as R&D and outputs such as invention, innovation, and productivity growth dominate this area of economic research. Even when assessments are undertaken of specific phases of the R&D cycle (basic research, applied research, and development), the linearity, feedback loops, and evolution of the associated markets that characterize the progression and utilization of technology are largely overlooked.

However, time is an extremely important dimension of economic growth and failure to manage it by both industry and government can lead to poor long-term performance for domestic industries. This perspective is particularly important in industries where technologies are a dominant driver of growth.

In essence, technologies evolve in cyclical patterns with shorter product-technology cycles embedded in longer cycles based on generic technology platforms. Successive platform technologies are themselves tied to one another by an underlying science base. A key economic characteristic of this "nested" set of cycles is the evolutionary pattern that alters the nature of technologies and hence investment incentives over each cycle.

The imperative to understand this process is the fact that economic growth is generated over an entire life cycle. Thus, the economic consequences of both corporate strategy and economic growth policy not taking cyclical patterns of technologies, markets, and hence investment patterns into account will be the loss of considerable domestic economic growth, either through inadequate rates of innovation in the early part of a cycle or through inadequate capital formation that results in offshoring of industries producing for domestic innovations in the middle and latter phases of these cycles (Tassey 2007, 2010).

The Nature and Structure of Technology Life Cycles

The shortest and most recognized life cycle is the *product* life cycle. Typically, a series of successive product cycles are derived from an underlying generic *technology platform*. Over much longer periods, a series of technology platforms emerge and fade, all which are based on a major advance in the underlying science. Collectively, the succession of these platform cycles form a "major cycle" (also called a "grand cycle" or "wave") that can cover decades (Tassey 2007, Chap. 7).

The Product Life Cycle. Business analysts have studied the product life cycle for decades.

They have found that as a product cycle evolves, attributes of the product technology become progressively standardized and the rate of change in specific attributes slows, indicating approaching exhaustion of potential new applications derived from the underlying technology platform. The result is an increasingly commoditized product.

A current example is the PC. With each product generation, the set of components and therefore product attributes become increasingly fixed and hence standardized. At these latter phases of the generic technology's life cycle, competition progressively shifts from major product innovation to reliance on incremental changes and process innovation. The greater emphasis on process efficiency means that competition is increasingly based on price (Abernathy and Utterback 1975).

The Technology Platform Cycle. Within a major technology's life cycle, significant innovations occur over time based on periodic advances in the underlying generic technology platform. For example, the limitations of standalone transistors wired together (speed, heat, weight) became obvious once experience with a series of product cycles was in hand. The need to improve these three attributes led to the invention of a new generic circuit technology – the integrated circuit (IC). Subsequently, a massive explosion of product cycles based on the IC ensued, as this new semiconductor platform technology evolved into multiple market applications. Parallel platforms also emerged, such as "quantum electronic devices" (semiconductor lasers and light emitting diodes) and "charged couple devices" (used in digital cameras).

In addition to the complexity resulting from products based on multiple platforms, one technology platform cycle does not necessarily end when a new one is created that appears to replace it. In the case of semiconductors, the technology platform underlying the transistor continued to advance, responding to technological opportunity and also to the fact that both the IC and the transistor remain complementary components of higher-level electronic technologies. The important point is that final-demand products and services are increasingly met by complex technology systems and, therefore, the performance of all system components must advance more or less simultaneously.

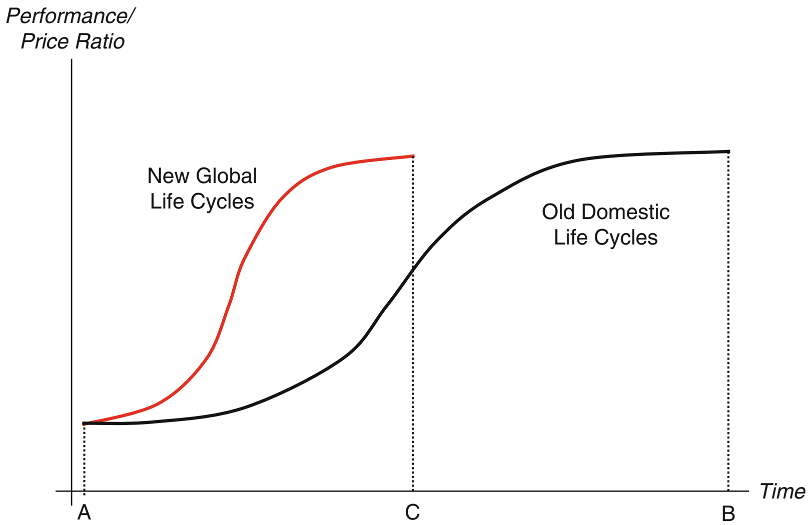
Several additional points are implied from these examples. First, once the generic technology is largely available, industry can more efficiently innovate at the product level. Second, the generic platform technologies for each component of a technology system must be available to allow parallel innovation to occur and thereby advance the system technology. This is the ultimate objective because it is the system that satisfies final demand. A current dramatic example is "advanced manufacturing" in which multiple product and process technologies are evolving simultaneously. This presents a much more complex policy management problem.

The length of a technology platform cycle and the competitive position of the domestic industry over such cycles are particularly critical in the case of "general-purpose" technologies like semiconductors because they spawn a host of innovative industries, such as computers and communications equipment, with huge aggregate economic impact. Thus, significant opportunities present themselves to economies that support broad-based growth strategies that enable economies of scope to be captured from each technology platform within a major cycle. However, if high long-term growth rates are to be maintained, the factors shaping the S-shaped growth curves, which characterize platform technology life cycles, must be understood and the barriers to efficient progression managed.

Initially, such a framework may sound abstract, but technology-based economies are increasingly focusing growth policies on accelerating the early phases of these cycles in order to attain first-mover advantage from breakthroughs in science. The effect of this competition among multiple technology-based economies is to (1) make the bottom of the S-shaped growth curve steeper, that is, to shorten the early phases of a cycle and thereby accelerate innovation within the domestic economy, and (2) compress the length of the life cycle in time. Both of these effects are illustrated in Fig. 1.

The phases of the technology life cycle have been given different labels by various

Technology Life Cycles, Fig. 1 Compression of technology life cycles



researchers. However, most important is the economic explanation for the "S" shape of the life-cycle curve. The initial segment is flat because a new technology typically evolves unevenly with respect to the set of technical attributes that its products and processes embody. Such gaps retard growth of the overall performance-price (*P-P*) ratio and thereby slow the attainment of a *P-P* ratio that exceeds the maximum attained by the existing technology. The result is slower market penetration.

As Joseph Schumpeter (1950) observed over half a century ago, radically new technologies can remain dormant for long periods of time (i.e., the initial flat portion of the *P-P* curve is stretched out in time). Nevertheless, a take-off point is eventually reached (the initial segment of the steeper middle portion of the *P-P* curve). This take-off point occurs when the new technology attains a *P-P* ratio sufficiently superior to the maximum for the existing technology to enable rapid market penetration or, as emphasized by Schumpeter, when an economic crisis occurs that radically changes relative prices.

With time and consequent improvements in both products and processes, the new technology becomes dominant, and large economic benefits in terms of profits and employment are realized. Eventually, however, the ability to improve the *P-P* ratio begins to decline. The result is a flattening of the top portion of the *P-P* curve. At this point, the technology is set up for replacement.

The Major Cycle. Technology platforms evolve over time based on an underlying science base. Solid-state physics progressed for decades before this science eventually reached the breadth and depth sufficient to allow semiconductor technologies to begin to be developed. Such decade-long major cycles or "waves" also appear to display a general long-term "S" shape with respect to economic impact. In the case of semiconductor technology, the underlying science of solid-state physics eventually matured to a level that allowed devices to be designed and manufactured that outperformed the existing electronic science, specifically vacuum tubes.

Joseph Schumpeter, known for his conceptualization of the "process of creative destruction" and therefore as the "father of innovation economics," had previously developed a theory of business cycles (1939) in which he was the first to observe that shorter cycles are nested within longer ones. He also characterized a "long wave" as having four stages: prosperity, recession, depression, and revival. The process of creative destruction begins slowly in stages two and three with invention but does not manifest itself in the form of significant marketplace penetration (innovation) until stage four.

At the global macroeconomic level, the post-World-War-II prosperity was built first on advances in manufacturing and then on information technologies. However, the emergence of Asian economies and, to a lesser extent, other emerging economies has changed relative prices and led to a global economic crisis resulting from efforts by industrialized economies to maintain their standard of living through debt. The current industrialized world (Europe, North America, and Japan) is somewhere between Schumpeter's stages two and three. One can see the seeds of the eventual stage-four revival in the rapidly increasing investment in global R&D. This investment will produce a wide range of new productivity-enhancing technologies that will drive advanced manufacturing and high-tech services. The resulting paradigm shift will redress the current imbalance between debt-driven economic growth and growth based on real (technology) assets.

Loss of Domestic Value Added over the Technology Life Cycle

Figure 1 implies that the highly competitive nature of the expanding technology-based global economy is reducing the risk-adjusted expected domestic value added from indigenous innovation and thereby affecting corporate investment decisions. Emerging economies covet the high-value added products and services arising from major technological advances in industrialized nations. They consequently initiate evolutionary growth strategies whereby their increasing technical skills and production capacity combined with lower labor costs allow attainment of global market shares in the middle and latter phases of an existing technology's life cycle.

This process of "convergence" in current technology life cycles with subsequent loss of market shares by the "first-mover" (innovating) economy begins when offshoring by the innovator's domestic industry is undertaken. At first, this strategy increases aggregate value added for the innovating industry, as larger global markets are penetrated. The offshoring takes the form of relocating the production of low and moderate technology-based products to be near new markets and to achieve labor cost savings. In the case of components, the cost savings allow reimportation by the original innovator or another firm in the domestic supply chain, which lowers domestic costs and thereby helps raise the productivity of the remaining domestic production.

Initially, such strategies yield larger profits for the remaining domestic production and help explain why US-based high-tech corporations had on average good balance sheets entering the recent Great Recession. Of course, these larger profits are derived from a smaller level of industrial activity within the relevant domestic supply chain (due to offshoring), and hence, the value added (the supply chain's aggregate contribution to GDP) may not grow and, in fact, may shrink.

To a significant degree, offshoring manufacturing from one or more tiers (industries) in a high-tech supply chain should be considered a strategic failure from a national economic growth strategy perspective. The reasons are (1) loss of domestic value added and (2) loss of co-location synergies in the domestic supply chain, which reduces the overall efficiency of the remaining industries. The more R&D intensive the supply chain, the greater the co-location synergies (Tassey 2010).

As technology life cycles mature, opportunities increase for converging economies to pick off portions of the value added in a supply chain. In the modern-day version of Schumpeter's creative destruction, Christensen (1997) argues that firms reaching market leadership positions through innovation increasingly focus on maintaining that lead through incremental innovation targeted at preferred customer segments of the overall existing markets. At some point, new entrants appear who may first focus on imitation aimed at serving neglected market segments. Eventually, however, some of these challengers or even yet additional entrants acquire sufficient technology development and deployment capabilities to take over larger or even dominant shares of existing markets.

As previously described for semiconductors, the cycle transition begins in the form of a hollowing out of incumbents' positions within the current technology life cycle. Christensen et al. (2004) characterize this process in terms of a "decoupling point." Typically, integrated manufacturers dominate the supply chain for a period of time until the interfaces between components are firmly established. These standardized interfaces allow innovative specialists in individual components to enter the industry. The tier in a supply chain at which the vertical disintegration occurs is the decoupling point. This point tends to move backward over time from the final product toward subsystems and then to component tiers.

In the current final phase of globalization of the technology-based economy, many nations are evolving beyond imitators to become innovators, thereby shortening windows of opportunity for achieving innovation and associated monopoly profits, as indicated in Fig. 1. This increased risk from greater competition and shorter investment time frames lowers expected rates of return on investment (RoI) in the next technology life cycle. A shorter technology life cycle means domestic firms, and their governments must anticipate the timing and nature of forthcoming life cycles and implement more efficient R&D strategies, as well as more efficiently promote follow-on scale-up and market penetration efforts. In summary, these trends have made the act of innovation more costly and risky for industry acting alone.

With respect to market penetration, when a new technology is initially commercialized, simultaneous scale-up of production capacity and product differentiation for multiple markets become critical issues. The importance of scale-up derives from the fact that the vast majority of the economic benefits from new technologies results from the growth of their markets after they have been first introduced (i.e., post-innovation). Early and substantial investment in process technologies and the actual scaling up of optimized production capacity are essential to attaining large market shares over the middle and latter phases of a technology's life cycle.

Finally, the global expansion of R&D and the use of the resulting technologies are stimulating highly differentiated demand and supply within product categories. The resulting pressure to at least semi-customize applications of high-tech product technology platforms is a fundamental change from the industrial revolution, where conditions for success were dominated by the imperative to achieve economies of *scale*. That is, markets in the past were driven by the need to produce large quantities of homogeneous products at low cost. This central tenet of economic growth required companies to become large enough to maintain capital structures sufficient to attain the desired economies of scale.

However, today scaling in the middle of the technology life cycle is becoming much more complex. Manufacturing processes increasingly must be flexible in order to achieve the economies of *scope* required to serve a heterogeneous set of sub-markets with the same generic production system. Doing so requires flexibility while maintaining low unit cost, which can only be achieved through new processing techniques, massive use of information technology, and a highly skilled and heterogeneous labor force. The forthcoming "smart revolution" will attain this "mass customization" objective, at least in the countries that make the required investments.

Thus, while scale-up – the process of achieving a minimum efficient scale of production – is still essential, the key attribute of competitive success over an entire life cycle will be the ability to achieve this minimum scale at low output rates and do so for a range of differentiated products. This is a massive systems problem and will require increased funding of process R&D, manufacturing engineering education, and technical infrastructure that supports integrating process technology components into highly flexible manufacturing systems. Productivity at the systems level therefore will be a determining factor in future competitive success.

Global Convergence over Technology Life Cycles

Longer term, it is this evolutionary process by which domestic supply chains of the innovating economy are hollowed out and are not replaced with new technologies that explains why aggressive emerging economies tend to "converge" with (grow faster than) established ones. This process of convergence, which usually takes place over several life cycles, has been well documented over the last several centuries encompassing two industrial revolutions, as technology became an increasingly significant factor in international competition. In the last four decades of the twentieth century, convergence accelerated significantly with a number of emerging economies doubling national income in 10–20 years compared with the 30–70 years required to double in the nineteenth century (Lucas 2009).

However, convergence in one technology life cycle no longer guarantees further progress in terms of global market shares in succeeding cycles. For example, since the invention of the transistor, most major semiconductor innovations have been made by US-based companies. However, competitive pressures have led US companies to establish an increasing share of advanced wafer fabrication facilities ("fabs") outside the United States or to rely on foreign "foundries," (specialized manufacturing companies) rather than invest in the domestic US economy. A number have become "fabless" or "fab lite" firms, focusing largely on design while contracting all or most product manufacturing to foundries. While the fabless strategy is extolled by corporate consultants, it has evolved out of necessity as many semiconductor firms failed to achieve large enough market shares to capture scale economies at the production stage in the early and middle phases of the technology life cycle.

Fabless semiconductor companies have been temporarily successful in the current mature phases of the CMOS technology life cycle by adopting highly accurate simulation techniques that drastically reduce the number of expensive and time-consuming iterations of the product design necessary to enable its manufacture. In the converging economies, dedicated foundries often do not even operate development-scale fabs, instead relying on real-time adjustments. Both of these single-phase strategies can work within the middle and latter phases of a particular technology's life cycle.

However, when disruptive technological change occurs (i.e., when a major new technology platform emerges), *both* strategies described above (contract manufacturing and design only) will hit a brick wall. The fabless firms will not be able to execute design for new manufacturing requirements without close interaction with manufacturing scale-up activity, and foundries will not be able to adapt to radically new product technologies without close interactions with the ongoing product R&D.

In contrast, the process of convergence among national economies in the modern global economy starts with a multinational company establishing an R&D capability in the host country to manage the offshored manufacturing. This capability serves as the genesis of a nascent innovation infrastructure. Supported by government investment in broader research capabilities for the emerging supply chain, domestic companies evolve "first-mover" capabilities for emerging technologies that drive future technology life cycles.

For example, Taiwan is achieving backward integration from test and assembly to wafer fabrication and more recently to design (the integrated device manufacturing model). Both Taiwanese industry and government now participate in global R&D networks to develop and assimilate new design and manufacturing skills. Taiwan's Technology Research Institute (ITRI) has collaborations with companies, universities, and governments all over the world. This is clearly a leading-edge technology strategy. While further behind in the convergence process, the Chinese are following the same backward integration path with the implication that their capacity to innovate will increase over time. Patent trends in nanoelectronics clearly show the threat of convergence in the next life cycle to be real. Economies that invest in more holistic technology-based growth strategies will find that the co-location synergies expand as supply-chain integration proceeds.

Thus, viewing the hollowing out of a domestic supply chain over a technology's life cycle as simply a matter of specialization according to the law of comparative advantage is turning out to be naïve in that not only is value added lost but co-location synergies often convey growing and permanent competitive advantage to those economies that adopt an integrated technology development and utilization model.

Loss of R&D and Manufacturing Advantage in the Next Life Cycle

As described above, major technology life cycles are of paramount importance to long-term economic growth because they enable a series of nested cycles that encompass a spectrum of related technology trajectories and hence markets. The cumulative economic impact is substantial. Unfortunately, the transitions between major cycles are usually traumatic. Schumpeter (1950) explained the cyclical pattern of technological change in terms of investments in capital stock and market relationships that lead to rigidity and decreasing returns on investment, setting the stage for a radically new technology to emerge and take over markets from the defender technology.

In the long run, the threat to the domestic industry that is the innovator in the current life cycle is the growing ability around the world to backward integrate to the underlying science itself. This acquisition of scientific capability gives a country's domestic industry a local supporting infrastructure that helps start the new life cycle. The global emergence of substantive research in nanoscience and nanotechnology is an excellent example.

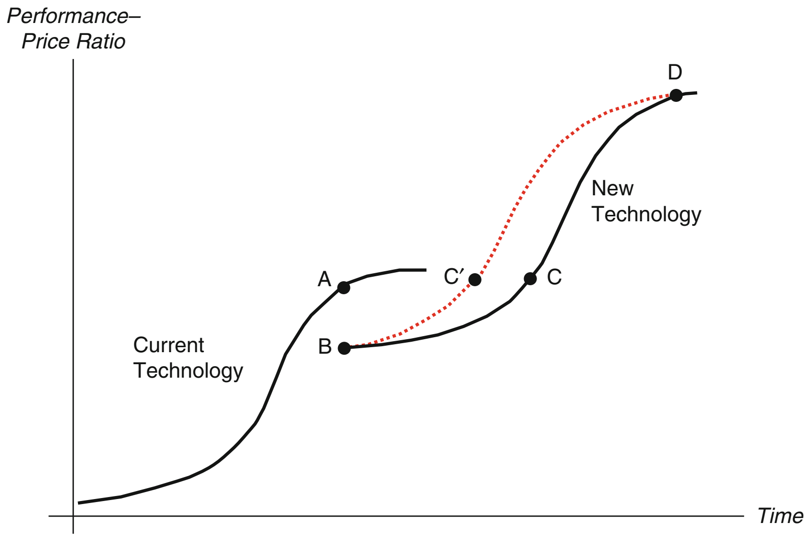
The problem of cycle transition is accentuated the more the technologies underlying successive cycles are different. Technologies based on different science require different technology development and production approaches. Both the R&D and production infrastructures within the industry will need to change. In fact, the entire supply chain in which the industry is embedded will likely be different as will the supporting technical infrastructure.

Successive technology life cycles where the underlying technology platforms are dramatically different raise the question of whether it makes sense to refer to the two cycles as "successive" as opposed to simply different technologies. The correct conceptual framework is to start with the marketplace function (e.g., communications) and then examine the succession of major technologies that provide this function. Successive technology platforms can be radically different, as in the case of traditional pharmaceuticals (small molecule chemistry) and biotechnology-based drugs (cell-based biology involving mainly large molecules).

That is, some modern emerging technologies are so broad in their disciplinary base and in their potential market applications that they do not "follow" in a clear way from previous technology life cycles. For example, emerging MEMS ("micro-electromechanical systems") technology encompasses a much larger set of physical domains – electrical, mechanical, thermal, optical, fluidic, and more – than existing complex technologies such as semiconductor electronics. MEMS technology has already produced new higher-performance products such as accelerometers for automobile airbags, tiny nozzles for ink jet printers, and projectors for high-end video displays, and continued commercialization of MEMS technology has been characterized by some analysts as the prelude to a second semiconductor revolution that will drive growth in the global economy for decades to come. However, the complexity factor has resulted in MEMS fabrication processes not yet achieving adequate characterization with respect to these multiple physical domains. If not addressed through efficient co-located research entities, the initial flat portion of the S-shaped *P-P* curve will be stretched out in time.

Even if the domestic economy manages to maintain competitive advantage in the initial transition to a new technology paradigm, the impacts on industry structure and the supporting technical and institutional infrastructures are dramatic and provide subsequent opportunities for convergence in other economies. For example,

Technology Life Cycles, Fig. 2 Life-cycle market failure: generic technology



the traditional pharmaceutical industry has sunk an enormous amount of resources into a small-molecule chemistry from which drugs are "discovered" through a largely trial-and-error approach. Even sophisticated research techniques such high-throughput screening only modestly upgrade a very inefficient R&D process. The declining relative efficiency of this industry is evident in the increasing reliance on marketing (the industry spends more on advertising than on R&D).

In contrast, the emerging biopharmaceutical industry is based mainly on the development of large-molecule drugs derived from a more fundamental underlying science (cell biology). The latter requires much closer and intricate involvement with the scientific infrastructure and a very different set of technical infrastructures. However, a "black-box" model of innovation has been followed by the US National Institutes of Health (NIH), with the result that the productivity of biopharmaceutical R&D investment has been low. Recognition of this problem is finally turning the biopharmaceutical industry toward a multielement technology-based growth model. In the last few years, research has increasingly emphasized proof of concept and improved infratechnologies, such as biomarkers. At the same time, this slowness to adapt is providing an opportunity for other economies to catch up (i.e., converge) by using more efficient innovation ecosystems (Tassey 2010).

A major institutional policy response in an increasing number of economies is the technology cluster concept, which is emerging as an important strategy for not just efficiently conducting breakthrough research but also for increasing the efficiency of subsequent commercialization. For example, the Nanoscale Science and Engineering cluster at Albany State University promotes co-location synergies between researchers and innovating firms within the cluster to facilitate the increasingly difficult initial phases of fabrication. The resulting reduction in time and cost enhances efficient transition to high-volume industrial manufacturing. The bottom line is that achieving co-location synergies means the value added from both R&D and manufacturing will accrue to the innovating economy – at least when the technology is in the formative phases of its life cycle.

Conceptually, the barriers to such cycle transitions are indicated in Fig. 2. As the current technology (left curve) matures, all product attributes and hence performance are maximized, and costs are reduced through optimization of production processes. Eventually, the industry approaches a maximum performance-price ratio for market applications due to the inherent limitations of the underlying generic technology platform (say, point A), which explains the flattening of the top portion of the S-shaped P-P curve.

Such a "cash-cow" status and the investments made to achieve it act as barriers to private-sector investment in emerging technologies that have greater potential but initially have significant P-P deficiencies (right curve). Companies do some long-term research in anticipation of eventually having to shift to a new generic technology platform. However, life-cycle compression due to increasingly intense global competition reduces risk-adjusted expected RoI and thereby leads to substantial underinvestment in the next technology platform.

In the absence of effective government support, this situation leaves the emerging technology with a set of attributes that are only partially developed. Production processes are often initially adapted from other existing technologies and are therefore not optimized for the new technology. The result is a P-P ratio such as point B. Because B is less than A, the new technology makes little progress penetrating the current technology's markets.

This fundamental problem of life-cycle transition can be addressed by government policies that overcome cycle transition barriers and thereby shift the new technology's P-P curve backward in time (to the dotted line), thereby providing new technology platforms that enable commercial applications to occur earlier. For example, the P-P ratio originally not projected to be achieved until point C is now attained earlier in time at point C'. Note that these two points are on the same horizontal line as point A on the P-P curve for the existing technology. As point A is close to the maximum performance-price ratio for the existing technology, getting the new technology to this point initiates the "take-off" for the new technology's market penetration phase. This is reflected by a steepening of the S-shaped performance-price curve for the new technology beyond C'. That is, once the maximum economic potential of the existing technology is exceeded, the new technology rapidly penetrates the target market, and the Schumpeterian process of creative destruction is unleashed.

The Linear Model of Innovation and the Technology Life Cycle

Within a life cycle, the requirement to have a sufficiently developed technology platform in place in order to achieve efficiency in applied R&D implies a linear model of innovation. However, the R&D literature makes clear that feedback loops occur and "cross-links" develop between technology trajectories to fuse complementary technologies within technology systems. Feedback loops are regular occurrences in which marketplace experiences become inputs for the redirection of R&D. In fact, some attempts at innovation may be necessary simply to provide feedback on the adequacy of the current development of the platform technology. The cross-linking necessary to effectively develop system technologies creates demand for advances in complementary technologies. For these reasons, criticisms of linear models of innovation (basic science, generic platform technology, innovations in that order) are justified.

Nevertheless, a "linearity" is present across a technology life cycle with respect to the technology's development and commercialization. Modern technologies are extremely complex systems that largely prohibit the "eureka" moments that appear in Pasteur's quadrant. For example, it is hard to imagine apoptosis, antisense, RNA interference, monoclonal antibodies, or other biotechnology platforms being developed through product experimentation or feedback effects rather than being derived from previous advances in bioscience. In fact, the greatest difference between traditional pharmaceutical research and biotechnology research is that the former was largely trial-and-error chemistry, whereas the latter is based on fundamental science and a set of generic platform technologies that are evolving from this science. Faith-based pharmaceutical research may support the existence of a nonlinear model of innovation, but it is far less efficient than the more linear evolutionary pattern of biotechnology research.

Another issue associated with the linearity implied by the technology life cycle concept is the fact that underinvestment in radically new technologies is explained to a significant extent by excessive time discounting. Life-cycle transitions typically encounter multiple performance problems that are only addressed over time. Moreover, small initial markets for the emerging technology do not induce significant process technology investment. The consequent suboptimal production processes result in relatively high unit cost. The combined result is a lower initial performance-price ratio (point *B* in Fig. 2) than is the case for the current mature technology. These factors stretch out the life cycle and thereby discourage investment by industry in the applied R&D that leads to innovations.

Offshoring also can stretch out the life cycle by blocking compensating innovation in the domestic economy. Optoelectronics – an increasingly important industry because of the forthcoming migration of computers to photonics-based technologies – is in the process of transitioning from a discrete to an integrated technology format (a technology life-cycle transition). Monolithic integration has performance and cost advantages and could potentially be a growth industry for the United States.

However, at this early phase of its life cycle, the mature *discrete* technology can be produced more cheaply in Asia. This prolongs the typical situation in which the new technology has a lower *P-P* ratio in the early phase of its life cycle, thereby slowing market penetration. Failure by US firms to accelerate the evolution of *monolithic* technology and to scale-up for initial markets in spite of the stretch out in cost disadvantage may allow competing companies in other economies to eventually commercialize the new technology and gain first-mover advantages (Fuchs et al. 2011).

From an R&D investment perspective, the prospect of such an initial *P-P* deficit leads the private sector to assign substantial technical and market risk to the possibility of investing in the development of the new technology. This "risk spike" (also referred to as the "valley of death") produces a discontinuity (i.e., nonlinearity) in the R&D cycle, resulting in underinvestment by the private sector in early-phase generic technology platform research. The collection of barriers facing private firms at this early point in the R&D cycle creates the need for government support, not just for basic science but for early-phase, proof-of-concept technology research and the development of a range of supporting infratechnologies (Tassey 2007, 2008).

Conclusion and Future Directions

The fundamental meaning of technology life cycles is that the dynamic element of technology-based competition is relentless. The conventional wisdom is that advanced economies must automate to compete with cheap labor-intensive manufacturing modes in converging economies like China. Yet, in recent years the claim of "re-shoring" due to rising labor costs in China and other Asian countries has led established economies to think that the manufacturing challenge is subsiding, if not over.

In fact, the dynamic element of technology-based competition remains in place. For example, although Chinese and other Asian suppliers of electronic components have begun to experience profit margin compression due to rising labor costs, this trend will provide short respite at best for competing industrialized nations, as Asian companies are responding by automating at a fast rate. Most industrialized nations now have innovation-system programs to reduce the risk spike and thereby shorten the R&D cycle. These efforts include not only R&D subsidies but, more recently, promotion of more efficient R&D mechanisms, especially various forms of research collaboration. The most advanced form of collaboration, research consortia embedded in regional clusters, can not only enhance research efficiency in general but also significantly increase co-location synergies between adjacent tiers in high-tech supply chains.

For today's science-based technologies, innovating and then acquiring market share in the early phases of major life cycles require large numbers of scientists and engineers both in industry and supporting university and government institutions to advance and broaden the applications of the original innovation. For example, cell-based drug development has evolved as a research and manufacturing technique over the past 25 years only through the efforts of thousands of biologists, geneticists, and chemical engineers who perfected the fermentation systems that increased the capacity to produce recombinant proteins at least tenfold just in the past decade and 30-fold since the inception of biotechnology (DePalma 2005). The efficiency with which this process is unfolding is not just a matter of private-sector R&D investment but depends greatly on the efficacy of the entire innovation infrastructure.

More broadly, effective management of the entire technology life cycle requires a comprehensive national innovation system based on the triple or, more recently, the quadruple helix model (Carayannis and Campbell 2012). Such cross-linked and multi-institutional models are more realistic and hence more accurate than the simplistic "linear model" of innovation that ignores not only the range of institutional actors but the growing complexity of both the sources of innovation and the processes of deployment of the resulting technologies.

In summary, no matter what the final outcome with respect to the distribution of value added across national economies in one technology life cycle, global markets will increasingly experience shifts in leadership in the following life cycle. This greater competition is due to the fact that a larger number of economies are acquiring the requisite innovation infrastructure to become competitive in technology-based markets.

Cross-References

- ▶ Business Cycles
- ▶ Business Model
- ▶ Business Start-Up: From Emergence to Development
- ▶ Entrepreneurship and Business Growth
- ▶ Nonlinear Innovations
- ▶ Risk, Uncertainty, and Business Creation
- ▶ Techno-Globalization and Innovation
- ▶ Triple Helics

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Technology Push and Market Pull Entrepreneurship

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Synonyms

Collaborative process; Competitiveness; Eco-innovation; Innovation ecosystem; Open innovation

Technology push and market pull entrepreneurs' approaches are defined and analyzed in this entry. Some commonalities generally observed are reminded, and challenges to be achieved while developing technology for or with entrepreneurs (or entrepreneurial teams) are pointed. Particular entrepreneur/team competencies to be surveyed through various stages of the technology-based innovation process are highlighted. These various stages are related to the "technology readiness level" scale (Mankins 1995). To accelerate and better consolidate technology transfer agreements between R&D capabilities and entrepreneurs (but not only), a newly proposed scale "demand readiness level" (Paun 2011) is analyzed. This new scaling tool will be used as a measure of the entrepreneur's understanding degree of its targeted market-expressed need.

Notions of Market Pull and Technology Push Entrepreneurship Definitions

The purpose of this entry is to report the perception of the entrepreneurship from other innovation process actors' perspective and provide efficient guidelines to manage this type of relationship.

Since the first definition of the innovation process by Schumpeter, the role of the entrepreneur as a driving force of this process was pointed out. In course of time, other aspects like R&D push (Abernathy and Utterback 1975), customer as innovator (von Hippel 1988), or various systemic approaches (Tucker et al.) of the innovation management were developed. This entry simply reminds some fundamentals that the innovation process actors have in mind while speaking about entrepreneurship.

Entrepreneurship is largely associated with entrepreneur like an individual (original theory in Schumpeter 1934). But entrepreneurship could be understood as a generalization of the entrepreneur spirit, actions, and behaviors. Entrepreneurship is a state of actions oriented to create value by a successful exploitation of a new idea. An individual could be entrepreneurial as an enterprise could be or a regulation authority or even a market could behave like an entrepreneur if particular conditions are occurring.

When a given actor could behave like an entrepreneur? It is generally observed by two main reasons starting with the emergence of a new idea. Based on this new idea, an individual or a group will believe in a strong opportunity for a successful exploitation, and all their actions will be oriented in promoting and developing this expected exploitation regardless of their structural economic environment (they could be simply individuals or employees of a large or a small enterprise or state agents and all this in a spin-off or a spin-in approach. . .).

If this new idea is related to a new emerging technology, in this case, the innovation process could be defined as a technology push entrepreneurship. If this new idea is related to a market's newly identified need (demand), asking of being met by a new product or service offer, this type of innovation process, where the demand will ask for technology, could be defined as a market pull entrepreneurship.

Commonalities: Technology Development Chain and Staging on the TRL Scale

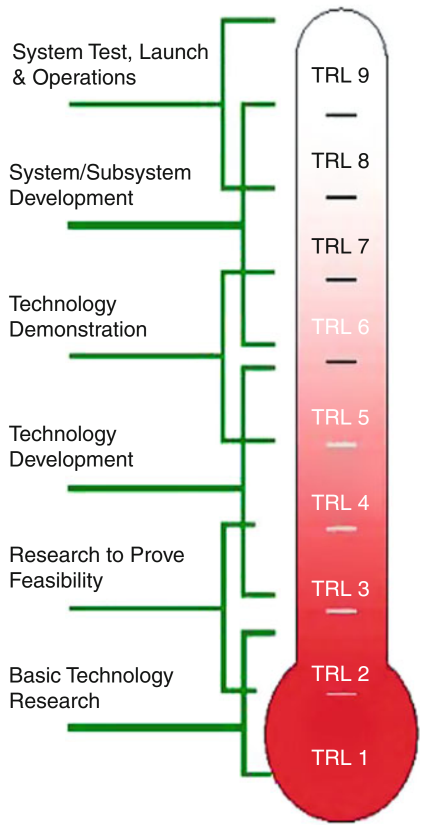
Let us take into consideration the commonalities occurring inside these two types of process specific to the technology-based innovation. Both approaches will integrate a technology development chain which will end with the introduction into a targeted market of a new product or service. The challenges related to the promotion, commercialization, and distribution of this new product or service are not the object of this entry. Let us focus on the challenges faced by the entrepreneurial team at various stages of the technology development chain.

The generally common tool adopted as referential perspective by the various technology-based innovation practitioner communities is the "technology readiness level – TRL" scale (Mankins 1995). Technology readiness level (Fig. 1) is a scale from 1 to 9 to assess the maturity of evolving technologies toward their successful certification and sales authorization for a given market. Only some of the important and major stages related to this scale will be pointed out.

Thus, TRL 1 represents fundamental (basic) research. TRL 2 represents the applied research. TRL 3–4 are relevant to the laboratory demonstration (feasibility and proof of concept), TRL 6–7 are relevant to the operational conditions demonstration and the industrial prototype, and finally the last stage, TRL 9, means the market certification and sales authorization.

Technology transfer offices, business incubators, R&D, strategy and supply chain industry executives, research and innovation agencies but also business angels or venture capital partners are looking and asking about the TRL while negotiating various agreements regardless of the technology push or market pull entrepreneurship.

All the decisions for various advancing actions will be referred to the current technology development or availability on the TRL scale. The entrepreneurial process will consist in permanently identifying, obtaining, and managing the needed and necessary capabilities (in terms of competencies plus means) able to assure the progress on the TRL scale. At each level, the actors are changing and their characteristics too. Up to the level of TRL3–4, the work will be carried by scientists, between TRL 3–4 and TRL 6–7 by industrial R&D offices competencies types, and beyond by industrial process designers. The decisions will be made on



Technology Push and Market Pull Entrepreneurship, Fig. 1 Technology readiness level original definition (Mankins 1995)

thinking patterns adopted by R&D directors, then by design offices, marketing directors, and production and supply chain managers. The investments will be driven from business angel to venture capital thinking patterns while progressing on the TRL scale.

All these actors are different, and the entrepreneurial team will need to understand, negotiate, and work with all of them using and being adapted to their specificities.

Hybridizing Market Pull with Technology Push

Using the TRL scale will provide an efficient tool in measuring the abilities of an entrepreneurial team to face and collaborate with all these actors.

Technology Push and Market Pull Entrepreneurship, Table 1 Demand readiness level original definition (Paun 2011)

Level	Description for the *demand readiness level*
1	Occurrence of a feeling "something is missing"
2	Identification of a specific need
3	Identification of the expected functionalities for the new product/service
4	Quantification of the expected functionalities
5	Identification of the systemic capabilities (including the project leadership)
6	Translation of the expected functionalities into needed capabilities to build the response
7	Definition of the necessary and sufficient competencies and resources
8	Identification of the experts possessing the competencies
9	Building the adapted answer to the expressed need on the market

But, using only this reference, all the thinking patterns will be technology push oriented. Why continue to refuse the evidence? Even the customer voice is sunk inside the TRL scale, and all minds are thus technology push driven.

How can the entrepreneurial team ability be measured to understand and identify a targeted market? Do market studies cross with technology acceptance studies? These type of tools completed by other various that the marketing profession has developed are not coming deep enough in the technology comprehension in order to be able to also measure and drive the technology development chain like the TRL scale is doing.

Pure market pull and pure technology push entrepreneurship is not existing. There is all the time a matching point between the two approaches. How to get this matching point? The successful exploitation of a new idea is always a result of a well-hybridized approach between the two of them (Paun 2012).

The "demand readiness level – DRL" scale (Paun 2011) completes the technology readiness level scale as matching tool for the hybridization between technology push and market pull entrepreneurship.

This new scale, the demand readiness level scale (Table 1), is able to measure the entrepreneurial team ability to understand and translate into needed capabilities the expressed need on a targeted market.

The "demand readiness level" (Paun 2011) is the new measure to assess the maturity of evolving demands identified by potential innovation actors toward an appropriate stage of conceptualization of the need in the market, allowing a matching point with scientific research teams capable to either propose as solution an existing scientific result through technology transfer process or translate the demand in new R&D projects. It actually means that it is the right timing to define an additional scale and plot it in a reverse manner related to the classic TRL scale in order to have the appropriate comprehension of the market pull process. Following schematic (Table 2) is reminded (Paun 2011) for a better comprehension.

For example, if an industrial partner has a DRL on 8, he will be able to identify and speak with the appropriate scientists to launch a collaborative R&D program for developing a new product or service. Same type of matching between different levels could be observed at each level of the previous table.

Looking in two reference systems, one for the technology push approach and the other one for the market pull approach, the given particular timing when a technology transfer agreement is ready for signature becomes predictable.

This is now better understood why "each case is a specific one" for various practitioners while facing entrepreneurs.

Innovation Process (Technological) Readiness Diagram: IRD Diagram

The following diagram (Fig. 2) combines the TRL scale with the DRL scale (Paun 2012). This diagram is showcasing the possible activities or transactions occurring at the different DRL and TRL levels.

As an example, if a company is advancing very high on the DRL at seventh to ninth level, its executives will be able to identify the existing

Technology Push and Market Pull Entrepreneurship, Table 2 Example of matching points between DRL and TRL levels allowing technology transfer agreements

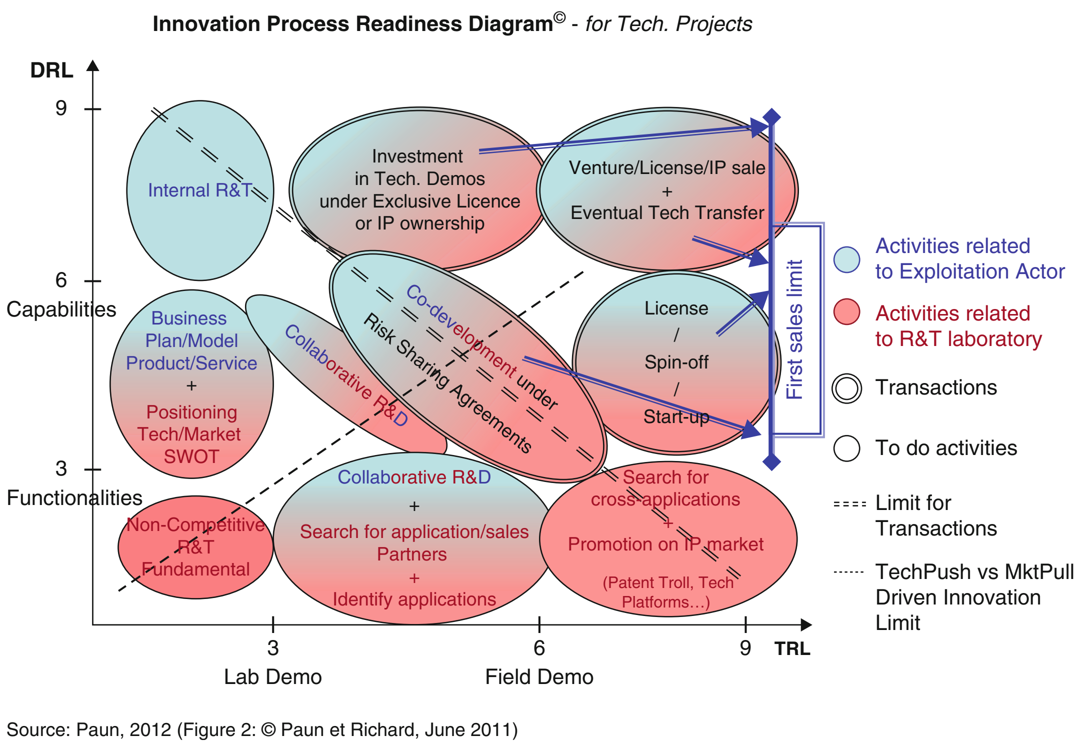
Level	Description for the *demand readiness level*	Description TRL level	Level
1	Occurrence of a feeling "something is missing"		
2	Identification of a specific need	Market certification and sales authorization	9
3	Identification of the expected functionalities for the new product/service	Product industrialization	8
4	Quantification of the expected functionalities	Industrial prototype	7
5	Identification of the systemic capabilities (including the project leadership)	Field demonstration for the whole system	6
6	Translation of the expected functionalities into needed capabilities to build the response	Technology development	5
7	Definition of the necessary and sufficient competencies and resources	Laboratory demonstration	4
8	Identification of the experts possessing the competencies	Research to prove feasibility	3
9	Building the adapted answer to the expressed need on the market	Applied research	2
		Fundamental research	1

experts possessing the right competencies for developing the innovative proposed product:

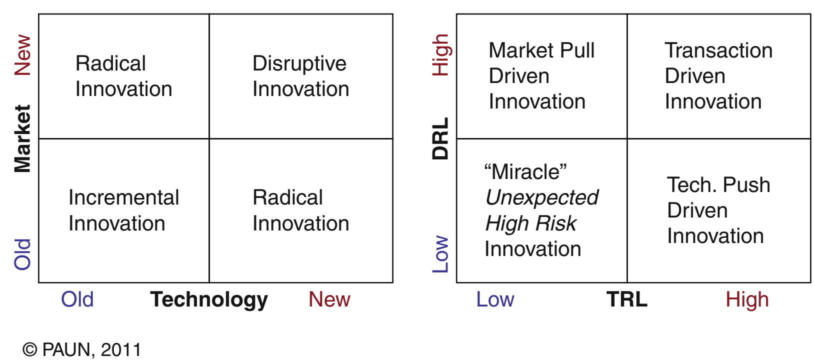
– If the existing state of the art shows only TRL 1–3 for the required technology, the company has all the interest to hire the existing experts and promote an aggressive internal research and technology program in order to get decisive competitive advantages.
– If the existing state of the art demonstrates that the existing technology already succeeds the proof of concept and the laboratory demonstration, the company will face three possibilities. If the demonstration was made by someone else, the company will invest in further developments (reducing the technology development risk for the existing developers) but only on the basis of an exclusive license relative to its domain. This could be made also on the basis of an IP acquisition. If the existing developer is one of the company's competitor, the company has all interest to consider the development of the intended new product on the basis of a concurrent technology starting with TRL 1–3 by hiring the right experts (return at the first described case). Finally, if by chance the existing laboratory demonstrated technology was obtained inside the company, this one will continue an investment program with reduced risk due to the high level of DRL reached in parallel.
– If the required technology needed to develop the intended innovative product corresponding the high level of obtained DRL was already demonstrated in operational conditions, this was made definitely by someone else, outside the company. This external actor could be someone who is currently running an innovation program in a technology push approach or someone who is already selling products or services with the needed technology in other market domain. Both cases will bring to a venture, a license, or an acquisition of IP rights. The type of transaction will mainly depend on the size of the external actor (a big industrial will prefer a venture if the business will be close to its core competencies or a license if it will be far, while a small industrial will better prefer a license or an IP acquisition).

These high DRL possibilities were thus identified. Other "hot spots" represented on the innovation readiness diagram could be easily identified as well.

The various limits corresponding to MarketPull versus TechnoPush innovation projects, transaction-based innovation projects, and obviously the limit for the first sales are also presented on the diagram.



Technology Push and Market Pull Entrepreneurship, Fig. 2 Innovation process readiness diagram for technology-based innovation



Technology Push and Market Pull Entrepreneurship, Fig. 3 Innovation typologies in DRL-TRL perspective (simplified IRD)

The following diagram proposed a simplified IRD, in Fig. 3, by simply classifying the various innovation processes in four categories: the MarketPull, the TechnologyPush, the transaction-based innovations, or the not-enough matured innovation process which could become eventually "miracle" innovations by investing with very high risk.

Conclusion and Future Directions

Since many years, the TRL scale allowed various analysis of the technology transfer and technological innovation processes by positioning the various stakeholders along this scale, including entrepreneurs. This entry reminds a new reference system for better addressing the market pull approach while doing technological innovation. The DRL scale could also be the object of the same dynamic exchanges, modifications, and analysis that the TRL scale induced among the academics or practitioner communities. The aim is that this new (only proposed in 2011) tool for a hybridized approach will significantly improve the entrepreneurship practices through a better understanding of the different factors and staging allowing the agreement signatures to create value.

DRL could also be used in the better understanding of the social innovation process especially, thanks to its capacity to identify stages and actors in the evolution of the demand from the simple identification of a need to the description of the specific solutions expected.

For a TT officer or a strategy industrial director, it will be important to survey the matching of the levels on the two scales while placing the participating actors, identifying the existing asymmetries between them, and activating compensation or reduction tools for dealing with these asymmetries. When the sum of the two indicators will equalize 10, the deal between the industrial and the R&D laboratory becomes feasible and will interest all the stakeholders of the innovation project, including the investors (private or public). Further research work is on the process together with members of ANRT, AI Carnot, C.U.R.I.E. network, Technology Transfer Society, in order to postulate that the technology transfer or development agreements are only possible if the sum DRL + TRL is at least equal to 10 regardless of the market pull or technology push entrepreneurship. If the sum will be smaller than 10, specific actions could be envisaged in market pull or in technology push approaches types.

With a better understanding and control of the hybridization strategy between technology push and market pull approaches, the innovation system tends to evolve toward a better compatibility with the social and environmental requirements inevitably market pull driven as in the case of eco-innovation.

Cross-References

► Entrepreneur
► Product Development
► Technology

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Temperament

▶ Creative Personality

Tendencies

▶ Patterns of Technological Evolution

Tenure Track and Cross-Employment

▶ Cross-Employment

Terminal Care

▶ Palliative Care and Hospice - Innovation at End of Life

Territorial Design

▶ Entrepreneurship in Creative Economy

Territorial Management

▶ Cyberentrepreneurship and Proximity relationships

Territory

▶ Business Climate and Entrepreneurialism

Territory and Entrepreneurship

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Synonyms

Regional entrepreneurship

The Regional dimension of Entrepreneurship

Entrepreneurship is involved in the territory development by contributing to the renewal of productive system and promoting the economic growth. It is well known that national context (laws, regulations, taxes, administration, etc., determined by national governments) matters for entrepreneurship and will influence entrepreneurial behaviors. Despite globalization and global sourcing, entrepreneurship has a pronounced regional dimension, and several streams of literature stress the importance of regional level and focus on the link between new-firm start-up activity and region-specific characteristics and attributes (Fritsch and Schmude 2006) – with the region typically being a subnational territory. Differences between regions in newly founded businesses' rates and success, in entrepreneurial attitudes, indicate a distinct importance of space and the local environment for entrepreneurship, and such differences tend to be rather persistent and to prevail over longer periods of time according to empirical research (Dejardin and Fritsch 2011).

These approaches are founded on the acknowledgment that territory is not a neutral space, and factors associated with particular regions matter (Reynolds et al. 1994). Territory is a necessary condition of economic actors' (public and private) action, and this action builds the territory in turn. Considering that entrepreneurial activity or new-firm creation varies across geographic space, the questions are: Why do some territories have entrepreneurial activities and others none? How do territory characteristics impact entrepreneurial activity? Understanding this relationship between entrepreneurial activity and territory is crucial because high level of new-firm creation contributes to regional economic dynamics and to renewal of productive system. Various studies on determinants of entrepreneurship have investigated the characteristics of successful entrepreneurs by looking into individual characteristics such as personality, educational level, experience of work, ethnic origin (Storey 1994), and others look at more structural variations in geographical areas such as demand growth, expected profits, nature of barriers to entry or industrial concentration, and infrastructures (telecommunication and transportation systems). However, the emergence of knowledge-based economy will highlight other elements.

Notions Around Regional Entrepreneurship

Entrepreneurial Dynamics

The concept of entrepreneurial dynamics refers to creation, evolution, and cessation of economic activity in a given space that is to economics transformation of a territory. It results in creation of new organizations or in development of existing organizations but also in the removal of existing firms and/or activities. The analysis of entrepreneurial dynamics allows to trace territory trajectories and to understand the evolution of productive systems. Scholars recognize that economic transformation of a territory is a low and complex process. Empirical studies have showed the relative inertia of regional business portfolio due to the path-dependent nature of entrepreneurial process. In doing so, the entrepreneurial dynamics fosters the creation of territory-specific resources.

Generic and Specific Territory Resources

Resources contribute to activity development. Every territory has specific resources built over time from generic resources. Some of them are weakly mobile and strongly attached to a territory. These resources make the territory more or less attractive for new entrepreneurial activity. Specific resources include characteristics of labor (quality, know-how, adaptability, flexibility, etc.), industrial organization (cooperation, financial support), etc. There is a dialectical relationship between specific resources and entrepreneurship: On the one hand, entrepreneurial activity is built on territorial specific resources, but on the other hand, entrepreneurs play a role in the creation of specific resources. In fact, there is a close relationship between incumbent firm behavior and their ability to attract new firms and expend their business environment.

Endogenous Development of Territory

Endogenous development uses specifically local resources to sustain economic development. Here, the ability of local communities to exploit local resources is a crucial vector of territory development. Another characteristic of endogenous development is the local control of innovation or social regulations. The endogenous theory of development deals with small business, economic density, and social construction of market. Entrepreneurial activity anchors to local identity and draws on specific resources, and sometimes the proportion of local entrepreneurs who undertake in their natal territory is larger than the corresponding fraction of employees (Michelacci and Silva 2007).

Exogenous Development of Territory

Exogenous development of a territory is largely stimulated by public policy. Public decision makers use a range of tools in order to foster territory attractiveness (e.g., tax advantages) and increase the rate of localization of new organizations in their region.

Occupational Choice

New-firm creation echoes of individual decision process. Why does a person decide to be an entrepreneur and start a new firm? A large part of the literature addresses this question remembering that individuals are faced with occupational choice: being employees, staying jobless, or becoming an entrepreneur (▶ Individual Determinants of Entrepreneurship). In this approach, new-firm creation results from an individual decision process, and personal attributes (personality, education, entrepreneurial vision, alertness to business opportunities, proactivity, familial tradition, and ethnic origin) play a major role.

However, individual entrepreneurial preferences and ambitions not only depend on the personal assessment of own capabilities and resources available but also are strongly colored by actual and perceived market opportunities, conditions of profit formation, wages paid, financial constraints, local or regional demand, competition, etc. Consequently, the explanations of entrepreneurship can be found at the individual level, regional level, and national level (Bosma et al. 2008). In fact, environmental context – national but also regional – does not get neglected in this decision process. Thus, in declining industrial regions, individuals are faced with contraction of labor market and weakness of employee perspectives. So, the solution to have a job may be to create it and to be self-employed. But, in the same time, in depressed economic context with a decreasing local demand, profit perspectives may be reduced and weakly attractive to entrepreneurial creativity.

Agglomeration Effects

Agglomeration effects concern benefits derived for a firm from its location near other increase with the number of the firms with the same location. They include, among others, access to higher education, exploitation of local knowledge spillovers, and the presence of highly sophisticated markets which offer a variety of niches that can be exploited by new firms. Traditionally, two types of agglomeration effects are identified: (1) Marshall-Arrow-Romer effect (1973) refers to localization economics built on the economic density and the territorial specialization of activity and (2) Jacobs effect (1969) concerns urbanization economics and the fact that cities offer a great range of infrastructure, which is of interest especially for younger and/or more highly educated people. Agglomeration effects have positive effect on new-firm creation, because the presence of numerous firms in a delimited space impacts the demand, enhances access to skilled labor, and stimulates knowledge externalities and business information exchange between firms. In fact, whether clusters, industrial districts, or other forms of localized productive systems, the geographical concentration of businesses favors new-firm creation.

Knowledge-Based Economy: What Is Changing Between Territory and Entrepreneurship?

Tangible and Intangible Determinants of Regional Entrepreneurship

Relationship between entrepreneurial activity and territory is complex. Traditionally, a large part of literature investigates tangible and intangible determinants of regional entrepreneurship by focusing on various factors such as unemployment, population density/growth, industrial structure (market size, competition, specialization, and market concentration), human capital or cognitive resources (educational level, work experience), availability of financing, accessibility, university research and development, availability of cheap business location, level of regional income or welfare, but also social diversity and creativity (▶ Environmental Determinants of Entrepreneurship). All these factors influence significantly regional variation in new-firm birth rates. Beyond tangible regional attributes, the issue for entrepreneurial region is also to facilitate the networking of economic actors (▶ Innovative Milieux and Entrepreneurship (Volume Entrepreneurship)). Belonging to a local network allows access to specific local resources and to social capital, may be counseling, produces information exchange and new ideas, and is a transaction facilitator using reputation effect. These points are particularly important in knowledge economy to boost the competitiveness of new firms.

Regional Growth Regimes

Consequently, there are considerable differences of regional new-firm creation rates, and these differences have consequences for regional development, albeit in the long run and for the role that new firm plays for development. Extending the concept of the technological regime (Winter 1984) to regional growth, scholars identify different types of regional growth regime. Audretsch and Fritsch (2002), for example, propose to distinguish the entrepreneurial growth regime in a region if growth results from a high level of new-firm start-ups and a turbulent enterprise structure, and the routinized growth for regions where above-average growth goes together with a relatively stable structure of large, incumbent enterprises, and new businesses do not play an important role. The chance for survival and growth is much lower in routinized growth regime than in an entrepreneurial regime.

It is important to keep in mind a recent result of research about the effects of new business formation on regional development, namely, the most important growth effects of new business creation tends to occur with a time lag of up to 10 years (Dejardin and Fritsch 2011). The dynamics of this growth regime is largely path-dependency. Scholars observed that regions with relatively high rates of new business formation in the past are likely to experience a correspondingly high level of start-ups in the future, and regions with a low level of new businesses today can be expected to have only relatively few start-ups in the near future.

Moreover, these effects are not the same according the type of start-up (for instance, industry affiliation of new firm plays a role) and their regional environment (high-density areas vs. rural region, density, and variety of economic activity). Individual entrepreneurial behavior is also affected by regional entrepreneurial culture and regional attitudes toward entrepreneurship (risk takers, positive attitudes toward self-employment), and a high regional level of visibility of new entrepreneurs stimulates ambitious entrepreneurship at the individual level (Bosma et al. 2008). Reintroducing the cultural and institutional dimension, territory is thought as a set of rules and values and as the result of common and shared representations which may support entrepreneurship (► Clusters).

The Knowledge Spillover Theory of Entrepreneurship

The knowledge spillover view of entrepreneurship provides a clear link that entrepreneurial activity will result from investments in new knowledge and that entrepreneurial activity will be spatially localized within close geographic proximity to the knowledge source. The ability of a region to produce knowledge and to promote its diffusion is analyzed by knowledge spillover theory of entrepreneurship (Audretsch 1995). The spatial component of this approach focuses on the generation of entrepreneurial opportunities which are linked to knowledge spillover. Entrepreneurial opportunities come from large companies, investments by incumbent firms, and public research organizations. Consequently, regions without larger research organizations will probably have fewer spin-offs because of a lack of technically trained people and a shortage of ideas, and conversely.

Entrepreneurship World Cities and Creative Class

The purpose of the entrepreneurial world cities approach is to go beyond the analysis of regional differences within a single country and to propose cross-country comparisons on world cities taking into account the impact of the urban environment. The main argument is that urban cities or metropolitan areas, because of their size, generate urban externalities or urbanization economics in addition to localization externalities (► Entrepreneurship in Creative Economy). So, the entrepreneurial advantage of cities is based on agglomeration effects, the main argument why cities should have higher start-up rates than nonurban regions. Furthermore, besides the enhancement of demand, cities also have larger shares of highly educated people increasing the pool of potential entrepreneurs. Finally, perceptions about entrepreneurship in urban areas may be distinctive and affect the pool of potential entrepreneurs (willingness, perceived skills, and ability to become an entrepreneur) and the demand side of entrepreneurship.

Cities and regions seem to function as incubators of creativity and innovation, and human capital factors play an important role in spurring regional growth. The hypothesis is that entrepreneurship is positively associated with regional environments that promote diversity and creativity. Entrepreneurial activities require not only a productive and supportive business climate along with an educated population but also a climate where creativity, diversity, and innovation are encouraged and valued (Lee et al. 2004). Besides infrastructure, access to capital, and so on, the context of a knowledge-based economy increases the importance of creative environments. These creative environments are particularly present in cites and more especially in cities with a high-level share of creative class. Due to the existence of geography of talent hypothesis (Florida 2004), highly qualified people tend to live in close spatial concentration. Creative cities combine Florida's 3Ts: technology, talent, and tolerance. According to this author, visions with holistic and long-term approaches for cities and regions are needed to "update" old industrial towns and attract visionary people. There is an interdependent relationship between characteristics of a metropolitan city, the number of talented people within this city, and the amount of entrepreneurial activities. Talented people are more creative than the rest of the population, they are more entrepreneurial, and they prefer cities with certain attributes like tolerance, economic welfare, and knowledge intensity. And finally, if talented people need a certain kind of environment, they also contribute to create this culturally rich and creative environment due to their regional and social embeddedness.

Conclusions and Future Directions

Local roots of entrepreneurship change with knowledge-based economy. Despite globalization and growing digital world, entrepreneurs need to be connected to their local territory to develop their business. Regions need entrepreneurship to change their productive system and be adapted. However, considering the existence of a path-dependency and persistence over time of regional entrepreneurship, one must take into account that this process changes are slow. Therefore, a policy that is aiming at stimulating the regional level of entrepreneurship needs patience and a long-term orientation (Fritsch and Schmude 2006). One of the most promising ways to stimulate regional entrepreneurship is probably to create and innovative, creative and entrepreneurial climate and to design a policy to promote regional entrepreneurship.

Cross-References

▶ Clusters
▶ Entrepreneurship in Creative Economy
▶ Environmental Determinants of Entrepreneurship
▶ Individual Determinants of Entrepreneurship
▶ Innovative Milieux and Entrepreneurship (Volume Entrepreneurship)

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Tertiary Education

► Higher Education and Innovation

Test of Creativity

► Measurement of Creativity

Thinking Skills, Development

► Inventive Thinking Skills, Development

Thought Experimentation

► Imagination

Trade Cycles

► Business Cycles

Training Methods

► Creativity Training in Design Education

Transdisciplinarity

► Interdisciplinarity and Innovation

Transdisciplinary Research (Transdisciplinarity)

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Synonyms

Mode 2 knowledge production; Post-normal science

Introduction

The term “transdisciplinarity (TD)” was coined to denote a search for the “unity” of knowledge or – more generally – the actual means with which such an integration of otherwise disciplinary fragmented knowledge can be achieved. Since its first appearance, “transdisciplinarity,” in fact, stands for nothing less than “the contemporary version of the historical quest for systematic integration of knowledge” (Klein 2010, p. 24; cf. Klein 1990, pp. 63–73).

Just like interdisciplinarity, the basic objective of TD has been from its beginning to make science and higher education more responsive to the complexity of life-world problems and more relevant for the public good and the legitimate needs of the society. Since then TD has been seen as a means to help research organizations to become active agents of societal innovations. The ambitious goal has been to make their knowledge more effective by overcoming the increasing fragmentation of knowledge both within the different scientific disciplines and within the society at large.

However, compared to the notion of "interdisciplinarity," TD aims at a more thorough integration of knowledge by focusing either (1) on *transdisciplinary concepts and methods* which are shared by more than one scientific discipline or (2) on the implementation of *participatory processes* within the research process which allow from the beginning deliberations with practitioners, citizens, and stakeholders about the purposes of a research project on the one side and an integration of first-hand nonscientific knowledge on the other. Although both conceptions of TD can – under certain circumstances – complement each other, they do not always go necessarily hand in hand.

Historical Development of the Concept

At a seminal conference on Interdisciplinarity in Universities (organized 1972 by CERI, the Centre for Educational Research and Innovation, a department of the OECD, the Organization for Economic Co-operation and Development), two different accounts were recommended on how a thorough transdisciplinary integration of knowledge can be achieved. One proponent was the Swiss developmental psychologist and epistemologist Jean Piaget, and the other the Austrian astrophysicist Erich Jantsch from Stanford University.

"A Common System of Axioms": TD as Shared Concepts and Methods

In 1972, an influential publication, released in cooperation with the OECD, defined "Transdisciplinarity" as

> Establishing a common system of axioms for a set of disciplines (e.g. anthropology considered as 'the science of man and his accomplishments' ...) (Briggs et al. 1972, p. 26).

In fact, this was a definition which was first of all advocated by Jean Piaget (1972) together with the mathematician André Lichnerowicz (1972). For Piaget, a transdisciplinary integration of different scientific disciplines was in fact first and foremost a task for mathematicians designing mathematical models: For example, he dreamed that someday, it would be possible to coordinate the relationships between physics and biology by new mathematical models similar to the relationships between mechanics and wave theory which have been finally coordinated within the new theory of wave mechanics (Piaget 1972, p. 138f.; cf. Lichnerowicz 1972).

Contemporary examples for this kind of TD would be, for instance, "social ecologic" models for the material and energy flow of societies, bridging the disciplinary boundaries between sociology and ecology by analyzing processes of society-nature interactions. But there are also TD concepts and methods which are not mathematical in essence, e.g., the (controversial) concepts of sociobiology where the principles of natural selection and evolutionist biology are applied to the study of social behavior and ethics. Further examples for nonmathematical TD concepts connecting different disciplines: narratology and semiotics (literary and media studies, linguistics, sociology, political science, history, epistemology), game theory (economics, political sciences, evolution theory), and systems theory (biology, sociology). TD research in this sense is searching for a kind of "meta-language" (Kim 1998, p. 21) in which problems of different disciplines can be expressed (for exponents of TD as shared concepts and methods see also: Lichnerowicz 1972; Kockelmans 1979, p. 128f.; Stichweh 1979; Miller 1982; Mittelstraß 1989, 2002).

"A Purpose-Oriented Coordination": TD as an Organizational Principle

At the same OECD conference, Erich Jantsch advocated a quite different concept of TD: For him inter- and transdisciplinarity were "the key notions for a systems approach to education and innovation" (Jantsch 1972, p. 107). Jantsch was the first who recognized that a transdisciplinary integration of different disciplines is not solely a problem of theories or methods, but a question of purpose. As he insisted: "*There is not a single system of science, there are as many systems as there are purposes*." (Jantsch 1972, p. 99) The purpose of research always influences the research outcome. As a rule, knowledge from different scientific disciplines is incompatible inasmuch as it has to serve different purposes. Therefore, if someone wants to integrate different knowledge domains, he or she must decide, first of all, which societal goals should be met and then to align the different purposes which are the main reasons for the fragmentation of knowledge into dispersed knowledge domains. Consequently, any TD integration presupposes a discussion of the intended aims and purposes before one can overcome the separation of disciplinary knowledge and expertise, hence the:

> essential characteristic of a transdisciplinary approach is the coordination of activities at all levels of the education/innovation system toward a common purpose. (Jantsch 1972, p. 114)

A thorough cross-disciplinary integration of disciplinary knowledge is only possible when at different organizational levels within the research organization, "political" decisions (in the broadest sense) about the intended purposes of the research outcome are made. He therefore conceptualized – in contrast to Piaget – TD first and foremost as an "organizational principle" (Jantsch 1972, p. 100) and proclaimed the need for a new kind of research organization, the "transdisciplinary university":

> The new purpose implies that the university has to become a political institution in the broadest sense, interacting with government (at all jurisdictional levels) and industry in the planning and design of society's systems, and in particular in controlling the outcomes of introducing technology into these systems. The university must engage itself in this task as an institution, not just through the individual members of its community. (Jantsch 1972, p. 102)

For Jantsch, however, "transdisciplinarity" still meant a unifying paradigm which is able to pull different scientific disciplines together within a vision of the reality as a whole. According to Jantsch one example of such a new "transdisciplinary vision" made its appearance in the 1970s with a new paradigm, the "self-organizing paradigm", which helped to find a unifying perspective "pulling together the physical and social sciences, the arts and the humanities, philosophy and knowledge transcending the rational domain, in short, the totality of human relations with the world." (Jantsch 1980, p. 308). For that reason he characterized his own concept of TD as "complementary" to the one of Jean Piaget (Jantsch 1972, p. 99). Furthermore, he did not explain clearly how the university should organize these interactions with the different societal actors and organizations; how a transdisciplinary university could achieve the competence and authority to plan for the society at large (Jantsch 1972, p. 121). In particular, how the university should cope with dissent within the society about the purposes and goals of research.

But nevertheless, with the emphasis on the purposes of knowledge and the organizational design of research institutions, Jantsch in fact shifted the focus from the level of concepts and theories to the realm of practical reasoning about legitimate societal demands and reasonable goals for TD research. Although he still insisted that a common purpose of knowledge could be the origin for a new set of unified theories and concepts, with the shift from theoretical to practical reasoning, a different kind of transdisciplinary integration of knowledge came into view: TD integration of knowledge not by means of systematic theories or theoretical models but on the basis of practical reasoning which first and foremost has to provide practical orientation and advice for public policies and collective decision making.

"A Transformative Practice of Knowledge": TD as Participatory Research

Although the term TD is sometimes used in a broad sense as "life-problem orientated" research which does not necessarily involve real participation of nonscientists and can therefore also be conducted by one researcher alone (see e.g. Jaeger and Scheringer 1998), many authors today define TD as a special kind of "life-problem orientated" research including some participatory procedures for different groups of stakeholders within the research process (Gibbons et al. 1994; Nowotny et al. 2001; Klein 2004; Pohl and Hirsch Hadorn 2007; Lieven and Maasen 2007; Russel et al. 2008; Arnold 2009; Hanschitz et al. 2009; Hirsch

Hadorn et al. 2008, 2010; Bogner et al. 2010). This kind of TD research implies among other things

> the giving up of sovereignty over knowledge, the generation of new insight and knowledge by collaboration, and the capacity to consider the know-how of professionals and lay-people. Collectively, transdisciplinary contributions enable the cross-fertilisation of ideas and knowledge from different contributors that leads to an enlarged vision of a subject, as well as new explanatory theories. Transdisciplinarity is a way of achieving innovative goals, enriched understanding and a synergy of new methods. (Lawrence 2004, p. 489)

Participatory TD opens new pathways for researchers to generate innovations, since new research topics and approaches become necessary to cope with the diversity of people, skills and knowledge domains which have to be integrated. However, this is not without consequences: for the benefit of (1) integrating scientific with nonscientific knowledge, (2) for getting closer to life-world problems, and (3) for focusing foremost on the creation of orientational knowledge to find workable solutions for decision making, the participatory kind of TD has to relax its criteria for transdisciplinary knowledge integration. It is one thing to integrate knowledge of different scientific disciplines within a unified theory but quite another thing to integrate diverse knowledge domains for the purpose of decision making and acting. In the former case, one is searching for a systematic theory or model, in the latter for practical knowledge, which provides orientation and advice for public policies and collective decision making.

Main Arguments for Participatory TD Research

The new claim that the concept of TD should be extended with instruments for the public participation of nonscientists is above all based on three connected arguments:

1. Since there is no societal consensus about purposes on which scientists can rely in their decisions, science has to enter into a dialog with society.
2. The division of labor in modern society leads to a division of know-how and a fragmentation of knowledge; therefore, a TD integration of knowledge has to be extended to the whole society and cannot be reduced to the integration of the knowledge of different scientific disciplines. Three problem areas can be identified:
   (a) *Experts* versus *principals (hierarchy)*: In the "knowledge society," experts at a lower level of the hierarchy have often knowledge and experience their principal lacks although the latter has the authority to decide.
   (b) *Experts* versus *experts (specialization)*: Specialists and single organizational departments have at their command only fragmented pieces of knowledge when they are tackling with societal problems. As one may say: "Communities have problems, every organization departments" (a variation on an often quoted phrase: "Communities have problems, universities departments," CERI 1982, p. 127).
   (c) *Experts* versus *citizens (practical experience)*: Contextual knowledge about circumstances apart from the abstract knowledge of scientific experts becomes more important when science has to be successfully applied in the daily life of common citizens.

The Three Phases of the Participatory TD Research Process

The participatory kind of TD research requires three distinct phases within the research process, dedicated to different tasks and in need of organizational designs. Although they can overlap, sometimes, it is even necessary to approach these phases in an iterative manner:

1. *Problem identification and structuring*: Typically, TD research has to start with only loosely defined objectives. Facts are unclear, problems vaguely defined, and values in dispute, but often it is much at stake for "those affected by the consequences" of the problem (Dewey 1927/1988). The very nature of the research purpose is often in dispute, since different interests and perspectives on the

problem are involved; therefore, it is highly recommended to deliberate with different stakeholders about a joint definition of the problem and on what research question the research should focus (Pohl and Hirsch Hadorn 2007; Hirsch Hadorn et al. 2008). Scientific experts need the help of citizens to identify the relevant societal problems and to define the research questions in a way that the research outcome will likely suit to the needs and expectations of those who are involved. Expert knowledge of different disciplines and professions along with important contextual knowledge and competences of laypeople should be examined for their relevance and integrated for a first problem definition. Furthermore, for scientific knowledge to become societally relevant, it is necessary to involve from the beginning those who are either affected by the consequences of these scientific and technological innovations or are in charge for implementing and using this knowledge later on in their occupational, family, or political life as citizens. The former can obstruct innovations later on when they think they are not in their interest, the latter can be reluctant to implement them.

2. *Problem investigation and analysis*: The joint problem definition has to be broken down into research questions which can be analyzed with the instruments and methods at hand. Different aspects have to be closely investigated to understand the complexity of the problem from different angles. Especially four central features have to be emphasized: It should deal "with problem fields in such a way that it can (a) grasp the complexity of problems, (b) take into account the diversity of scientific and life-world perceptions of problems, (c) link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good." (Pohl and Hirsch Hadorn 2007, p. 20)
3. *Bringing results to fruition*: The TD research outcome has to be put in practice to trigger innovations within society. It is necessary to synthesize and to translate the research outcomes for the different stakeholders since they have to understand and implement this knowledge in their daily routines. As part of a joint quality assurance, the results have to be monitored: either by an "extended peer review" (including representatives of groups of different stakeholders) or more decentralized by separate evaluations by the scientific peers on the one hand and the different groups of stakeholders on the other (see "Evaluation of Participatory TD Research").

A Question of Knowing: Searching for New Sources of Knowledge

Another kind of knowledge the scientists sometimes lack but should be interested in is contextualized knowledge. To give an example, the political scientist and anthropologist James C. Scott convincingly argued that the modernization of agriculture in the twentieth century with the help of scientific standardizations but without taking the experience of the local peasants, woodsmen, and hunters into account repeatedly yielded catastrophic results. Many projects actually failed without the "nonscientific" practical knowledge of the local communities about local circumstances and their complex interrelations, like knowledge about seasonal time sequences in the local flora and fauna, specific differences in soil quality across the region, water supply, and changing weather conditions. Scott called this practical knowledge of the local communities "metis"; it consists of a set of "rules of thumb" acquired by long experience. The essence of this kind of knowledge is "[k]nowing how and when to apply the rules of thumb *in a concrete situation*" (Scott 1998, p. 316).

The Benefit of "Societal Learning": Triggering Social Innovations

At least since the 1970s, fundamental changes between science and democratic society occurred, when the severe criticism of antinuclear and environmental movements have become prominent, as well as the accusations against psychiatric and social expertise of being oppressive and of serving the vested interests of those who are in charge. Political dissent made it quite clear that in a democratic society, it is not easy to reach an agreement on a generally accepted definition of what constitutes a legitimate "public interest" and a common purpose at all. How then can research organizations find generally acceptable purposes of knowledge on which scientists and society alike can agree? At this point Erich Jantsch' concept of TD was adapted and became more sophisticated by taking up an idea first developed in the 1920s by the philosopher John Dewey: the idea of *participatory engagement of citizens* with the aim to deliberate about the desired aims and purposes (Dewey 1927/1988).

John Dewey proposed a new contract between scientific experts and those citizens who are affected by the consequences of scientific or technological innovations, since both can learn from each other. It is just as with shoemaking: "The man who wears the shoe knows best that it pinches and where it pinches, even if the expert shoemaker is the best judge of how the trouble is to be remedied" (Dewey 1927/1988, p. 207). For different reasons, participatory TD has therefore some common features with Eric von Hippel's concept of "user innovation," which is based on the deliberate attempt to support the participation of so-called lead users in the product development process (Hippel 1988, 2005).

(a) *Consensus conferences:* In fact, Dewey's idea of democratic deliberations about purposes has been taken up since the 1970s and put in practice by some researchers even before the term "transdisciplinarity" was first used. Most notably when in 1987 a participatory method of technology assessment was established with the first Danish "Consensus conference" (about genetic engineering) organized by the Danish Board of Technology (Blok 2007). As a dialog between experts and citizens about emerging technology issues, the consensus conference (also known as "citizens' panels") has been aimed especially at identifying potential side effects of technological change and evaluating its societal impact. Such public conferences intend to find socially accepted ways for technological changes, helping technological and scientific inventions to become socially accepted technological innovations by actively addressing emerging conflicts and until then unforeseen social consequences.

(b) *Postgraduate and adult education:* Other means of integrating scientific and nonscientific knowledge domains have been developed by some institutions since the 1970s especially in postgraduate and adult teaching courses (e.g., the 1979 established Austrian IFF: Arnold and Dressel 2009). When universities acknowledge that (especially vocational) students already bring considerable knowledge, skills, and competences to the university, they can redesign specific courses of study with the aim to encourage these students to share their professional experience and knowledge with their colleagues and to mobilize these resources in their research for their final thesis. Transforming the traditional professor-student relationship into a kind of transdisciplinary cooperation, treating students more like equal partners in a participatory research process. Basis for such a redefinition of the different social roles within the learning process is, however, a persistent focus of these study programs on life-world problems, which not only cross the narrow disciplinary boundaries of scientific knowledge but are also accessible for the lessons of life experience and the knowledge of practitioners. Only then is the hierarchy between scientific and nonscientific knowledge sufficiently leveled, so that a collaborative learning process seems promising.

A Question of Purpose: Searching for the Public Interest

In a society based on the division of labor and on individual rights of the citizens, the common good and common interests are never easy to identify. There is no authority to speak for society; if "society now 'speaks back' to science" (Nowotny et al. 2001, p. 50), it is never society as a whole but individual persons or institutions that may be in conflict with other parts of society. In this situation, participation is more complicated than some researchers may think. That is why critics have claimed that with the involvement of stakeholders and the participation of nonscientists in the research process, transdisciplinarity willingly compromises its credibility and "objectivity" by running the risk of becoming partisan and subservient to political interests. This criticism has to be taken seriously, particularly since some researchers seem to mistake the participation of one stakeholder with the successful inclusion of the common interests of a society. Nevertheless, society does not exist as one uniform entity. As science is divided into a variety of disciplines, society is shaped by the functional division of labor, conflicting interests, social hierarchies, and sometimes fierce competition. In other words, "socially robust knowledge" (Nowotny et al. 2001, p. 166ff.) can be achieved either by appeal to the consent of (at least) the majority or by alignment with the interests of the powerful. In the first case, scientific research is oriented toward the common good (which is compatible with traditional notions of "objectivity"); in the latter case, however, it becomes tinged with unreliability and social bias.

For example, if a transdisciplinary research team cooperates with a hospital with the aim to find out how to improve the quality of the hospital, the question is: With whom do they cooperate? Does their research network provide special participatory roles for all stakeholders? Is the hospital represented only by the management or the clinical staff? What about the patients and their relatives or the nonacademic nursing personnel? What about external stakeholders like the health ministry, the pharmaceutical industry, or the health insurance companies? In an ideal setting, all of them would have to be included. But sometimes conflicts between these stakeholders can be fierce and the weakening of organizational hierarchies, for example, between the scientific staff and the nursing personnel, may be opposed by those who benefit from these hierarchies. Transdisciplinary research has to fight against such obstacles, but in situations when conflicts between different interests and perspectives are threatening to break up the whole research network, a reasonable compromise in the research design has to be negotiated.

Evaluation of Participatory TD Research

A key question for transdisciplinary research networks remains: Who should evaluate the success and the quality of research outcomes? Should the evaluation of scientific quality by the scientific community be kept apart from the evaluation of research outcomes and benefits by (for) nonacademic research participants, or should transdisciplinary research foster a new kind of quality assurance by an "extended peer review" where judgments of scientific peers and nonscientific stakeholders can be integrated (Funtowicz and Ravetz 1993)?

An extended peer review is a valuable option and indeed obligatory especially when research funds are dedicated to financing transdisciplinary research and research proposals have to be evaluated. Furthermore, an extended peer review can be a valuable tool to foster communication and deliberations between different groups within a TD research network, which can help to overcome disagreements and to broaden the perspective of each of the different research participants (including those of the scientists) through regular discussions about the aims and the quality of the research process.

Nevertheless, decentralized evaluations by the different participating groups within the research network remain a valuable alternative especially in situations where lasting conflicts between different societal actors are not expected to vanish during the research project and the network's capacities (in terms of time and money) would be overcharged by a mediation process. In such a situation, the expected societal influence of the project will be limited since these conflicts will be likely to overshadow any implementation process. But that does not necessarily mean that the results could not be valuable for scientists and some of the stakeholders as well.

Conclusion and Future Directions

TD is an attempt not only to add but to integrate different knowledge claims. Some still hope to find this unity of knowledge in a unified theory, others hope for a unity on a more local level;

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some restrict TD to the integration of scientific knowledge within the academia and their different disciplines, others are searching with the help of participatory procedures for a more thorough integration of scientific and nonscientific knowledge. But all hope to provide better founded knowledge and more comprehensive solutions for relevant societal problems. However, TD – especially in its participatory version – is not only about crossing boundaries of knowledge, but (like interdisciplinarity) it is also about cooperation and bringing different people and organizations with different knowledge together. Hence, transdisciplinary research has to spend considerable time communicating about purposes, appropriate research questions, methods and conflicting knowledge claims, coping with problems of finding a common language and common interests, to put cooperative research and knowledge production on a firm and joint basis.

Despite the fact that the term "TD" was initially invented as designating a special kind of interdisciplinarity, today the core meaning of TD has shifted to describe participatory research in the first place. At least since then it became necessary to distinguish between interdisciplinarity and transdisciplinarity as two concepts, although closely linked but not identical. As a matter of fact, a disciplinary kind of TD is entirely possible when – without any interdisciplinary cooperation between different disciplines – participatory procedures are included in disciplinary research designs. But transdisciplinarity without interdisciplinarity does not seem worth aspiring for. It is unlikely to get the whole picture of the complexity of societal problems (not to mention finding appropriate solutions) without making recourse to the whole diversity of scientific methods and disciplinary systems of knowledge. Therefore, integrating transdisciplinary and interdisciplinary cooperations has to be more than ever an important aim for TD research projects in the future.

However, since TD is in fact more like a craft or an art than a science, there are unavoidable differences between discipline-oriented and practice-oriented members within every interdisciplinary TD research team. Scientists trying to explain natural and social phenomena have often different research questions than practitioners trying to devise actions, processes, or technical solutions that serve some specified purpose. An interdisciplinary and transdisciplinary research team has to bridge these differences, combining scientific analysis with real-world solutions.

To cope with this situation successfully, TD needs organizational expertise: Transcending institutional boundaries with the aim of knowledge integration requires some experience in project management, especially in building bridges between different social realms of experience. Therefore, to create, to maintain, and to share TD expertise, separate organizational units have to be established within universities (e.g., as departments) or as autonomous division within other research institutes. This represents the only way to nurture what can be called transdisciplinary "communities of practice" where not only the formal rules but also the nuts and bolts of TD practice can be learnt from colleagues as tacit knowledge in an informal way (cf. Wenger 1998; Arnold and Dressel 2009).

As long as the public was convinced that science is an instrument of technical and economic progress, scientific research could be seen as providing value-free devices for innovations whose use and best application could be discussed afterward. In all likelihood, since this consensus has vanished, public debates about the purposes and implications of scientific research will haunt the scientific communities in the future (Ezrahi 1990, 1994). Hence, with its participatory involvement of those who are affected by the consequences, TD research seems to be an adequate and needed instrument for scientific research in a plural democratic society with its debates about purposes and the accountability of public spending: It involves negotiating with stakeholders or citizens about purposes, drawing on their noncertified expertise as knowledge resource, and making it more probable and easier for the participants implementing scientific findings and new solutions in their day-to-day decisions. Therefore, important questions for future research are how to use this instrument successfully and what kind of problems one has to face in different social settings with different scientific disciplines involved.

Cross-References

► Interdisciplinary Research (Interdisciplinarity)
► Mode 1, Mode 2, and Innovation

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Transformation

► Corporate Entrepreneurship

Translational Medical Science

► Translational Medicine and the Transformation of the Drug Development Process

Translational Medicine

► Translational Research

Translational Medicine and the Transformation of the Drug Development Process

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Synonyms

Basic science; Bench to bedside; Biologic agents; Clinical research; Clinical and translational science; Clinical trials; New molecular entities; Open source biotechnology; Personalized medicine; Pharmaceutical innovation; Pharmaceutical products; Research continuum; Translational medical science; Translational research; Translational science

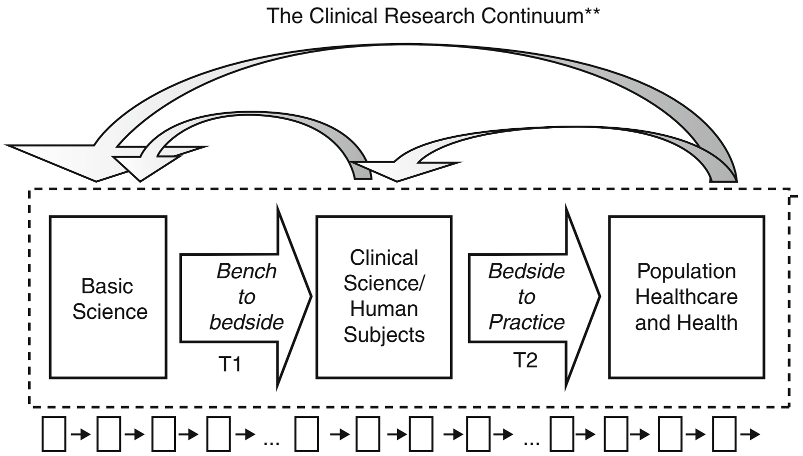
Introduction

Since the advent of Modernity and the rationalization of medicine, research in biomedical sciences has traditionally been classified into basic ("the bench") and clinical ("the bedside"). Basic research activities rely on advances in molecular biology techniques and, in the last two decades, have exploited our knowledge and understanding of the mechanisms of disease by opening the black box at the subcellular level.

On the other hand, clinical research in the form of clinical trials relies on observational high-quality research on population samples (in the sense that clinical trials focus on the inputs and outputs and not on the internal complexity, i.e., the mechanism of action of the drug) and has led to the generation of safety and efficacy data for new drugs and relevant health interventions, altering clinical practice in medicine.

In an attempt to combine the advantages of these arbitrary discrete areas of research in the field of biomedical sciences, the concept of translational medical research or, more commonly, translational medicine has emerged. The term was used in 1994 in the field of oncology in order to describe the bidirectional exchange of information between the laboratory and the clinic in an attempt to identify and exploit new molecular targets for the therapy of leukemia (Karp and McCaffrey 1994).

In its essence, "translational" research is an attempt to integrate advancements in molecular biology with clinical trials, in other words to successfully implement a laboratory concept into a clinical protocol, taking research from the "bench to bedside" (Goldblatt and Lee 2010). In order to come up with biologically and clinically meaningful results though, translational research should be bidirectional, i.e., not only from bench to bedside, but also from bedside to bench since



Translational Medicine and the Transformation of the Drug Development Process, Fig. 1 The clinical research continuum (Source: Sung et al. 2003)

research ideas often originate from observations in everyday practice and from the need to address certain public health concerns (Marincola 2003). In this sense, translational frameworks for public health research have already been proposed as a response to the complex reality of the public health environment (Ogilvie et al. 2009).

In an often cited model proposed from Sung et al. (Fig. 1) the clinical research continuum is depicted as a process ranging from basic research to clinical science involving human subjects and from there to improved population healthcare (Sung et al. 2003). In this model, potential barriers to progress are identified as translational blocks. These refer to impediments in transforming basic laboratory research findings into clinical science (first translational Block-T1) and obstacles in the processes of research translation into clinical practice (second translational Block-T2) (Zucker 2009).

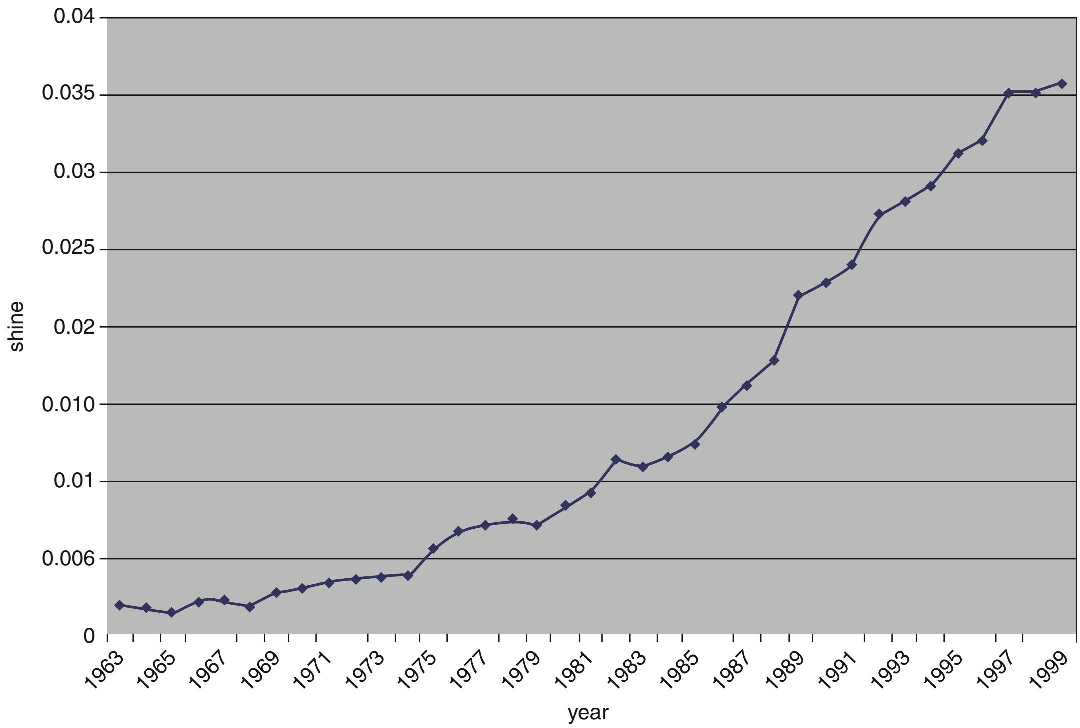
It should be noted that despite and to some extent because of its wide applicability, questions have been raised as to what exactly translational medicine is and whether it comprises merely an euphemism for preclinical and clinical pharmacology (Johnstone 2006; Dische and Saunders 2001).

Development and Dissemination of Translational Medicine

The emergence and dissemination of translational medicine relies on three major pillars, i.e., development of new technologies, increased funding and support in the form of relevant infrastructure, and change of the regulatory framework.

First, development of molecular techniques such as the polymerase chain reaction (PCR) and its variations has allowed the determination of the sequence of chemical base pairs which make up DNA (Bartlett and Stirling 2003) along with the physical and functional identification and mapping of the human genome, thus increasing by many factors the substrate for relevant research which can lead to the unveiling of pathogenetic mechanism and the development of appropriately designed drugs (International Human Genome Sequencing Consortium 2001). Furthermore, the development of information systems in the field of biomedical informatics and the wide dissemination of World Wide Web has allowed the efficient management of data, information, and knowledge from the bench to clinical practice and has enabled the networking between scientific groups and the pharmaceutical sector (Sarkar 2010).

Second, recognizing the increasing role of translational medicine in the development of new medicinal products, National Institutes of Health (NIH) have established the National Center for Advancing Translational Sciences, a new center to speed up movement of discoveries from lab to patients as well as a new program that will fund institutional Clinical and Translational Science Awards (CTSAs) (ncats 2012).



Translational Medicine and the Transformation of the Drug Development Process, Fig. 2 US research university patents as a percentage of all domestic-assignee US patents, 1963–1999 Source: (Mowery and Sampat 2005, p. 120)

Furthermore, NIH foster clinical and translational research by funding facilities and resources such as the General Clinical Research Centers, clinical-trial networks, and molecular-screening libraries, among others (Zerhouni 2005). This enormous progress has turned out to be a major challenge for the European Research Area as well. Trying to shorten delays in drug development the European Union has established EATRIS, the European Advanced Translational Research Infrastructure in Medicine, a distributed pan-European infrastructure consisting of a network of biomedical translation research centers across Europe with the aim to support a faster and more efficient translation of research findings into the final medicinal products (eatris 2012).

Third, the enactment of The Bayh–Dole Act or Patent and Trademark Law Amendments Act in 1980 allowed universities and small businesses to elect ownership of inventions made under federal funding for the purpose of further development and commercialization (P.L. 96–517 1980).

As an effect, a continuously increasing participation of US universities in the national patenting system has been documented since 1980 (Fig. 2) (Mowery and Bhaven 2005).

In this legislative and technologically and financially rapidly evolving environment, the emergence of translational medicine has promoted control of clinical research by the academic community, which was hitherto organized by the pharmaceutical industry, albeit using university hospital facilities (Stephen 2008).

As a result, a plethora of new companies has emerged, mainly in the form of small- to medium-sized biotechnology companies as spin-offs from renowned universities. The success of this revolutionary development within the biopharmaceutical industry can be seen in that between 1997 and 2002, 40% of the drugs introduced into medical practice came from biotechnology companies. With pharmaceutical companies having major holdings in some of these biotechnology firms, the biopharmaceutical revenues today have reached over US$60 billion (Demain 2010).

Discovery of a new molecular pathway in a university setting is followed by the development of a new biologic agent and, under the umbrella of the new regulatory framework, ends with the founding of a new biotechnology company. Companies that enter the biotechnology sector have already developed a relevant biological product and usually have completed phase I clinical trials, i.e., the experimental drug has been tested in a small group of people (20–80) for the first time to evaluate its safety, determine a safe dosage range, and identify side effects. However, due to the high costs of drug development, these companies cannot raise enough funding to support phase II and phase III clinical trials. Analysis from publicly available data shows great variations in cost estimates for drugs entering human clinical trials for the first time between 1989 and 2002, depending on many different factors such as the kind of therapy or the developing firm and ranging from US$500m to US$2b. High costs are in part owed to late-stage failures and the rising costs of phase II and phase III trials (Adams and Brantner 2006).

The opening of the black box and the unveiling of pathogenetic mechanisms underlying disease has led to the discovery and early development of a plethora of new biologic agents. This has led to the emergence of the concept of personalized medicine defined as the customization of healthcare, where treatment is being tailored to the individual patient by use of genetic or other information (POSTnote 2009). Knowledge of disease pathophysiology and genetic risk factors could enable the pharmaceutical industry to develop a more efficient drug development process. However, in terms of market shares, this would also mean the fragmentation of the relevant market for each drug. It is self-evident that personalized or targeted medicine means that the number of drugs involved in the treatment of a certain disease will increase since within this certain disease, there will be small groups of patients that share common characteristics and are expected to respond well to a therapy with different agents. Consequently, that would mean less revenue for the pharmaceutical company involved in the development and launch of the new agents whereas the developmental costs would grow higher since the recruitment of patients for the conduct of the necessary clinical trials would be significantly more difficult and time consuming. This inadequacy between expectation and reality could in part explain that although merger and acquisition (M&A) activity in the biotech industry looked robust in 2011, there was a noticeable lack of activity of the pharmaceutical industry. Given the critical role that the pharmaceutical companies could play in supporting the biotech innovation ecosystem, this lack of activity is unsettling (ernst and young 2012).

Although a number of tools have been developed as financial leverages for the small biotechnology companies which hold patents of new biologic agents, this is not enough to overcome the high R&D expenditure needed for the conduction of phase II and moreover phase III clinical trials. This unmet need has called for innovation in all aspects of drug development.

Translational Medicine as Promoter of Innovation

Innovation is recognized as a highly complex social phenomenon related at the level of the industry to every aspect of a sector. The pharmaceutical industry is one of the sectors that mostly rely on research. Indeed, the research-based pharmaceutical industry's key contribution is to turn fundamental research findings, both basic and applied, into effective treatments. Therefore, the pharmaceutical industry apart from being of high growth is almost by default innovation intensive. However, innovation is increasingly costly and risky. High costs are in part owed to late-stage failures and the rising costs of phase II and phase III trials. Furthermore, although the global pharmaceutical industry has demonstrated consistent strong growth patterns in the last years, productivity has fallen. Indeed, a substantial body of empirical evidence has shown that although R&D expenditures have been significantly increased over the last two decades, this increase has not been matched by a proportional growth in applications for new drug approvals (Schmid and Smith 2005; Paul et al. 2010).

These challenges call for change, for innovation. Scientific innovation is certainly part of the solution; however, there are many other levers of change. Innovation in the field of more traditional management processes such as cost containment tactics, acceleration of launch, effective multidimensional decision making (in terms of program termination, acceleration, resourcing, prioritization, etc.), talent management, portfolio, problem solving, and foremost reshaping of the relationships with the academia and the regulatory framework is necessary to reap significant rewards. The model of drug development is linear only in theory. In praxis, we are confronted with a messy, highly convoluted system of relationships within and between the industry, the academia and the regulatory framework. All these parameters need to be put in context.

The emergence of translational medicine was heralded as the advent of a new era in biomedical sciences. As already mentioned, the emergence and dissemination of translational medicine relied on three major pillars, i.e., development of new technologies, increased funding and support in the form of relevant infrastructure, and change of the regulatory framework. It is exactly those areas of activity within the pharmaceutical industry that have experienced innovative changes attributable at large to translational medicine. It can be argued that the impact of translational medicine on the innovativeness of the biopharmaceutical sector can serve as a case study for innovation systems in the sense of return of investment (RoI) in terms of innovation performance and innovation capabilities.

In the field of biomedical technology, translational medicine has necessitated the development of new molecular biology techniques. Combined with the developments in the field of computer science, the discipline of bioinformatics has emerged and a number of new medical technologies have been developed to “optimize the transformation of increasingly voluminous biomedical data, and genomic data in particular, into proactive, predictive, preventive, and participatory health” (Butte 2008). Based on the multipurpose generic technology of polymerase chain reaction, computerized tools have enabled the study of DNA copy aberrations, polymorphisms, genomic rearrangements, SNP arrays, mutation detection genome-wide studies, and high-throughput sequencing (Gonzalez-Angulo et al. 2010). New molecular methods such as the use of microarrays for gene expression analysis are novel approaches to the task of classification of neoplastic disease triggered by translational medicine whereas high-throughput and proteomic methods have allowed the use of groups of entities as biomarkers rendering the use of the latter clinically meaningful (Ginsburg and Willard 2009).

Translational medicine has also fostered the emergence of appropriate financial tools, new business models, and modern clinical trial designs. Manufacturing of biologics is a technologically complex, highly regulated process. In contrast to traditional drugs, manufacturing of new biologic agents requires more planning, investment, and skilled personnel. This has led to the development of new both public and private financial tools oriented at permitting and sustaining development in the sector. Furthermore, in the academic area, new university programs have been established that investigate the strategic aspects of discovery, marketing, finance, and business development in the biopharmaceutical industrial sector (Wharton 2012). New business models have also emerged. As the manufacturing of biologic agents is a highly complex process, the product is not defined merely by its molecular composition but, also, by the process with which it is made.

As a result, companies are required to invest in full-scale plants in order to perform phase III trials. As small-scale biotechnology companies cannot afford this level of investment, “contract manufacturing organizations” (CMOs) have emerged and have provided strategic value to the biotechnology industry with economically viable and sustainable models. Along with new financial tools and new business models, planning and conduction of clinical trials have also been influenced in the new era of translational medicine. More integrated models that use adaptive designs with the use of modeling and simulation have emerged, allowing for cost containment by early recognition of attritions and acceleration of launch in successful cases.

These profound changes have also necessitated changes in the relevant regulatory framework. In the early years, companies were required to file two license applications for a biologic product, a Product License Application (PLA) and an Establishment License Application (ELA) which have now been replaced by a single Biologics License Application (BLA), allowing companies to outsource manufacturing as long as product comparability is established. Furthermore, despite profound differences with the software industry and the relevant limitations, research has shown that open source practices are extensively used in biomedical research by universities and, to a lesser extent, by biotechnology companies mainly in the sense of involvement in research alliances based on open source practices such as sharing of R&D data including and especially focusing on pooling of data from clinical trials.

Conclusion and Future Directions

Translational medicine has offered the unique possibility for a tailored approach to patient treatment. From an innovation perspective it has greatly enhanced the innovativeness of the firms that constitute the biopharmaceutical sector. The emergence of new technologies, the development of new investment and business models, and the change of the regulatory framework have triggered a reciprocal development with positive feedback characteristics. Scientific and economic challenges along with operational issues present hindrances that still need to be overcome. In this direction, innovation in these fields can offer great services to this life-altering business.

Cross-References

▶ Academic Entrepreneur, Academic Entrepreneurship
▶ Business Model
▶ Business Start-Up: From Emergence to Development
▶ Collaborative Innovation and Open Innovation
▶ Entrepreneurship and Business Growth
▶ Financing Entrepreneurship
▶ Patent System
▶ Product Innovation, Process Innovation
▶ Technological Invention of Disease
▶ Technology Life Cycles
▶ Translational Research
▶ University Research and Innovation

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Translational Research

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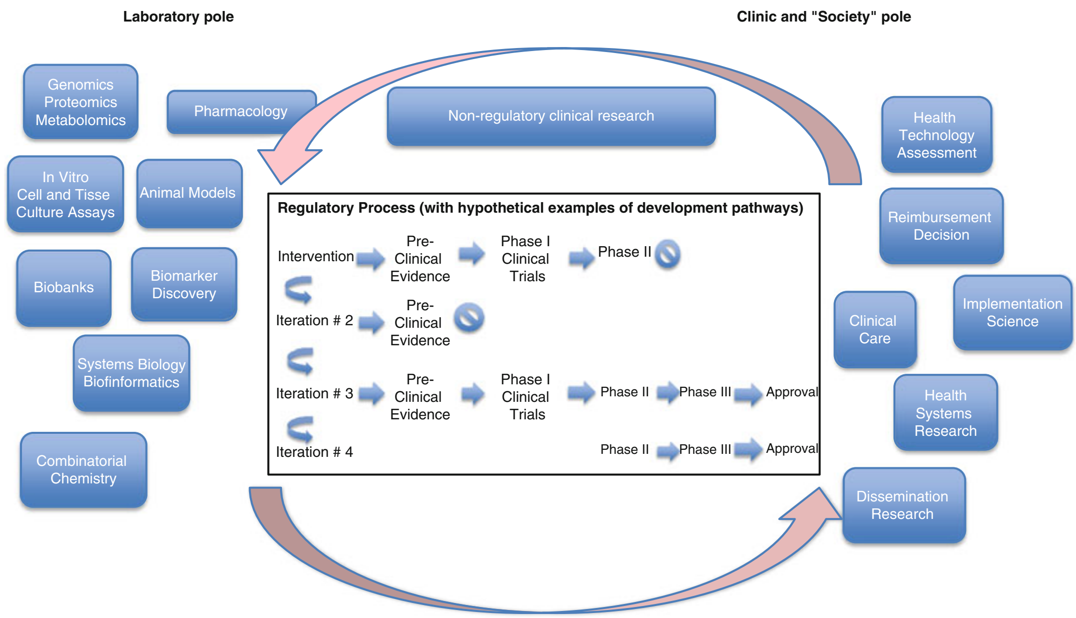
Synonyms

Translational medicine; Translational science

Definition

The terms translational research (TR), translational medicine, or translational science are currently seeing widespread usage in a variety of biomedical and health research fields. Yet, they remain slippery concepts which cannot be narrowly defined. Indeed, TR has been used to describe research and development activities taking place anywhere in the biomedical innovation process, from animal studies to verify hypotheses about the molecular mechanisms of disease or physiology to health outcomes or health technology assessment studies (Woolf 2008). Most often, however, TR is used by biomedical actors to design those studies which are performed to validate hypotheses that can lead to potential therapeutic or diagnostic developments. This includes studies with animals, in vitro cell cultures, biomarker discovery, and validation studies, but also early clinical trials up to proof of concept (Marincola 2003; Khoury et al. 2007; NCI 2007; Wehling 2010; Drolet and Lorenzi 2011).

Figure 1 offers a model of the research and technological development (RTD) process for new therapeutic products, indicating which



Translational Research, Fig. 1 *Sites of translational research*. Figure 1 represents a modelization of potential pathways in conducting TR. The *bubbles* represent clusters of practice, of expertise, and/or of material systems of experiment. Single TR projects may connect any number of these areas of scientific practice, and different projects do so differently. Passing from the laboratory to the clinic however, when it is accomplished through the development of new health interventions, requires regulatory approval of these interventions. The approval process is constructed by regulatory authorities as a linear sequence of stages that must be successfully completed to allow legal common usage of these innovations (Source: figure elaborated by the authors)

experimental approaches or sites are most likely to be mobilized specifically for TR efforts. Although the development of a new clinical innovation is always preceded, in time, by various forms of TR, no single experimental area in the model can be said to always, invariably be translational. Animal models studies, for example, are commonly employed both in research programs aiming at the advancement of theoretical knowledge of biology and over the course of development of a new drug (diagnostic development, for its part, might most likely not involve animal models at all).

Considering the proliferation of TR initiatives and the simultaneous difficulty of delineating a single area of research that can fruitfully be identified as the exclusive domain of this approach, it would be easy to dismiss TR as just a trendy expression, a repackaging of the well-established activities of drug discovery or biomedical RTD. The emergence of this new concept, however, is associated with a number of claims about how to increase the success rate of biomedical innovation in a time of pharmaceutical crisis. A situation of crisis is perceived based on observations that the cost of RTD for new drugs is steadily increasing in recent years, while approval of new products is decreasing over the same period. This productivity issue is compounded by a historical situation where current blockbuster drugs, that provide pharmaceutical firms with a sizable part of their profits, are falling off patent and are not being replaced by new patent-protected blockbusters (these issues are examined in greater detail in section "Historical Emergence of Discussions on Translational Research"). It is perhaps best to consider TR as a sort of reform movement within biomedical research with a specific agenda of privileged epistemic, institutional, and material practices. A definition that might capture this inherently performative dimension of TR concepts and models, while capturing the type of technical practices, material cultures, and institutions most often associated with TR, might be formulated like this:

> The term translational research denotes forms of cooperation and coordination in biomedicine that aim to intensify patient-oriented research and to increase the volume, success rate, and speed of research and technological development activities for new or improved health interventions.

Common proposals for achieving these goals, as advocated within TR approaches, include tightening the links between clinical practice and laboratory-based investigations, stepped-up efforts to develop biomarkers for drug development, or increasing attention to factors that shape the effectiveness of new health interventions in clinical contexts. Lander and Atkinson-Grosjean (2011) identify three pathways of performing TR, each associated with specific goals and domain of practices: clinical utility, commercial utility, and civic utility. Clinical utility is sought by doing "patient-oriented" (Chiorazzi 2009) laboratory or clinical research that may provide new interventions for improving the care of patients (most commonly drugs, surgeries, vaccines, or the advanced interventions involving manipulation of patients' cells and genetic material now starting to emerge; diagnostic devices; care management guidelines). Commercial utility is realized when biomedical innovation leads to revenues for sponsors of these new interventions (whether they be public or private organizations), in turn generating employment and institutional development, fuelling the bio- or health-economy sector promoted by many governments. Finally, civic utility can be said to be attained through research that leads to new knowledge that enables prevention and healthy living, exemplified perhaps best by public health guidelines. One could also consider, however, that civic utility is achieved through the formation of communities (such as patient groups) or when research efforts empower individuals by providing them with knowledge of their biological makeup, which they can then use in their daily negotiations with health, disease, and identity (Parthasarathy 2007).

Historical Emergence of Discussions on Translational Research

Rather than through a strict definition, scholars of biomedical policy are perhaps best informed about the specific set of issues that TR advocates and are concerned with by looking at the historical use of the concept. Indeed, it could be argued that the crucial feature of TR is an interest or sensibility for specific families of institutional, experimental, and material practices in biomedical innovation, rather than any single research or institution-building program.

In 1975, the US National Institutes of Health (NIH) director of the time, Dr. Donald S. Fredrickson, published his thoughts on the difficulties of bringing basic biomedical knowledge findings to bear in clinical contexts in a note called *On the Translation Gap*. With the completion of the Human Genome Project in 2003, the doubling of the NIH budget between 1998 and 2003, and the contemporary realization that increases in resources and basic knowledge would not easily or automatically lead to revolutionary new applications in healing and prevention practice, considerations about a gap between intensive laboratory efforts and their clinical application became all the more pressing. Stemming from this predominantly Anglo-Saxon context, discussions about the need of a TR agenda in biomedical research became increasingly formulated by actors in the field: an approach, field, or systematic awareness to improve the "translation" between the "worlds" of basic research, preclinical research, clinical research, and health care. The goal is to increase the rate of biomedical innovation with clinical impact, at a time of major crisis for the pharmaceutical industry. As of 2011, the concept of TR has taken a momentous leap in usage, with major research funds being dedicated to translational activities, training programs, and institutes sporting the label to advertise their focus in most OECD countries (for examples of such initiatives, see Zerhouni and Alving 2006; Collins 2011; Morgan et al. 2011; Shahzad et al. 2011).

The most likely origins of TR concepts can be traced to the development of a policy program devised at the National Cancer Institute of the US NIH called Specialized Programs of Research Excellence (SPORE – NCI 2007; Keating and Cambrosio 2012). Starting in 1992, the program established a series of specialized units within American academic medical centers with an explicit goal to support RTD efforts with a potential to lead to new interventions against cancer within a short-term horizon. SPORE centers are expected to support project mobilizing both cellular and molecular laboratory research and clinical care and research capacities, along with infrastructures for biobanking and for biostatistics, as well as to support the careers of professionals specializing in TR.

But the establishment of the SPORES and subsequent centers modeled after them did not take place in a vacuum. Three series of subsequent or parallel developments can be identified as strong factors in shaping the current practices labeled as TR. Each will be briefly examined here.

The capacity of academic medical centers to fruitfully engage and integrate practices in clinical research, clinical care and experimental medicine, and laboratory-based frontier research in biology has been tested by the increasing sophistication of both sides of the bio/medical field (Coller 2008; Wilson-Kovacs and Hauskeller 2012). Indeed, there is a long history of reform and realignment between laboratory biology and clinical innovation (Marks 1997). As such, many policy interventions have been elaborated with the hope of fostering brokering activities at the interface between clinical and laboratory practices, with attention centering especially on the support of classes of professionals such as clinician-scientists that can navigate these different fields and organizations and act as coordinators of projects spanning these various systems, including the typical TR project. Discussions of TR conceptualization and practice have thus made the participation of and support for clinician-scientists a central theme of many TR initiatives (Zerhouni 2003; Zerhouni and Alving 2006; Coller 2008, 2009; Wilson-Kovacs and Hauskeller 2012) and linked, to a large extent, the extension of TR capacities to the organizational core for experimental medicine and "patient-oriented" laboratory research provided by university clinics and medical faculties.

More recently, many advocates of the genomics focus in biomedical policy since the 1990s (best illustrated by the international Human Genome Project – HGP) had highlighted the potential of these projects and their experimental platforms for grounding future efforts in clinical innovation (Nightingale and Martin 2004; Martin et al. 2009; Hogarth et al. 2012). Yet, new major clinical innovations based on these previous efforts are still eagerly awaited, and commentators have decried a situation where the biomedical field would be sitting on a gold mine of post-genomic research just waiting to be properly exploited (Collins 2011). Many TR initiatives have thus sought specifically to make genomics relevant to the clinic (in contrast with increasing the rate of clinical innovation that succeeds, whichever the experimental source).

The latest, but possibly the most urging series of developments to have shaped the trajectory of TR concepts, has been the increased perception of a situation crisis in the pharmaceutical industry. With its 2004 report *Innovation/Stagnation*, the US Food and Drug Administration (FDA) brought together the development of TR capacities with needs for making the drug development process itself the object of experimental research and conceptual formalization:

> In FDA's view, the applied sciences needed for medical product development have not kept pace with the tremendous advances in the basic sciences. The new science is not being used to guide technology development process in the same way that it is accelerating the technology discovery process. For medical technology, performance is measured in terms of product safety and effectiveness. Not enough applied scientific work has been done to create new tools to get fundamentally better answers about how the safety and effectiveness of new products can be demonstrated, in faster time frames, with more certainty, and at lower costs (Food and Drug Administration 2004, p. ii).

The FDA also used statistics concerning the approval of new drugs and registration of new experimental compounds to support contention of diminishing innovation in the pharmaceutical industry, leading to higher RTD costs for lower amount of innovative drugs entering the clinic. In 2011, this prognosis seems to have partly realized, with large pharmaceutical companies slashing thousands of RTD jobs as their recently off-patent portfolio "blockbuster" drugs selling for billions annually had slowly started to not be replaced by new blockbusters (MacIlwain 2011; Milne 2009). As such, the TR initiatives aiming to revitalize academic experimental medicine as well as to make genomics compatible to the purposes of clinical innovation are also now expected to help the pharmaceutical industry refill its pipeline.

The Organization of Translational Research: Pharmaceutical RTD in Academic and Heterogeneous Settings

While section "Historical Emergence of Discussions on Translational Research" has shown the historic sequence of broader developments that have lead to the emergence of policy-level discussions (by which one should also understand exchanges between researchers in peer-reviewed journals on research priorities, notably) about the possibility of an area of research such as TR, it is still unclear what concrete experimental and institutional practices feed and realize these visions. This section briefly draws on preliminary results from recent empirical research of the authors to accomplish just that (Biegelbauer et al. 2012).

A most interesting characteristic of TR initiatives (as in other generic RTD initiatives – see Biegelbauer 2007) has been that they tend to place coordination responsibilities for RTD projects squarely in the academic camp (Silber 2010). While previous approaches such as biotechnology entrepreneurship or industry partnerships placed the locus of responsibility (both legal and coordinative) in either an arm's length organization or in the private partner, now academic consortia are often expected to take the lead. This perception has implied the formation of large-scale consortia putting together various academic departments and institutions in bids to pool partners that might together provide the whole spectrum of experimental infrastructures and disciplinary expertise necessary to leading an RTD project from hypothesis of intervention, through preclinical testing, to phase I and phase II testing (for therapeutic modalities), and then to collaboration with a large pharmaceutical firm for regulatory approval and commercialization. This model has been translated into TR initiatives that try to create central research cores with specialized (and expensive) equipment of a scale previously employed mostly by industry and try to network these nodes with partners with complimentary capacities. The emphasis on medicine and the clinical experience in TR discourses means that most partners in TR consortia might end up being academic organizations, although industry is very present in some initiatives. It should also be noted that academics still resort often, within broader TR projects, to spin-off formation as a means to attract venture capital and displace commercial risks away from public institutes. Academic consortia may also well turn to contract research organizations to produce regulatory-compliant evidence from animal studies, for example, thus avoiding the need to establish complex and expensive in-house good manufacturing practice (GMP) production facilities.

Through the formation of these consortia, TR is bringing about a new form of organizing biomedical innovation, where experimental and commercial risks for pharmaceutical development seem to be displaced toward the public sector. In the authors' own research, advocates of TR approaches have often mentioned how they considered the state of pharmaceutical crisis and the retreat of industry from the earlier stages of RTD to offer an opportunity for university and public institutions (Lehner et al. 2011). These organizational forms should be analyzed in comparison to previously studied forms of large-scale, multidisciplinary, and collaborative scientific enterprises (Vermeulen and Penders 2010). Especially interesting here is the role that clinician-scientists and other forms of brokers and coordinators that work across organizational and disciplinary boundaries play and of the intellectual and material practices through which clinical innovation is constructed. The later point indicates the need to better understand how advances in genomics and laboratory pathophysiology can be effectively mobilized to conduct experiments that are relevant to human biology and clinical contexts (with some ground having been recently covered by Keating and Cambrosio 2012).

More broadly, this overview of recurring organizational features of TR initiatives shows the interdependence of these emergent forms of governance with the development of the three policy issues identified above: expectations of increased RTD outsourcing from the pharmaceutical industry justify the extension of academic capacities for therapeutic product development, for example.

Current Analyses and Interpretations of TR

Few analyses have been published specifically on TR as a recent, emerging phenomenon in biomedicine by scholars from science and technology studies (STS), innovation studies, or more broadly with a social science background. This is in sharp contrast with reviews, commentaries, and editorials on the phenomenon, authored by members of the biomedical professions and which are abundant.

Nonetheless, a few important studies can be pointed out. Löwy (1996) provides an ethnography of the interactions between clinical and basic research teams in the course of developing potentially groundbreaking immunological interventions, touching on many of the issues that would later become core themes in discussions of the biomedical community about TR. Keating and Cambrosio (2003) have provided an interesting conceptual framework for analyzing the increasing integration of laboratory and clinical approaches, of biology and medicine, in modern biomedicine, based around the concept of "biomedical platforms" that cut across organizational and professional boundaries. Following these authors' argument, which states that medical practice and research into human biology are now deeply interdependent activities, the divides between "bench and bedside" diagnosed by many TR advocates would appear to be a comparatively minor point of resistance within an otherwise broadly realized convergence. In their latest work, Keating and Cambrosio (2012) contend that even as medical and biological research practices are increasingly interdependent, there is an increased perception within the biomedical community that *therapy* and *research* are becoming independent practices. TR emerges as a reaction to this drift, a set of initiatives trying to recapture earlier successes in having both repertoires of practices build on one another.

Lander and Atkinson-Grosjean (2011), defending the concept of the hospital and clinic as "hidden research system," argue that recent biomedical policy has overemphasized cooperation between industry and university in seeking to foster the development of new health interventions. Webster et al. (2011) have shown how, in the current field of stem cell therapeutics development, a pharmaceutical model of innovation coexists with a "medical innovation" model based on more restricted and clinically based networks of RTD work. Also working on the field of stem cells, Martin et al. (2008) contend that the relation between clinical and laboratory-based sites of biomedical knowledge production has indeed seen much variation over the last 60 years but that current implementations of TR are very much laboratory-centered and follow a science-push model (Biegelbauer 2000), relegating clinical experimental systems to subordinated instruments of evidence generation. Yet, the development of new therapeutics and innovative health interventions is often associated with the emergence of specific innovations and know-how in networks accomplishing clinical research (Keating and Cambrosio 2012), and it is now increasingly untenable to consider these areas of the biomedical enterprise as rote screening of fully formed products waiting for regulatory approval (Nightingale and Martin 2004).

Wainwright and colleagues (Wainwright et al. 2009a, b) have published a number of studies that capture the interactions and negotiations for authority taking place between the different disciplinary and institutional cultures taking place in the development of stem cell therapeutics. These authors use the theory of action and field from Pierre Bourdieu to analyze how the construction of knowledge, experimental platforms, and institutional settings for TR initiatives is determined by struggles for authority and for setting collective definitions of legitimate TR practices between the groups collaborating in them. Wilson-Kovacs and Hauskeller (2012) study the claims of clinician-scientists as a specific professional group vying to establish themselves as the privileged "translational investigators" within an arena of contesting disciplinary stakes over TR, hoping to make of their individual multidisciplinary competences in both laboratory research and clinical care a recognized principle of authority in the field. Morgan et al. (2011) have shown how policy initiatives aiming to support TR activities in academia such as a translational cluster they studied are likely to run into these competing disciplinary claims over the best way to conduct these efforts, with the clinical and industrial principles often required in TR projects being problematic to assert in contexts where the pursuit of experimental biology for its own sake may constitute the dominant frame for evaluating the worth of given research practices.

The disciplinary and professional tensions evident in TR initiatives, as well as the organizational specificities described in section "The Organisation of Translational Research: Pharmaceutical RTD in Academic and Heterogeneous Settings," may also make them interesting case studies for scholars interested in recent developments in practices of interdisciplinarity and transdisciplinarity. Large-scale collaborations to develop a new therapeutic may involve a number of experimental phases each demanding their own expertise and socio-technical systems, necessitating sophisticated coordination. Such organizational forms may be made unstable by the need of single participating groups to produce reputational attainments (linked to academic career advancement) that are distinctively their own rather than that of the whole network. In other words, these interdisciplinary collaborations may prompt fears that certain actors be subordinated to others (Barry et al. 2008) or that short-term applied problem solving does not contribute to the long-term maintenance of disciplinary jurisdiction and expertise (Lyall et al. 2011).

However, studies have shown that the stabilization of interdisciplinary fields can be supported by the mobilization of specific groups of investigators that act as "interdisciplinary integrators" and "boundary spanners" (Lyall et al. 2011; Calvert 2010). These categories might be fruitfully applied to the group of clinician-scientists, which have often been leaders in the establishment and diffusion of the notions of translational research. Taking this claim further, one could make use here of contentions that the emergence of interdisciplinary fields are the results of "scientific and intellectual movements" that seek to legitimate new or peripheral experimental or institutional practices in the face of established disciplinary customs. Disciplinary conflicts around TR projects would here be recast as "collective efforts to pursue research programs or projects for thought in the face of resistance from others in the scientific or intellectual community..." (Frickel and Gross 2005, p. 206). Emerging interdisciplinary research programs may threaten to destabilize existing jurisdictions over academic and scientific "resources, identities, and status" (Jacobs and Frickel 2009, p. 57).

Maienschein et al. (2008) have taken a more critical stance over the broad movement toward TR in recent biomedical policy. They warn against the potential dangers of prioritizing TR excessively, which may distort the long-term viability of the biomedical research enterprise by draining resources away from the basic research that might form the basis of future TR. To this critical approach, one could add recent studies of the biotechnology sector that have questioned the wisdom of massive public support for an industry that has yet, after 25 years of activity, to be profitable (Pisano 2006; Mirowski 2011) or that dispute the wisdom of making promises of short-term clinical innovation as a means to justify large-scale investments in biomedical research (Nightingale and Martin 2004; Martin et al. 2009).

The obvious step to take here is to ask just how is this that TR initiatives should be able to succeed where the biotechnology sector has failed. First attempts at evaluating the consequences of TR initiatives on research relevance have found a positive effect of these new modes of innovation, although using broader understandings of relevance then those usually emphasized in the biomedical and policy literature (van der Weijden et al. 2012). TR advocates consulted with through the authors' own empirical research often draw a distinction between the aims of TR and biotechs in how a dedicated firm becomes just a smaller instrument within a larger process. Further research on the experimental and institutional practices and structures found in TR initiatives could provide new empirical modalities outside those already established in the innovation studies literature on academic entrepreneurship and technology transfer (Grimaldi et al. 2011).

Finally, other commentators have put into doubt the very idea of a state of crisis in pharmaceutical innovation, arguing that figures of the costs of developing new drugs are greatly exaggerated (Light and Warburton 2011). If this argument is substantiated, then the perceived justification to develop biomedical RTD capacities in academic TR centers and public-private TR consortia would be seriously undermined: TR initiatives would then play into the industry's tendency to strategically downsize in-house RTD activities rather than act as an aid to an ailing sector. As such, the study of the material, intellectual, and institutional developments taking place in biomedicine in the wake of the TR movement might provide new and crucial empirical material for the strand of studies concerned with the critique of the global pharmaceutical industry (Fisher 2009; Pollock 2011).

Conclusions and Future Directions for Research

Hogarth et al. (2012, p. 121) note in their agenda for social science studies of "personalized medicine" that "Just as we invest billions of US dollars in identifying the mechanisms of disease, it is necessary to also put some resources to work in identifying the complex social interactions that allow new technologies to serve a socially beneficial role." Whether they are interested in analytical considerations or in more active participation in the governance of biomedical innovation systems, innovation studies and STS scholars cannot rest on previous achievements of their disciplines to make sense of the emerging institutional, epistemic, and material practices that the modern life sciences give rise to. Summarizing the empirical observations and arguments presented above, the following questions point the way toward promising directions for further research on translational research:

- Through which practices are clinically relevant biomedical innovations achieved? How are genomics knowledge and other basic laboratory biology knowledge typically mobilized in the clinical innovation process? What different models or regimes of practices can be identified (as in Webster et al. 2011)?
- How does the TR movement affect previous assumptions from the innovation studies field and from policy-making that center on biotechnology firm formation as a privileged instrument of biomedical innovation?
- TR claims to be able to bring clinical experience back into the biomedical innovation process. How is this achieved?
- How have TR policies implemented so far fared, and do these experiences hold lessons for forthcoming initiatives?

The following lines conclude this overview of TR by opening the emerging set of problematizations and reflections presented above to parallel developments in critical studies of biomedicine. Establishing links between these areas of reflection could advance STS scholars' comprehension of how the movement of TR is set to change not only the organization of biomedicine and its experimental practices but also the relations of the field to society more broadly.

TR advocates have argued that the approach offers new opportunities for supporting noncommercial biomedical research and for pushing further the integration of local communities and of a global health agenda into it (Milne and Kaitin 2009). It remains to be seen if the alternatives of "patient-centered research" put forward by TR advocates will, if at all, realign relations between citizens, patients, health-care providers, the pharmaceutical industry, and biomedical researchers. TR, in the iteration that seeks to make genomics relevant for clinical contexts, might increase the pressure to develop genomics screening directly advertised to buyers, for example, thus compounding developments toward the reframing of patients as consumers of health products that are relatively autonomous from health-care provision networks (Parthasarathy 2007). In some clinician-scientists' version of the story, however, the lead (but not the participation) of the pharmaceutical industry and the laboratory-based molecular biologists could be reduced to allow more clinically oriented research, with patients and local communities as privileged partners. Yet, TR could also be deployed as an intensified search for cost-effective and sophisticated health interventions for western patients, compounding the global pharmaceutical industry's drive toward subcontracting and delocalization of research in Asia, Africa, and South America (Mirowski 2011). TR is still unsettled, an area of biomedicine in the process of being constructed. There is much remaining to do to understand how existing epistemic, material, institutional, and political practices are reshuffled by it.

Cross-References

- ▶ Academic Entrepreneurship
- ▶ Citizen Science in Health Domain
- ▶ Entrepreneurship Policy
- ▶ Epistemic Governance and Epistemic Innovation Policy
- ▶ Healthcare and Innovation
- ▶ Innovation and Entrepreneurship
- ▶ Interdisciplinary Research (Interdisciplinarity)
- ▶ Interdisciplinarity and Innovation
- ▶ Technology Push and Market Pull Entrepreneurship
- ▶ Translational Medicine and the Transformation of the Drug Development Process

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Translational Science

▶ Translational Medicine and the Transformation of the Drug Development Process
▶ Translational Research

Trend-Following

▶ Networks and Scientific Innovation

Trends

▶ Patterns of Technological Evolution

Triple Helics

▶ National Innovation Systems (NIS)

Triple Helix of University-Industry-Government Relations

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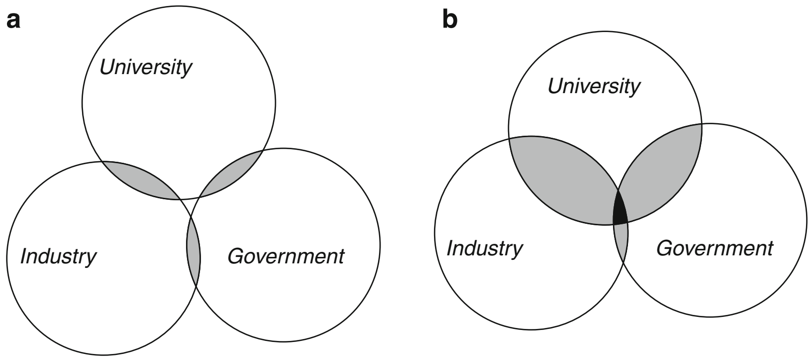
Introduction

Etzkowitz and Leydesdorff (2000) further elaborated the Triple Helix of University-Industry-Government Relations (cf. Etzkowitz and Leydesdorff 1995; Lowe 1982) into a model for studying knowledge-based economies. A series of workshops, conferences, and special issues of journals have developed under this title since 1996. In various countries, the Triple Helix concept has also been used as an operational strategy for regional development and to further the knowledge-based economy, for example, in Sweden (Jacob 2006) and Ethiopia (Saad et al. 2008). In Brazil, the Triple Helix became a "movement" for generating incubators in the university context (Almeida 2005).

Normatively, a call for collaborations across institutional divides, and the awareness that the roles of partners in such collaborations are no longer fixed in a knowledge-based economy, provides a neo-corporatist model of economic and social development that is compatible with neo-liberalism (Mirowski and Sent 2007; cf. Rothwell and Zegveld 1981). The city of Amsterdam, for example, adapted the Triple Helix as its working model for economic development as recently as 2010. (See at http://www.iamsterdam.com/nl/economic-development-board/over-edba/visie-ambitie/hoe-werken-we.) In the Latin American context, the Triple Helix model accords with Sábato's (1975) "triangle" as a program for endogenous development of technology and innovation. The emphasis on bottom-up learning processes (Bunders et al. 1999) can help to avoid reification of systems (or states and inter-state dependency relations) as barriers to innovation. In an overlay of communications between industrial, academic, and administrative discourses, new options and synergies can be developed that can strengthen knowledge integration at the regional level. In a study about regional innovation systems, Cooke and Leydesdorff (2006), for example, noted the possibility of "constructed advantages."

The Origins of the Triple Helix Model

The Triple Helix thesis emerged from a confluence between Etzkowitz' longer-term interest in the study of university-industry relations (e.g., Etzkowitz 2002) and Leydesdorff's interest in an evolutionary model that can generate a next-order hyper-cycle – or in terms of the TH, an overlay of communications (cf. Leydesdorff 1995). After Etzkowitz' (1994) participation in a workshop and a proceedings volume, the metaphor of a Triple Helix emerged in discussions about organizing a follow-up



Triple Helix of University-Industry-Government Relations, Fig. 1 A triple helix configuration with negative and positive overlap among the three subsystems

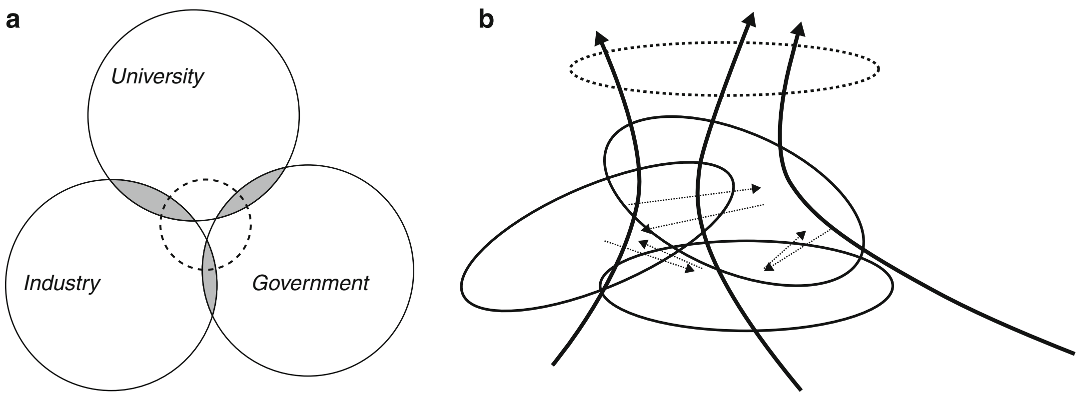
conference under this title in Amsterdam in January 1996 (Etzkowitz and Leydesdorff 1995; cf. Lowe 1982).

From a (neo-)evolutionary perspective, a double helix can be expected to generate a relatively stable trajectory when the two subdynamics mutually shape each other in a coevolution. For example, in a political economy, the market and the state can be expected to generate equilibria (cf. Aoki 2001) which are upset by knowledge-based innovations (Nelson and Winter 1977, 1982; Schumpeter 1939). Alternatively, when the state and its knowledge infrastructure constrict market forces (as in the former Soviet Union), a suboptimal lock-in can be sustained for considerable periods of time. The interaction of three (analytically independent) subdynamics, however, can destabilize, hyperstabilize, metastabilize, or eventually globalize a relatively stabilized system and thus change the system at the regime level in terms of lock-ins and path-dependencies (Dolfsma and Leydesdorff 2009; Dosi 1982; Viale and Pozzali 2010).

The Triple Helix model of university-industry-government relations is depicted in Fig. 1 as alternating between bilateral and trilateral coordination mechanisms or – in institutional terms – spheres. The systems remain in transition because each of the partner institutes also develops its own (differentiating) mission. Thus, a trade-off can be generated between integration and differentiation, and new systems in terms of possible synergies can be explored and potentially shaped. As the various bilateral translations function, a Triple Helix overlay can also be expected to develop as a system of meaning exchanges among differently coded expectations (Fig. 2).

If one envisages the overlay (in Fig. 2a) as hovering above the sheet, one can imagine a tetrahedron emerging from the bottom with four (three plus one) different types of communications involved. Political, scientific, and economic exchanges are different, but these media (e.g., power, truth, and money; Luhmann 1995) can also be exchanged. In the overlay, translations among the various media can further be invented and developed.

Etzkowitz and Leydesdorff (2000) specified the top-level overlay as a *sub*dynamic and therefore differently from the specification of "mode-2" by Gibbons et al. (1994; cf. Nowotny et al. 2001). "Mode-2" replaces "mode-1," but a subdynamic functions among other subdynamics. The complex system can operate "transdisciplinarily," and one can translate contexts of discovery and justification into contexts of application (and *vice versa*), without damaging the integrity of the underlying processes. This imaginative restructuring may loosen existing boundaries at the institutional level and thus begin to reshape "systems of innovation." Unlike discussions about national (Lundvall 1988; Nelson 1993) or regional (Braczyk et al. 1998) systems of innovation, the Triple Helix model enables an analyst to consider empirically whether specific dynamics (e.g., synergies) among the three composing media emerge at national and/or regional levels. In other cases, sectors and/or technologies (e.g., biotechnology)



Triple Helix of University-Industry-Government Relations, Fig. 2 A differentiated triple helix with dynamic overlay

may be more relevant systems of reference for innovations than geographical units of analysis (Carlsson 2006).

Globalization: A Transformation of the Triple Helix?

In the case of Japan, for example, and using a specific operationalization, Leydesdorff and Sun (2009) found that since the opening of China and the demise of the Soviet Union (1991) – both major changes in international competition – the national system of Japan has increasingly become a retention mechanism for international relations. Thus, a further differentiation between the national and the global level emerged in this explanation. In principle, the Triple Helix indicator – that is, the mutual information among three dimensions – can be extended to more than three dimensions (Kwon et al. 2012).

In a study about Hungary, Lengyel and Leydesdorff (2011) found that its national system of innovations fell into three regional systems of innovation following the transition of the 1990s and the accession to the EU in 2004. The authors distinguish (1) a metropolitan area around Budapest, (2) a knowledge-based innovation system in the western part of the country which is integrated into other EU countries, and (3) an eastern part of the country where the old (state-led) dynamics still prevail. The national level no longer adds synergy to these three regional systems.

The roles of the academic, industrial, and governmental contributions are also not given. The central role of universities in many TH studies is based on the assumption that this system is more adaptive than the others because of the continuous flux of students (Shinn 2002). In a recent study of Norway, however, Strand and Leydesdorff (in press) found foreign direct investment via the offshore (marine and maritime) industries in the western part of the country to be a greater source of synergy in the knowledge-based developments of regions than the university environments of the major centers in Trondheim and Oslo.

Two conclusions can be drawn from these nation-based studies: (1) medium-tech industry is more important for synergy than high-tech and (2) the service sector tends to uncouple from geographical location because a knowledge-intensive service is versatile and not geographically constrained. These conclusions accord with the emphasis in the literature on embeddedness (Cohen and Levinthal 1989) and the footlooseness of high-tech industries (Vernon 1979). Certain Italian industrial districts, for example, while very innovative, are under the continuous threat of deindustrialization because incumbent multinational corporations may buy and relocate new product lines

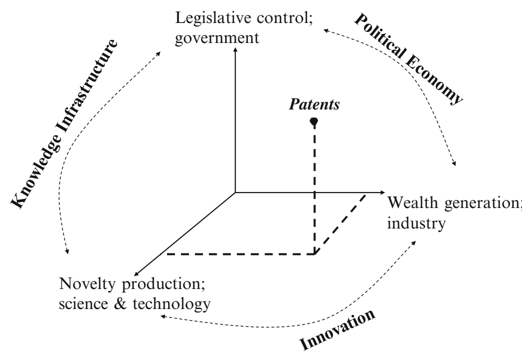
(Beccatini 2003; dei Ottati 2003). In institutional analyses that focus on local and regional development using the Triple Helix model, these structural effects of globalization are sometimes backgrounded.

Different Versions of the Triple Helix Model

The Triple Helix (TH) can be considered as an empirical heuristics which uses as *explanantes* not only economic forces (e.g., Schumpeter 1939; Nelson and Winter 1982), and legislation and regulation by (regional or national) governments (e.g., Freeman 1987; Freeman and Perez 1988), but also the theoretically endogenized dynamics of transformations by science-based inventions and innovations (Noble 1977; Whitley 1984). The TH model does not exclude focusing on two of the three dynamics – for example, in studies of university-industry relations (Clark 1998; Etzkowitz 2002) or as in the "variety of capitalism" tradition (Hall and Soskice 2001) – but the third dynamics should at least be declared as another source of variation.

TH models can be elaborated in various directions. Firstly, the networks of university-industry-government relations can be considered as neo-institutional arrangements which can be made the subject of social network analysis. This model can also be used for policy advice about network development, for example, in the case of transfer of knowledge and the incubation of new industry. The new and potentially salient role of universities in knowledge-based configurations can then be explored in terms of different sectors, regions, countries, etc.. (Godin and Gingras 2000; Shinn 2002). Over the past ten years, this neo-institutional model has also been developed into a discourse about "entrepreneurial universities" (Etzkowitz 2002; Mirowski and Sent 2007). Regions are then considered as endowed with universities that can be optimized for a third mission and different from higher education and internationally oriented research.

Secondly, the networks span an architecture in which each relation occupies a position. One can

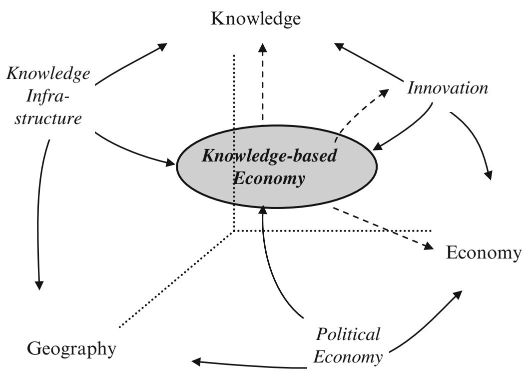


Triple Helix of University-Industry-Government Relations, Fig. 3 Patents as events in the three-dimensional space of triple helix interactions (Source: Leydesdorff 2010, at p. 370)

thus obtain a systems perspective on knowledge-based innovation in a hypothesized space; this theoretical construct – the knowledge-based economy – can be informed by systematic data analysis (e.g., Leydesdorff and Fritsch 2006).

In Fig. 3, patents are considered as positioned in terms of the three social coordination mechanisms of (1) wealth generation on the market by industry, (2) legislative control by government, and (3) novelty production in academia. Whereas patents are output indicators for science and technology, they function as input into the economy. Their main function, however, is to provide legal protection for intellectual property. In other words, events in a knowledge-based economy can be positioned in this three-dimensional space of industry, government, and academia. When events (e.g., patents) can also circulate, a three-way interaction can be expected. This knowledge-based economy contributes to the political economy by ensuring that the social organization of knowledge as R&D is endogenized into the system dynamics (Fig. 4).

The three functions in Fig. 3 can also be considered as interaction terms among relational exchange processes (e.g., in an economy), political positions in a bordered unit of analysis (e.g., a nation), and the reflexive and transformative dynamics of knowledge. When these interaction terms exhibit second-order interaction, a knowledge-based economy can increasingly be shaped (Fig. 4) (Foray 2004; Leydesdorff 2006).



Triple Helix of University-Industry-Government Relations, Fig. 4 The first-order interactions generate a knowledge-based economy as a next-order system (Source: Leydesdorff 2010, at p. 379)

In my opinion, the crucial research question is under which conditions do the three functions operate synergetically, to what extent or at which level, and at what price. Is a country or region able to retain "wealth from knowledge" and/or "knowledge from wealth" (as in the case of oil revenues)? Such a synergy can be expected to perform a life cycle. In the initial stage of emergence, "creative destruction" of the relevant parts of the old arrangements is the driving force. New entrants (scientists, entrepreneurs) can be expected to attach themselves preferentially to the originators – the innovation organizers – of the new developments.

In addition to "creative destruction" as typical for Schumpeter Mark I, Soete and Ter Weel (1999) proposed considering "creative agglomeration" as typical of the competition among corporations. This changes the dynamics of development in the later stage of development and is sometimes called "Schumpter Mark II" (Freeman and Soete 1997; Gay 2010). In a bibliometric study of the diffusion of the new technology of RNA interference (Fire et al. 1998; Sung and Hopkins 2006), Leydesdorff and Rafols (2011) found a change of preferential attachments from the inventors in the initial stage to emerging "centers of excellence" at a later stage. In the patent market, however, a quasi-monopolist was found (Leydesdorff and Bornmann 2012) located in Colorado, whereas the research centers of excellence were concentrated in major cities such as London, Boston, and Seoul. Drug development requires a time horizon different from that required by the application of the technique in adjacent industries, such as the production of reagents for laboratories (Lundin 2011).

In other words, the new technologies can move along trajectories in all three relevant directions and with potentially different dynamics. The globalization of the research front requires an uncoupling from the originators and a transition from mode-1 to mode-2 research in order to make the technique mutable (Latour 1987). From this perspective, "mode-1" and "mode-2" are no longer considered as general systems characteristics of society and policy making but as stages in the life cycles of technological transformations. An analogon of Schumpeter Mark I and Mark II within the domain of organized knowledge production and control can thus be specified.

Universities are poorly equipped for patenting (Leydesdorff and Meyer 2010). Some of the original patents may profitably be held by academia. In the case of RNA interference, for example, two original US patents ("Tuschl-I" and "Tuschl-II") were co-patented by MIT and the Max Planck Society in Germany (MIT Technology Licensing Office 2006), but a company was founded as a spin-off to further develop the technology. As noted, the competition thereafter shifted along a commercial trajectory. In summary, whereas one can expect synergies to be constructed, the consequent system "self-organizes" in terms of relevant selection environments while leaving behind institutional footprints. Three dimensions are important: the economic, political, and socio-cognitive potentials for change. Both local integrations and global pressures for differentiation can continuously be expected.

Conclusions and Future Directions

What is the contribution of these models in terms of providing heuristics to empirical research? First, the neo-institutional model of arrangements among different stakeholders can be used in case study analysis. Case studies can be enriched by addressing the relevance of the *three* major dimensions of the model on an equal footing *ex ante*. Research can then inform about specifics, such as path dependencies (e.g., Etzkowitz et al. 2000; Viale and Campodall'Orto 2002). Thus, the Triple Helix perspective does not disclaim the legitimacy of studying, for example, bilateral academic-industry relations or government-university policies. However, one can expect more interesting results by studying the interactions among the three subdynamics.

Secondly, the model can be informed by the increasing understanding of complex dynamics and simulation studies from evolutionary economics (e.g., Malerba et al. 1999; Windrum 1999). Thirdly, the Triple Helix model adds to the metabiological models of evolutionary economics the sociological notion of meaning being exchanged among the institutional agents (Leydesdorff 2011; Luhmann 1995). Finally, on the normative side of developing options for innovation policies, the Triple Helix model provides an incentive to search for *mismatches* between the institutional dimensions in the arrangements and the social functions performed by these arrangements.

The frictions between the two layers (knowledge-based expectations and institutional interests), and among the three domains (economy, science, and policy) provide a wealth of opportunities for puzzle solving and innovation. The evolutionary regimes are expected to remain in transition as they are shaped along historical trajectories. A knowledge-based regime continuously upsets the political economy and the market equilibria as different subdynamics. Conflicts of interest can be deconstructed and reconstructed, first analytically and then perhaps also in practices in the search for solutions to problems of economic productivity, wealth retention, and knowledge growth.

The rich semantics of partially conflicting models reinforces a focus on solving puzzles among differently codified communications reflexively. The lock-ins and bifurcations are systemic, that is, largely beyond control; further developments are based on the variation and the self-organizing dynamics of interactions among the three selection environments. These subdynamics can also be considered as different sources of variance which disturb and select from one another. Resonances among selections shape trajectories in coevolutions and the latter may recursively – that is, selectively – drive the system into new regimes. This neo-evolutionary framework assumes that the processes of both integration and differentiation in university-industry-government relations remain under reconstruction.

Cross-References

- ▶ Academic Entrepreneur, Academic Entrepreneurship
- ▶ Business Incubator
- ▶ Creative Destruction
- ▶ Creativity and Systems Thinking
- ▶ Knowledge Society, Knowledge-Based Economy, and Innovation
- ▶ Mode 1, Mode 2, and Innovation
- ▶ *N*-Tuple of Helices
- ▶ Quadruple Helix
- ▶ Quintuple Innovation Helix and Global Warming: Challenges and Opportunities for Policy and Practice
- ▶ University Research and Innovation

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TRIZ Forecasting

► Directed Evolution® Technology

TRIZ Software for Creativity and Innovation Support

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Introduction

The Theory of Inventive Problem Solving (TRIZ) has many tools of various degrees of complexity.

Typical TRIZ knowledge includes numerous examples and illustrations (learned from instructors and accumulated from one's own experience) and other (mostly tacit) knowledge about how to successfully utilize TRIZ methods and tools resulting in long learning curve necessitated by the large amount of knowledge that must be acquired from various sources and through substantial practice before becoming a successful practitioner.

The first attempt to facilitate utilization of TRIZ was made by G. Altshuller in the mid-1960s when he built an electromechanical version of the Contradiction Matrix with the 40 Innovation Principles. The first ideas for utilizing a computer for TRIZ-based inventive problem solving was discussed in 1978 (correspondence between Zlotin and Altshuller). In the mid-1980s, the emergence of personal computers allowed for the computerization of selected instruments of classical TRIZ (principles, standards, effects) conducted under the leadership of Valery Tsourikov. Since then, various software packages have been developed, mostly converting existing TRIZ tools into electronic format and offering limited value as they still required substantial TRIZ education for effective use. Other software offer ways to search for information with various degree of effectiveness or represent attempts to create simplified and engaging software (TechOptimizer, Goldfire Innovator, CreaTRIZ, TriSolver, TRIZ Explorer, TRIZContrasolve, Guided Brainstorming, and others).

New approach to TRIZ computerization was introduced in the early 1990s. It was based on the following considerations:

1. The computerization is a part of the automation of human activity. Studies in the history of automation show that the most common mistake in the automation process is the attempt to build machines that copy the human ways of operation. For example, the first locomotives had "legs," the first sewing machines had "hands," etc. History has shown that attempts such as these do not succeed; real success comes only after the old technology (process) is replaced with the one that has been invented with automation in mind. In the case of the sewing machine, it was the invention of a needle with the hole in the sharp end and the use of two threads instead of one.
2. There are two main issues in every computerization attempt: (a) the existing process that has to be computerized and (b) available software developer tools. These two issues are connected like two communicating vessels: the clearer and better the process is defined, the less sophisticated software tools are necessary for its computerization.

Given the above, the new approach was focused on substantial restructuring of existing multiple TRIZ processes and tools originally created for mental utilization and development of new ones to ensure successful computerization and thus facilitating mass utilization of TRIZ (Zlotin 1999; Zlotin and Zusman 2005).

Analytical and Knowledge-Based Tools of TRIZ

Classical TRIZ (TRIZ developed between 1946–1986 by Altshuller and under his leadership) included the following set of tools:

1. 40 Principles & Contradiction Matrix
2. Separation principles
3. The System of (76) Standard Solutions
4. Effects
5. Patterns/Lines of Evolution
6. Selected Innovation Examples
7. Substance-Field Analysis
8. Algorithm for Inventive Problem Solving (ARIZ)

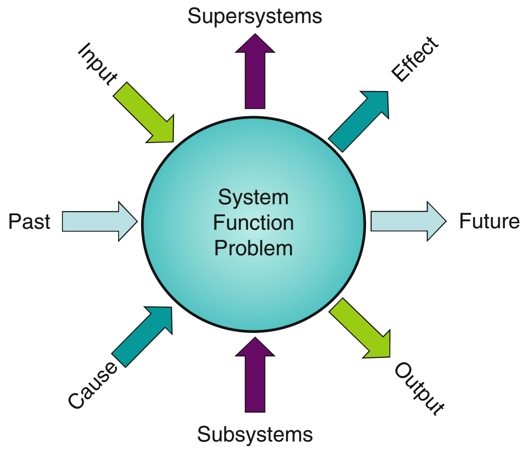
The first step in restructuring TRIZ was dividing all tools into two groups:

- Knowledge-based - tools offering knowledge extracted from patents and other sources of information representing the best innovation practices (positions 1–6 from the list above).
- Analytical – tools helping to analyze the initial problem situation and formulating directions for solutions (positions 7 and 8).

This understanding of the existing tools' nature helped identify the main directions for further improvement with computerization in mind:

- Integration of existing tools to avoid confusion caused by their multiplicity
- Development of "missing" analytical tools to provide complete support of all steps in the problem-solving process, including problem definition and formulation

As a result, two new analytical tools have been developed: Innovation Situation Questionnaire® and Problem Formulator®. The other results included development of the System of Operators – an integrated knowledge-based tool.



TRIZ Software for Creativity and Innovation Support, Fig. 1 System approach (Ideation International 2004). Each *arrow* represents a possible angle to look at the situation

Innovation Situation Questionnaire®

The Innovation Situation Questionnaire® (ISQ®) (trade mark of Ideation International) is a set of questions helping collect and organize available knowledge about a problem situation for the purpose of supporting the problem-solving process. Although typically subject matter experts for a given system know their system well, this knowledge is usually focused on performance and/or production. While this is helpful and even necessary, knowledge of this type can produce strong psychological inertia factors that hinder the creative process.

ISQ questions are divided into three sections:

1. Looking for solutions to the problem as it is originally stated by subject matter experts exploring relevant knowledge base representing best innovation practices collected across various engineering disciplines.
2. Creating detail description of the problem situation, based on *TRIZ system approach* (see the Fig. 1 below), including the structure and functioning of the system in which the problem occurs, root causes of the problem (if they are known; if not, specific instructions helping finding them are offered) and possible consequences if the problem remain unsolved.
3. Understanding and documenting system's resources and limitations, including criteria the solutions found and should comply with.

The intended results of working with the ISQ are:

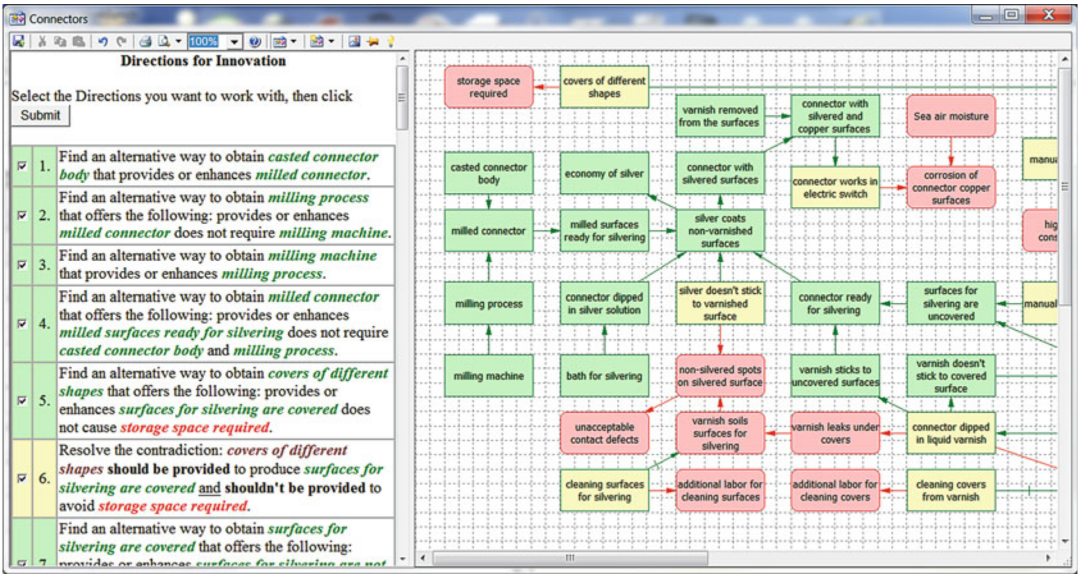
- Documented knowledge necessary for problem solving
- A creative "mindset" that increases the probability of generating new ideas
- Preliminary new ideas for solving the problem

Problem Formulator®

The Problem Formulator® (trade mark of Ideation International) is an analytical tool for transferring knowledge about a particular problem situation from the user's mind into a comprehensive set of Directions for Innovation (problem statements). Problem Formulation process included two steps (see Fig. 2):

- Building a diagram (visual model) that describes the problem (innovation) situation in terms of cause-effect relationships
- Converting the diagram into an exhaustive set of Directions for Innovation

On the diagram above, green boxes denote useful factors; red boxes, harmful or undesired factors; yellow boxes, contradictions (see below). The arrows between the boxes indicate cause-effect relationships.



TRIZ Software for Creativity and Innovation Support, Fig. 2 Problem Formulator Diagram and computer-generated Directions for Innovation (Innovation WorkBench® software from Ideation International)

Each computer-generated Direction for Innovation serves as a "pointer" to a relevant portion of the knowledge base.

Integrated and Structured TRIZ Knowledge Base

Historically, various TRIZ knowledge-based tools such as the 40 Innovation Principles, the separation principles, effects, and others were developed as independent tools (Altshuller 1984; Altshuller et al. 1989). The expectation existed that older tools would eventually be replaced or absorbed by more advanced and effective tools (such as a complete System of Standard Solutions). As a result, by 1980s, many TRIZ schools practically stopped teaching the 40 Innovation Principles providing only brief information about this tool.

Later, it became apparent that excluding the 40 Innovation Principles from a practitioner's "toolbox" had a negative impact on one's practical problem-solving abilities, primarily due to the fact that the older tool had its own advantages, like simplicity. Also, several very effective recommendations from the 40 Innovation Principles were not included in the System of Standard Solutions (e.g., "transformation of harm into a benefit"). On the other hand, simple reinstating of all 40 Innovation Principles would result in duplication because in many cases similar recommendations were included in different tools.

All problems mentioned above have been resolved through the development of an integrated operational knowledge-based tool (System of Operators) that included all recommendations contained in the 40 Innovation Principles, System of Standard Solutions, Utilization of Resources, etc. This new system should work with any problem model known in TRIZ: technical contradictions, physical contradictions, substance-field models, etc.

It is also interesting to note that the original principles were much more specific than the 40 Innovation Principles known today. Many of them had adaptations to specific characteristics they were intended to deal with. For example, the principle "segmentation" for the purpose of weight reduction differed from the "segmentation" used to reduce dimensions (Altshuller 1964). Later, Altshuller withdrew such specifics from the principles, apparently for the sake of universality and compactness of the Contradiction Matrix. However, this "detailization" can now be reconsidered in the light of the possibility of utilizing computers.

Besides "picking up" (selecting for use) an operator based on a particular characteristic, it would be useful to do this based on the type of drawback involved or on a desired function. Providing such "entrances" to the System of Operators requires that the operators be classified according to their possible application. For this, a complete redesign of all existing operators (principles, standard solutions, etc.), making them much more detailed and specific, can be achieved. This work has been started by Lev Pevsner (Pevzner 1990) and proved to be extremely useful. Such "detailization" can be accomplished in two ways: through segmentation of the existing operators (from the top down) and through the generalization of illustrations associated with each operator (from the bottom up).

The first TRIZ knowledge-based tool – 40 Innovation Principles – did not have any structure, just a set. To offset the lack of structure, Altshuller has created Contradiction Matrix to allow selecting from one to four principles from the set for a particular pair of parameters in conflict. The next knowledge-based tool – separation principles - did not require any structure because their number was rather small (four to seven depending on interpretation). There were several attempts to increase the number of innovation principles, within TRIZ and outside (Polovinkin 1988), with limited or no success, mainly because extended number of principles required certain structure to help with their utilization.

The System of Standard Solutions was the first knowledge-based tool with a structure corresponding with SF-models and certain problem-solving and innovation needs. At the same time, a need to build SF-model prior to selecting an appropriate group of solutions substantially limited its effectiveness as it required extensive training. In addition, this tool was lacking the technical language typical engineer was used to.

Based on the considerations above, a general list that included all operators derived from the existing principles, standard solutions, lines of evolution, etc., was developed. After excluding instances of duplication, a preliminary structure of the operators was suggested as follows (Tables 1, 2):

TRIZ Software for Creativity and Innovation Support, Table 1 Main groups of operators

Group name	Area of application	Example
Universal	Any	Inversion
Semi-universal or general	Wide	Increasing function efficiency
Specific (i.e., specialized)	Narrow	Increasing convenience

Later, several additional groups were introduced:

- Auxiliary (smart introduction of substances and fields)
- Selected patterns/lines of evolution

Altogether, about 400 operators have been created (some are not included in the count above, e.g., over 60 direct and associated operators for resolving contradictions). Apparently, this number can be effectively utilized once stored in professional full scope software (Innovation WorkBench® software, Ideation TRIZSoft®). Another structure was suggested for a simplified software or "mental" use.

Using Contradiction as a Structure for Operators

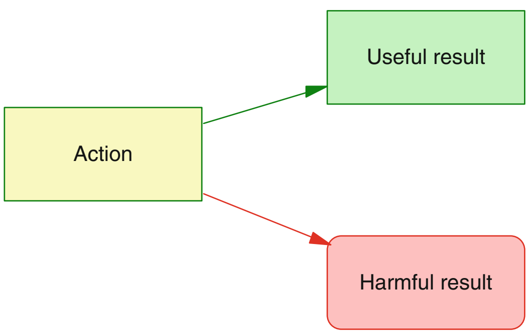
The following is a well-known TRIZ statement: if one has a difficult problem, one has faced a contradiction. A typical contradiction in most cases could be graphically described as shown on Fig. 3:

This graphical depiction of a contradiction is quite convenient because it can be utilized for both types of contradictions known in TRIZ – technical and physical:

- Technical contradiction: An action creates an improvement (useful result) but also causes deterioration (harmful result).
- Physical contradiction: An action should be provided to achieve useful result and not provided to avoid harmful result.

TRIZ Software for Creativity and Innovation Support, Table 2 Structure of the system of operators (see more detail in Appendix)

Group name	Subgroup name (number of purposes/specific factors were applicable)	Number of operators	
		Direct	Additional
Universal	Inversion	3	
	Integration	3	
	Segmentation	5	
	Partial/excessive action	4	
Semi-universal (general)	System synthesis (3)	9	
	Increasing effectiveness	8	
	Eliminating harmful effects (6)	30	
Specialized	Improve useful features (12)	91	100+
	Reduce an undesired factor (18)	148	150+
	Improve a system for management/control (3)	23	25+
Auxiliary	Introducing substances (11)	41	45+
	Introducing fields (3)	18	8+
	Utilization of resources (7)	38	60+
Selected patterns/lines of evolution	Increasing ideality	12	100+
	Building bi- and poly-systems	16	
	Segmentation	4	
	Developing substance structure	4	
	Dynamization	5	
	Increasing controllability	10	10+
	Universalization	4	6+
	Matching/mismatching	4	



TRIZ Software for Creativity and Innovation Support, Fig. 3 Graphical depiction of contradiction (Ideation International 2004)

Traditionally, classical TRIZ provides two knowledge-based tools to address the above: a set of several innovation principles (from the list of 40) and separation principles (4–7). However, vast experience of numerous TRIZ practitioners has shown that no matter how desirable it could be, not every contradiction can be resolved, especially when the given system is on its maturity stage, and resources for further development within the existing paradigm are practically exhausted (Zlotin and Zusman 2009). At the same time, it does not mean that the situation cannot be improved. Based on the graphical model shown above, the following typical directions for solutions could be identified:

1. Find a way to eliminate, reduce, or prevent harmful result under conditions of the given action.
2. Find an alternative way to obtain useful result that does not require the given action (meaning, the associated harmful result does not take place).
3. Resolve the contradiction: the given action should be provided to produce useful result and should not be provided to avoid harmful result.

TRIZ Software for Creativity and Innovation Support, Table 3 Simplified set of operators

Elimination	Alternatives	Resolution
• Remove/modify the source of harm • Modify harmful effect • Counteract harmful effect • Protect the subject of harm • Increase the resistance to harm • Eliminate the effect of the harm • Convert harm into benefit • Exclude the subject of harm	• Modify existing way • Mobilize internal resources • Increase effectiveness of the action • Change the principle of operation • Find additional benefits	• In space • In time • Between the parts and the whole • Based on different conditions

TRIZ Software for Creativity and Innovation Support, Table 4 Complete innovation platform and corresponding knowledge-based tools (Zlotin et al. 2011)

Application name	Short description	Knowledge-based tools
Inventive Problem Solving (IPS)	Solving difficult problems and improvements in technical and non-technical areas	• System of Operators for solving technological problems • Operators for solving non-technical problems (business, management, logistics, services, etc.) • Innovation guide (collection of physical, chemical, and other effects) • Collection of illustrations
Anticipatory Failure Determination (AFD)	Proactive process for analyzing, predicting, and eliminating failures in systems, products, and processes	AFD checklists: • Ways to produce harm • Operators for failure prevention/ elimination
Directed Evolution® (DE)	Predicting next generations of products, services, and technologies via inventing and developing a comprehensive set of scenarios describing future generations of a system.	• Patterns and lines of evolution (12 patterns and over 500 lines) • Bank of evolutionary alternatives (futuristic concepts for various industries)
Control (Management) of Intellectual Property (CIP)	Evaluation and enhancement of intellectual property (IP) related to proprietary technologies, inventions, patents, and patent portfolios	IP checklists: • Invention evaluation (over 35 parameters) • Invention enhancement

From the list above, three groups of operators could be identified: elimination, alternatives, and resolution (Fulbright 2011).

For each group, a set of operators is suggested as in Table 3.

This structure and the limited number of operators make it easier to memorize and thus to become an element of TRIZ way of thinking in addition to a number of universal operators and the main TRIZ concepts like ideality, contradictions, resources, system approach, and patterns/ lines of evolution.

The first extensive knowledge base and new process was developed for inventive problem solving (IPS) (Zlotin 1999).

Complete Innovation Platform

IPS is only one of the existing innovation needs. To address all needs and develop a complete innovation and problem-solving system suitable for computerization the following steps have been taken:

TRIZ Software for Creativity and Innovation Support, Table 5 Extended Structure of the System of Operators

Group name	Subgroup name	Specific factor/purpose	Number of operators: Direct	Number of operators: Additional
Universal	Inversion	n/a	3	
	Integration	n/a	3	
	Segmentation	n/a	5	
	Partial/excessive action	n/a	4	
Semi-universal (general)	System synthesis	Improve a prototype	1	
		Use other systems	1	
		Combine known systems	7	
	Increasing effectiveness	n/a	8	
	Eliminating harmful effects	Isolation	8	
		Counteraction	6	
		Other impact	6	
		Eliminate cause	2	
		Mitigate the results	4	
		Benefit from harm	4	
Specialized	Improve useful features	Reliability	4	5+
		Action speed	1	17+
		Mechanical strength	7	9+
		Composition stability	5	6+
		Convenience	18	30+
		Productivity	2	25+
		Manufacturing accuracy	12	20+
		Dispensing accuracy	10	10+
		Shape	8	10+
		Universality	4	6+
		Controllability	10	10+
		Degree of adaptability	6	10+
		Selective mode	4	2
	Reduce an undesired factor	Weight	17	5+
		Dimensions	7	6+
		Energy consumption	5	10+
		Object complexity	20	30+
		Energy waste	8	10+
		Time waste	9	30+
		Cost	20	30+
		Mechanical impact	9	20+
		Mechanical obstacles	4	10+
		Wear	12	10+
		Noise	5	
		Contamination	4	7+
		Overheating	6	5+
		Undesired adhesion	3	10+
		Fire or explosion	4	10+
		Interaction with environment	8	5+

(*continued*)

TRIZ Software for Creativity and Innovation Support, Table 5 (continued)

Group name	Subgroup name	Specific factor/purpose	Number of operators Direct	Number of operators Additional
		Potential harm from humans	6	
		Incompatible useful actions	1	10+
	Improve a system for management/control	Bypass the problem	5	5+
		Direct ways	14	10+
		Indirect ways	4	10+
Auxiliary	Introducing substances	Exclude elements	3	5+
		Substitute	3	10+
		Transient use	4	10+
		Substance withdrawal	2	5+
		Use copy or model	2	5+
		Introduce additives	6	10+
		Introduce void/foam	3	
		Devices for energy accumulation	1	1
		Introduce a mediator	7	6+
		Substance modification	6	5+
		Transformation to mobile state	4	10+
	Introducing fields	Intensification	2	3+
		Transformation	8	5+
		Generate informational field	8	
	Utilization of resources	Substance	10	30+
		Field	3	10+
		Space	6	
		Time	10	30+
		Informational	5	
		Functional	2	2+
		Transformation	2	2+
Selected patterns/lines of evolution	Increasing ideality		12	100+
	Building bi- and poly-systems		16	
	Segmentation		4	
	Developing substance structure		4	
	Dynamization		5	
	Increasing controllability		10	10+
	Universalization		4	6+
	Matching/mismatching		4	

1. Identifying all needs related to problem solving and innovation and development of a comprehensive set of applications that will address these needs.
2. Development of computer-aided processes for each application.

This approach resulted in development of the following applications and corresponding knowledge – based tools (Table 4) and supported by the family of TRIZ-based software (Ideation TRIZSoft®):

Conclusion and Further Directions

1. To facilitate TRIZ dissemination around the world, computer support becomes an essential productivity tool.
2. Historical attempts to develop software tools were mostly converting various TRIZ tools into electronic format and offering limited value as they still required substantial TRIZ education for effective use.
3. New approach to computerization undertaken by the authors has resulted in restructuring existing and development of new analytical and knowledge-based tools embedded into various professional software packages. Simplified tools could be utilized mentally and/or utilized via abridged software tools.
4. Further directions in developing software for creativity and innovation support could be:
   - Building more interactive and engaging user interfaces suitable for novices and younger generation
   - Enhancing analytical TRIZ tools
   - Updating and enlarging knowledge-base tools
   - Developing new TRIZ tools and processes facilitating computerization, including adopting new enabling informational technologies, like voice recognition, artificial intelligence, semantic analysis, etc.

Cross-References

▶ Creativity and Innovation: What Is the Difference?
▶ Directed Evolution® Technology
▶ Invention and Innovation as Creative Problem-Solving Activities
▶ Inventive Problem Solving (TRIZ), Theory
▶ Inventive Resources
▶ Patterns of Technological Evolution

Appendix: Extended Structure of the System of Operators

See Table 5.

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Twenty-First Century Fractal Research and Education and Innovation Ecosystem (FREIE)

▶ Mode 3 Knowledge Production in Quadruple Helix Innovation Systems: Quintuple Helix and Social Ecology

Two Hs from Harvard to Habsburg or Creative Semantics About Creativity: A Prelude to Creativity

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Synonyms

Comparative word analysis; Semantic survey; Vocabulary research

Introduction

An American legend tells how a Puritan preacher founded a famous school in Boston, but in reality, he did not. At the time, printing presses were rare; hence, any books were treasures greater than gold. After his death in 1638, his books were donated to the local community school, so his fellow theologians from Cambridge requested his surname be given to the school. Very creative thinking for New World Puritans known for their black-white/wrong-right binary mental images! What follows is a semantic safari through time, hence history, and especially through language, to hunt for answers to the question: How to be more creative? Constructive Cartesian criticism subdivides what is important to understand into smaller, more precise parts, making it easier to understand it all as a complete whole. Part by part/piece by piece, it is possible to construct what is considered to be critical to understand. To understand creativity, it is necessary to consider a five syllable English lexem from the Latin root, *créo*, to make. Following French Cartesian thinking, it is logical to subdivide the word into its ten letters: C-R-E-A-T-I-V-I-T-Y. Following a more Puritan binary mentality, it is easy to imagine a bipolar analysis comparing two opposing ideas linked to each letter. For creativity's sake, each letter is elegantly embellished by the French touch of *Patricia de Beaunant*, whom the late Wally Findlay considered to be one of the greatest living pastelists of our day.

Cultivate/Communicate. Language communicates the memory of humanity cultivating the cultural heritage of the human race. Recorded human history began with the invention of writing language down to communicate what happens. Ever since languages have made an eternal contribution to the preservation of civilization over the centuries. The Persians engraved on metal plates and the Egyptians on stone tablets while today we attempt to scratch out electronically what is worth remembering. The Bible and the Koran communicate ideas from monotheistic Semitic cultures about right and wrong. The Greeks cultivated the beauty of feelings and thoughts and defined perfection as corporal, mental, and spiritual equilibrium. The lengthy verses of the *Mahabharata* communicate centuries of Indian culture and inspired the *Gitanjali* offering another highly cultivated point of view about human existence: The absence of harmony is violence. France's enlightened philosopher, *Montesquieu*, defined culture as habits of living or *moeurs*. The dancing and chanting of African cultures gave the beat, the rhythm, everyone listens to and lives by in the twenty-first century. The Polynesian cultures carved their sacred taboos on wooden staffs passed down through tribal patriarchs while North American Indian cousins communicated through their tall wooden carved totem poles. Ancient pictographics, logographics, ideographics, and hieroglyphics have been replaced by virtual screen graphics of I.C.T. (Information and Communication Technologies) tools which monopolize a new global culture. Do websites and E-mails cultivate cultural harmony better than Sumeria's 600 cuneiform symbols or Biblical Hebrew's 22 letters? Who are the culturally responsible scribes in the twenty-first century? Mark Zuckerberg of Facebook? Taylor Thomson of Canada? Are websites, laptops, Ipods, cell phones, cinema, etc., the virtual tentacles of an omniscient I.C.T. octopus siphoning out individual cultural identity? Creative people are responsible for the future of the human race because their creativity can cultivate civilization. How to be more creative? Be more sensitive to culture and civilization.

Reason/Rupture. For most industrialists, creativity means technological innovation. What is the difference between inventions and innovations? An invention only becomes an innovation after it is legally registered, therefore protected, then put to use, and becomes profitable. Innovations can result from market necessity, market opportunities, or through internal company Research and Development initiatives and can eventually cause a market rupture. An innovation is considered to be a rupture when the application of it, access to it, and the use of it are universal enough to change the lifestyle of society. Cell phones had first a limited military market but after becoming accessible to the general public, and almost every member of a household, they caused so great a change in the way society lives today there has been a rupture with past buying habits creating a new cell phone lifestyle. Rupture innovation usually has a reason behind it explaining why/how the rupture occurred as a direct result of an innovation. Originally, security was the reason behind military cell phones later catalyzing a universal market opportunity for the general public changing the way we live forever. Consider the English schoolboy, Wills (William Webb Ellis), who in 1823 simply broke the rules of the game, a form of rupture, by running all the way down the sports field of his school holding the ball in his hands to the goal line posts and changed Rugby forever. Between 1750 and 1859, handling the ball was forbidden and the number of players unlimited, resulting in myriad mauls and injuries. The boys at the same school published the first set of rules in 1870 making their innovation universally accessible on the sports market. A catalytic reason behind it all can be traced to the headmaster who wanted to increase his influence on the educational market. The way football was played at his school in the city of Rugby, England became the good example of his philosophy, emphasizing sports as an essential element to a balanced education for fine young English gentlemen or P.L.U. (people like us). How to be more creative? Spend more time and energy making available now what was not accessible before.

Expand/Evolve. For industry, creativity has a strong degree of utility and therefore must be productive. Being productive means expanding the market position in evolving markets. The market is a mirror reflecting the economy and follows the economy's ups and downs as Keynesian cycles of supply and demand. Perhaps on the horizon of today's economy, there is greater possibility to envisage an economic model based on economic survival cycles that go from one crisis to another rather than from/to depressions or recessions or expansion. The main tools of production in any economy are also cyclic. Beginning with primitive times, mankind, as a hunter, was the main source of economic production, while animals were a vital economic resource for food, shelter, clothing, tools, and weapon making in a nomadic world. After a nomadic-based economy, man evolved into a more sedentary society of farmers creatively cultivating and storing food in the same location on the same land from year to year. Animals became the main tool of economic production while rich fertile land became the major economic resource. Agriculturally based economies eventually evolved into industrialized societies where man's mechanical and technological creativity replaced animals by machines, by electronics, by automation, by computers, by robots, and now mechatronics. Recent renewal of the importance of human creativity puts man again at the very heart of economic expansion because knowledge has become the main source of economic development. Today, companies must manage employee know-how, skills, and brains as well as vacations, health care, and retirement. Today, company production tools require continual creative redesigning to maintain a profitable position on globally competitive markets. In any economic system, in any century, man's ability to judge and make choices to decide makes him superior to animals, all machines, or any technology. His exponentially creative genius shall remain the main tool of future economic production whatever economic resources are available or depleted. How to be more creative? Develop greater capacities to judge, choose, and decide.

Antiquity/Assets. Subdividing the cultural heritage of the human race into six successive succinct segments of economic creativity shows how, since antiquity, human creativity appears to be an East/West romance of competition. To begin, around 5000 B.C., there were pockets of economic creativity in Asia with local assets of pottery, farms, and fishing. Africa's Nile River area assets included grain harvests, painting, weaving, and sculpturing. Europe's Macedonian farms prospered as did her stone and copper craftsmen but America's nomadic hunters just kept on hunting. 3000 B.C. brought wheeled transportation, ceramics, metals, and walled cities in Asia plus bronze, cuneiform writing, pyramids, and hieroglyphs in Africa. Europeans built Stonehenge and America's assets became pottery and planted corn. 1000 B.C. is when Asia's Aryan tribes gathered along the Ganges River, Egypt's Pharaohs flourished, and Semitic monotheism expanded. Europe's Mycenaean assets were based on Aegean Sea trade while America's Olmecs now had hieroglyphs and calendars plus farms appeared along the Ohio River Valley. In 1000 A.D., the assets of gun powder, silk, and spice from Asia modernized the world but Byzantine, Rome, and Slavic Christians suffered from religious strife. Vikings visited North America and the Amazon River Valley became a trading corridor in South America. It is only around 1500 A.D. when

Western creativity surpassed Eastern creativity. The assets of America's Aztecs now included metal, stonework, sculpturing, and painting. Asia's Ming Capital had Mongolian tribe troubles, Africa's tribal empires developed, and Europe's Gutenberg contributed to the cultural heritage of the human race the timeless asset of his printing press. The year 2001 imposed global management of assets via the Organization of Petroleum Exporting Countries, Europe's Economic Community, North America's Free Trade Agreement, the International Monetary Fund and the World Bank. Today, Asia's Pacific Rim Economic Cooperation is recuperating pockets of economic creativity back from the West into her Eastern spheres. How to be more creative? Be a survivor. Be more competitive.

Taylorism/Taoism. At the apogee of the industrial revolution, a young steel worker in Pennsylvania, Frederick W. Taylor, was creative enough to follow his employee instincts and intelligently observe the industrial reality around him and let his imagination fly by asking, What if? What if the employer supplied the employees with tools, materials, specialized training, and bonuses for achieving objectives set? What if employee advancement and promotions were based on individual achievement and merit? What if the employer accepted responsibility for on-the-job safety? Could an employee be safer by doing the same task over and over again until he became a specialized expert in that particular task, thus reducing the risk of work accidents? What if each task was scientifically analyzed step by step, then compared to possible optional ways of performing the same task to find the most efficient way to carry out that task? He creatively convinced his superiors to furnish smaller shovels to the workers shoveling coal into the steel furnaces, thus increasing the total daily amount of coal shoveled by minimizing individual physical fatigue from each shovel-full lifted up. On the other side of the world, Asian creativity had blossomed with ideas of Taoism. Applied to industry, Taoism promotes indirect material management intervention. Taoism proposes controlling first the immaterial and intangible, permitting a more natural and spontaneous happening of that which is material. It means managing indirectly and outside of the material setting or managing beforehand before the work is executed. In other words, work well planned is work well done. Though centuries apart, Taoism is like Taylorism because they both prescribe foreseeing all that is necessary beforehand. This is very different from the Chinese *wu-wei* interpreted as laisser-faire by France's *François de Quesnay* in the eighteenth century. Taylorism and Taoism encourage trusting and having confidence in employees, so employees feel free to work naturally and spontaneously favoring a mind-set more fertile for creative employee thinking to occur. How to be more creative? Be free thinking and more imaginative.

Instinct/Intelligence. Intelligence has several sources, forms, and modes of operation. The most common source of intelligence seems to be that which is tacit or simple, natural and often unexpressed, not learned but instinctive. Unlike twentieth century thinking, twenty-first century creative thinkers do not ignore instinct as a source of intelligence and recognize, encourage, and applaud human instincts in global decision making. Another source of intelligence is the implicit or that which is evident, schematic, and rules based being learned by observation. The highest source of intelligence to consider is structured, rich, profound, articulate and acquired through being taught. Various forms of employee creativity can include discovered intelligence (facts, data, descriptions, qualitative, and objectives), organized intelligence (differences, changes, insight, vision, calculated, corrected and condensed forms) plus applied intelligence (judgments, choices, decisions, qualitative actions/reactions). Describing, having insight, and judging are results of employee instinct tempered by work experience. In most work settings, employee intelligence operates, or is manifested, in a linear mode of authority under a hierarchy, or a circular mode of cooperation in teamwork, or the boomerang mode of feedback through follow-up. Instinct holds its own in all three operating modes as a legitimate source of employee creativity. Following authority, effective team participation, benefitting from feedback, requires a certain degree of instinctive employee awareness and consciousness. Intelligent employees optimize opportunities to increase their creativity through meetings, training programs, reporting, E-mails, faxes, memos, telephone calls, coffee breaks and lunch hours, or hi-how-are-you moments in hallways, elevators, and underground parking or other sharing moments in front of lavatory mirrors, water fountains, and coffee machines. Increasing employee intelligence increases employee creativity. Hence, employee intelligence scarcity can lead to an overall corporate state of creative amnesia. How to be more creative? Cooperate instinctively and communicate more intelligently.

Vision/Violence. If the twenty-first century is uncreative it will be because man will have forgotten how to think. Without a renewing of mental images and imagination to be more creative; civilization will die. Man must not be afraid to think creatively by exploring the corridors of his mind, open those closed doors, and trespass thresholds of new mental images. Only creative thinking will find the saving solutions to heal a world of violence. There are many forms of violence today other than military conflicts such as pollution, waste, oligopolies, cartels, maintained unemployment, institutionalized poverty, economic racism, consumer hedonism, hard drugs, pagan pedophiles, etc. Is not violence simply the absence of creativity? Is creativity a plausible remedy for violence? No, creativity may not stop violence immediately but it can be an intermediate, even long term, balm of Gilead; a healing salve soothing smoothly pain and wounds resulting from various forms of violence. In Post World War II society, there was a new generation of Americans who witnessed bilateral harmonizing of the businessman's value of profitability with the artist's value of sensitivity. Updating for today's global society, the new generation will more than likely be one of creative people with a trilateral vision harmonizing business, art, and science for future enrichment of the cultural heritage of the human race. Both artistic scientific businessmen and scientific business-minded artists will be able to offer a kaleidoscope of creativity overlapping opposing ideas to efface all forms of world violence. In other words, the twenty-first century may well witness a renaissance of creativity through scientists with a keen sense of utility plus an artistic sensitivity and a business sense of profitability. The life of Leonardo de Vinci, a mentor and a hero for creativity in the twenty-first century, is an example of harmony between art and science from which his patrons greatly profited. Aside from his artistic and scientific contributions to the cultural heritage of the human race, his life shows us it is important to renew creativity from generation to generation. How to be more creative? Increase reactivity to renew the hope of improving things.

Individual/Industry. One main difference in industrial management practices between the twentieth and the twenty-first centuries is well expressed in 12 words; 6 for the twentieth and 6 for the twenty-first. A very common management policy in the twentieth century was: “Stop talking and get to work.”, but later became “Start talking and go to work.” in the twenty-first century. Steve Jobs was known to say: “Hire intelligent people and let them tell you what to do.” One can summarize twentieth century industrial mentality in three key ideas: efficient teams + bossy superiors + business objectives which now transform into individual interaction + conscientious coaching + moral responsibility in the twenty-first century.

Individual identity in industry is no longer sacrificed for the group because today’s teamwork is a balanced blending of individual differences, meaning greater self-investment resulting in richer results and increased industrial creativity. People working together in industry, who have almost everything in common, cannot really work very creatively because their sameness breeds similarity not creativity. Differences breed creativity. It was the courageous creative thinking of individuals such as the Wright brothers, Fayol, Ford, Edison, Einstein, Job, Gates, and others who made the twentieth century industry so creative. The new management model of the twenty-first century is moving on from the traditional American Janistic groupthink model to a more transcultural approach (continent to continent around the globe), fostering more creative bosses who are closer to the Latin word, *pater*, meaning: father. This semantic root of the French lexem for *patron* (boss) implies paternalistic consideration for individual employee cultures and differences and is very similar to Robert Greenleaf’s servant leadership. Acultural corporate conformity can kill individual creativity. Creativity is spontaneous and contagious and feeds on confidence and trust between fellow team members through mutual cultural respect. Creativity is neither exclusive nor monopolistic. It was Peter Drucker who suggested creativity may well be a new basis of competition in twenty-first century post capitalistic society. How to be more creative? Promote cultural equilibrium and avoid economic excess.

Tomorrow/Today. The engineer's role in industry is to creatively benefit today from the past to foresee the future. The priority is timing not time. This means engineering continuity should be out of time and place as well as timely. Shall Renault's *AVANTIME* model and Toyota's Today Tomorrow concept be seen as prophetic or as pathetic marketing concepts? Bill Gates perceives tomorrow's talent today more in several Asian locations (Bangalore, New Delhi, Singapore, Sydney, Hong Kong, Guangzhou, Shanghai, Taipei, Beijing, Tokyo) and less in North American locations (San Francisco, Toronto, Boston, New York). These pockets of creativity attract, like magnets, the highest I. (Intelligence) Q. (Quotient) potential, thus the best of the present generation. Will it last? Can China's population continue without women? Will India's or Brazil's or Russia's infrastructures ever be updated? Are **B**razil/**R**ussia/**I**ndia/**C**hina today's most promising of **BRIC**ks to build tomorrow's world economy? Free Market Capitalism breeds consumer credit, inflation, pop culture, juvenile delinquency, and social unrest. Perhaps twentieth century technology Wizards of Oz may become twenty-first century Wizards of Oops? In the 1930s, the creativity of the French born design engineer, Raymond Loewy, relooked America (household appliances/television/radios/cars/trains/planes/buses/Coca-cola bottles/Shell logo, etc.). Lowey remains out of time and place because he is still the reference point inspiring today the vision of what modern tomorrow is expected to look like. Modern society could never exist without his concept of aerodynamic lines. Good taste is timeless. Class has always been a question of perception. Tomorrow needs people today to prepare it and make it happen. A Russian born philosopher from the same 1930s' American creative scene warned about future consumerism: "Whoever you are, you who are hearing my words, I am speaking …to your mind, and I say…whoever you are – you who are alone with my words at this moment, with nothing but your honesty to help you understand – the choice is still open to be a human being." How to be more creative? Foresee now what to do later better.

You/Yourself. "WHO are YOU?" The answer to this question is what dear Alice was so desperately running around asking everyone else about in her Wonderland. Updating for twenty-first century society, this Victorian fairytale by an Oxford Mathematics professor suggests the anxious Alice in each of us is latently looking for answers to questions like: WHAT is YOUR work culture? No doubt the professional labyrinths, in your wonderful Workland, have their own overzealous inefficient energy wasting Mad Hatters or always late unorganized arrogant rabbits or dogmatic dreary, but deadly, queens of no heart! Questions like: "WHO are YOU?" and WHAT is YOUR work culture? are equivalent to How creative ARE you? What you are determines how creative you are. Perhaps such questions are more appropriate to industry, when asked in a more different creative way such as: Who ARE you? and What IS your work culture? The verbs "are" and "is" are plural and singular conjugations of the infinitive "to be" and refer to what is going on now in the present, or the way things really are, not euphoric conceptual possibly might-be and should-be pronouns like "who" or "you." Do you want to be more creative? Then concentrate more on the "are" and the "is" and less on the "who" or "you." Think and act more in terms of "us" and "we" and less in terms of "them" and "me."

Knowing who you are, your limits and potential, will allow you to be more creative.

Leave behind the Shrek film's Pinocchio self-protection syndrome; "Well, I know where he is not." and admit: No, I do not know; so please tell me!. Only then can you, yourself, blossom. The first step in learning and improving is recognizing that we do not know because only then will we take time to make the effort to learn. Creativity is based on knowledge acquisition. No matter whatever wonderful Workland you stumble in and meander through, continual employee knowledge acquisition is the golden thread of Adrian to follow, leading you safely in and out of professional labyrinths to escape the Minotaurs of unemployment. How to be more creative? Know yourself better by discovering what you do not know.

Conclusions and Future Directions

As this neuron creativity cruise now comes to port and is moored at the docks of our thoughts, another legend again unfolds but this time in the Old World almost four centuries later. In 2009, a fellow Thunderbird MBA graduate, Marcus of Austria, accompanied me to visit a historical sight frequented somewhat by tourists in Stratford-Upon-Avon. The private guide was kindly provided by the Shakespeare Trust who oversees and manages the sight visited. As the guide recounted how the sight was identified then saved, her story seemed to inspire an almost comical Cartesian dichotomy for my Habsburg friend but a binary black-white/wrong-right judgmental Puritan mental image of disappointment for me. It seems the reality of this legend is a local social figure, a so-called actress or patron of the arts, who persuaded, in her own very creative way, her wealthy American friend and benefactor, an alumnus of that so very famous school in Boston, to financially arrange the acquisition and caring of the English cottage in question. The English cottage in question is considered to be an ancestral family residence through the maternal lineage of our pious Puritan preacher who never founded anything. Oh may her audacious, but useful, creativity not inspire him to roll over in his grave! Is creativity French Cartesian logic or binary Puritan black-white/wrong-right thinking? Is being more creative seeing what others cannot or will not? How to be more creative? Being more creative is neither Old World Habsburg nor New World Harvard. Being more creative is simply seeing things in ways others do not.

Cross-References

► Creativity
► Culture
► Knowledge Management

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