Engineering practices
The Knowledge of Action
Pratiques d’ingénierie. Les savoirs de l’action
Practicas de la ingeniería. El saber que hay en la acción

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Introduction

1 What do engineers really do at work? What knowledge do they produce or use in situ? In fact, our own knowledge in this area is limited. When it comes to engineering, historical and sociological literature focuses on the profession, on the role of engineers in society, their training institutions, the positions they occupy, their identity (Faulkner, 2000, 2007, 2009), the low percentage of women engineers, the functions they fulfill, and the “non-technical” knowledge they need. Basically, existing writing homes in on what makes up their life but not what they really do. As for engineering knowledge, publications are more interested in the rationality of engineers or their scientific bases and cognitive problem-solving processes. Engineering in action and in situ seems to escape their radar.

2 Engineering is reputed to rely on formal scientific knowledge. Engineers are seen to base their thinking on mathematics especially. This thinking involves methodically examining a problem and its possible solutions and then exploring these thoroughly before formalizing the solutions using unambiguous languages such as industrial drawings or computer code.

3 Most engineers are indeed confronted with problems they must solve. Yet, once they have actually commenced their activity, they are obliged to work to tight deadlines, in the field and in action. They must be able to coordinate a range of different fellow workers, as well as cope with order givers, customers and users. This suggests that the skills they call upon most often come from their informal knowledge, which they gradually gain through experience. What can we learn from reality?
Design studies have been the subject of empirically founded analyses for the last twenty years. However, beyond the highly valued field of design, engineering activities and practices are still part of a basically unknown universe, mostly ignored by the human and social sciences. Little has been written about the way engineers use and adapt scientific knowledge in action, or the role of formal reasoning, mathematics and models in action, and again the way this knowledge is implemented and has an impact on field knowledge. Little is known about the knowledge produced in the field, when engineers are faced with the unexpected events and incidents of project and production management.

The dominating simplistic vision of engineers’ work stems from their training, with its scientific loftiness and social aura. In fact, many engineers at work are more focused on action in the field (mines, oil platforms, factories, research laboratories, site meetings, etc.), and produce knowledge that they themselves have difficulty explaining. Beyond the socio-political aspects pertaining to engineers and an analysis of the roles they are asked to play, we still know very little about knowledge in action.

This edition of the Revue d’Anthropologie des Connaissances aims to provide a modest contribution to this question. It covers some empirical and theoretical research that aims to shed light on concrete work practices in engineering, especially the way these relate to production and the use of knowledge in situ. It also aims to provide the reader with a number of analyses homing in on engineers at work. This introductory article presents an overview of the main contributions to this area of engineering studies.

**Engineering practices and knowledge as fashioned by history**

Engineering knowledge has evolved with the profession’s institutional status. With respect to the birth of the modern-day engineer, historians (Mazzotti, 2002; Dias de Figueiredo, in this edition) point to the close relations linking formal knowledge with the professionalization process and the birth of the modern State (emergence of administrative and bureaucratic structures).

Thus, up until the start of the 18th century in France (Grelon, 1998), engineers were the civil servants of a monarchical and centralized state. They were selected and trained by administrative authorities so that they could build strongholds and seaports, manage arsenals and develop artillery, but also build a network of roads and bridges to control the country. Engineers were part of a military body and were above all in charge of managing men. Later, after 1720, the State created bodies of civil engineers, who were also public employees. Their work was mainly administrative, requiring a gift for command and technical skills so that they could manage road and bridge building (École des Ponts et Chaussées specialized school created in 1747), mining (royal inspectors and École des Mines specialized school created in 1783), and water supplies (Reynolds, 1991). Gradually, their training included scientific disciplines and mathematics until the École Polytechnique was created in 1794. This engineering school promoted theoretical training in mathematics, to such an extent that this discipline became the cornerstone of all engineering training. However, even in the 19th century, when industrialization was just beginning and companies had started poaching or hiring state engineers, or recruiting them as they abandoned state employ, engineers were put in charge of
managing projects. Scientific knowledge and mathematics still only played a marginal role alongside technical and management expertise and the ability to command.

9 The industrial revolution in the United Kingdom led to the emergence of another family of engineers. These were practitioners of the manufacturing industry who were put in charge of the technical management of factories. They were workers who were promoted to technical supervision and solution design positions. Their work was nevertheless not very highly valued; it was seen as unfit for gentlemen, who considered themselves destined for a career in financial and accounting management. In France, this civil engineer model inspired the creation of another specialized engineering school, the École Centrale des Arts et Métiers. Unlike the others, this school only recruited young people with no industrial experience, preparing them to take on the role of factory manager. Modelling itself on the schools, which trained engineers for state service, it reinforced basic theoretical training. In France overall, whatever the type of school, engineering knowledge became much more theoretical.

10 Although there are close links between the scientific knowledge taught, the make-up of the professional group and the modernization of the State, historians (Mazzotti, 2002) nevertheless query the meaning of these causal relations. Is modern engineering knowledge primarily the fruit of advanced mathematical knowledge and scientific progress, hence propelling engineers from a craftsman’s status to that of a professional (an intrinsic effect of scientific progress)? Or, on the contrary, is the emergence and stabilization of new forms of knowledge, especially mathematics, the result of a process legitimizing a new distribution of power linked to administrative reforms and the public authority’s need for an elite body of professionals justifying this transformation? From this viewpoint, engineering knowledge and practices are the negotiated result of social, political and economic interactions (Alder, 1997; Kranakis, 1997). The development of abstract and complex “advanced mathematics” is thus a means of justifying the selection of an elite body rather than of establishing the formal knowledge required in the practice of the profession. In this case, training in mathematics also enshrines an ideological dimension (Picon, 1992; Brian, 1994: Mazzotti, 1998). A third analytical point of view is put forward by Massimo Mazzotti (2002): moving beyond the debate on causal relations, he focuses on the case of the professionalization of civil engineers in Naples at the start of the 19th century and shows that the legitimization of the new mathematical knowledge of engineers and their action in the modernization process of the State is part of a movement to make cognitive resources available to help with social reform. He underlines that “the battle for modernization had to be won not only “with” but “in” school books on mathematics.” (Mazzotti, 2002, p. 88).

11 This historical shaping of the formal and informal knowledge of engineers is obviously not limited to this episode of history. On the contrary, as Antonio Dias de Figueiredo points out in this edition with respect to the multiple mutations and identity crises occurring over time, engineering knowledge has been widely reconfigured. Covering over 2000 years of history, he identifies four dimensions of engineering practices reflecting four knowledge registers: craftsmanship, design, basic sciences and social sciences. These registers are divided into two areas: practice/theory and society/matter-energy-life. He suggests that, in practice, each engineering movement, if not each engineer, uses these registers in various ways according to the dynamics of the profession, the requirements and pressures linked to circumstances and the historical
context. Engineering is thus impelled by the genius of the craftsman, the visionary, the rationalist or the entrepreneur according to circumstances.

These engineering practices and knowledge vary over time but also in space. Thus, several engineering traditions have emerged in Europe. Alongside the rationalizing and bureaucratic engineering practised in France, ambitious projects based on learning to use an empirical and practical approach to problems became fashionable in the United Kingdom, including measurement and testing and a general weariness in relation to complex mathematics and scientific theories. In Prussia, with the university reform of Wilhelm von Humboldt, in Berlin, close relations developed between teaching and research. This ultimately met the need for specialist technicians (in electrical engineering, electromechanical engineering and chemical engineering) for the second industrial revolution. These different models remained separate, resulting in a range of engineering training, designs and engineer profiles, and hence engineering knowledge geared towards the management of large public projects or factories, innovation in workshops or specialized technical expertise within a vast industrial division of labour.

Different technological development paths as well as bodies of knowledge, design traditions and working methods emerged according to historical circumstances and social, institutional and ideological contexts (Kranakis, 1989). These influenced technical careers and skills differently according to the country (Crawford, 1991). Eda Kranakis (1997), in Constructing a Bridge, shows this through her analysis of the development of suspended bridges in the 19th century. She reports on the action of inventors and designers and what fashions their working methods in their immediate environment, pointing out the differences in France and America in terms of design objectives (inventing a bridge with potential for industrialization/erecting a monumental and visually-pleasing work of engineering), research traditions (theoretical/empirical) engineering teaching, and the way they organize and manage projects.

Engineering knowledge in practice

In communication designed to attract young people to this discipline, engineering is presented as a rational activity involving problem-solving and innovative solution design.

The knowledge covered in training

Thus, as well as gaining a solid basis in mathematics and science during their training, students also learn to model problems and evaluate (compare) solutions. They learn the basic principles underlying a range of tools and methods (for measurement, analysis, modelling and evaluation), as well as how to use them (in classes focusing on the design and engineering office, the lab, the workshop or the field). In order to solve their problems and evaluate their solutions, they learn to use scientific knowledge and to take into account a series of requirements: technical codes and standards, manufacturability, ethics, health and safety issues, and durability. However, time requirements and economic considerations are given little attention in class whereas in companies they are of prime importance (Koehn, 1999). During their training, learner engineers are invited to use their imagination to find solutions that they then explore.
before choosing the one that best seems able to solve the problem. They must then
describe the solution (for example by drawing it) in order to present it to their teacher,
who plays the role of customer. Next, they put forward arguments reflecting the
rationality behind their reasoning and their mastery of the knowledge acquired in
terms of behaviour and modelling laws. Sometimes, they have to discuss several
possible solutions before choosing the optimal one. This engineering training channels
a vision of the engineer as somebody who, alone (or as part of a small group of peers),
solves complex technical problems using calculations. Furthermore, once the solution
has been found, their work as an engineer stops there. What happens next is reduced to
a simple question of implementation. Putting the solution into practice and managing
any problems that it might throw up are not generally part of the training. Sometimes
this training is backed up by lessons in project management but these classes do not
concern the implementation of the solutions defined in other classes.

Engineering literature does nothing to allow the engineering student to forge a
different representation of the profession. It outlines solutions (technical or based on
algorithms), discusses their underlying principles or associated methods, compares
solutions and presents test results, but does not deal with the concrete activity of
engineering. Publications dealing with the actual work of engineers are scarce, even
when it comes to implementing a solution in a company. An analysis of a corpus of
560 publications focusing on ERP systems (Enterprise Resource Planning) (Heili &
Vinc, 2008) shows that, apart from describing solutions, the publications only discuss
the ability of these IT systems to be relevant management instruments with respect to
the challenges raised by the environment.

Thinking driven by calculations, modelling and formalization

Engineering work is often presented as involving thinking based on calculations,
modelling and formalization. It necessitates simplifying reality in order to build a
plausible and operable representation of a problem. This representation is linked to the
real world through measurement operations that provide the basis for calculating
solutions. It follows that this approach to the world is used to think about problems and
solutions in highly diverse situations: ensuring the defence of a Nation, saving ports
from the risk of sand build-up, boosting the economy of a country by adding road and
waterway networks to the landscape, optimizing production processes, developing
knowledge about human behaviour based on the traces left by communication
technologies, etc. Not one of these fields of engineering action is disconnected from
society or from economic, political, ethical and aesthetic issues. From this viewpoint,
modelling and calculation work is thus always geared towards things that are
important and make sense for social groups (Vatin, 2008). Social values, efficiencies and
equities are all interlinked.

François Vatin (2008) takes the example of forestry engineers and the calculation of the
forestry optimum. He shows that the calculation and its apparent objectiveness are
linked to social values. The forest is considered as a public good because it is strategic
from a military point of view (supply of lumber for the marine). It is nationalized (the
Church is expropriated from its forests) and partially sold in line with the liberal social
ideal of the French revolution. With forest privatization leading to accelerated
deforestation, the State imposes conservation measures on private owners. The forest
is then placed under the authority of a body of public engineers modelled on the existing bodies of bridge and mining engineers. The forestry engineers then create their own review (the *Annales forestières*, echoing the *Annales des Mines* and the *Annales des Ponts*). This allows them to debate forestry questions and draw up a doctrine for rational forest use benefiting the community.

For these engineers, it is a question of optimizing marginal productivity and hence reconciling the interests of forest owners with those of the Nation. Determining the production optimum nevertheless proves to be complicated and requires several generations of engineers. They eventually realize that they need to distinguish between different types of interdependent optima (growth in tree volume, circumference; individual tree/coppice). Each raises practical problems in terms of measurement. Furthermore, there is the additional concern of the financial yield of forests. This leads to the outlining of an annual forest income and its capitalized value (income from logging if it were placed in a remunerated account). The engineers therefore invent a “composite maximum”, which results in a conflict between individual interests and general interests. This leads them to distinguish between a “real” economy and a speculative economy, and to then take into account the different owners’ interests according to whether they are large (including the State) or small. Here, the idea is that the larger owners can support forests with longer cycles (timber forests for the Marine) while the smaller owners find satisfaction in coppices.

The calculation and optimization operations performed by the engineers are not cloistered from the rest of the world. They are obviously mixed up with questions of fairness, justice, strategy, power struggles between different actors according to their status, and interests and concerns for the present and future. With their calculations, the engineers find themselves at the heart of society and its problems. Their calculation methods are so tied up with the interests and challenges of society that they fail to calculate a decision reflecting the interests of all the different actors concerned across several generations (given that engineering must also take into account the future of humanity and the planet, the preferences of different actors in terms of living intensely now or adopting a moderate attitude for the benefit of future generations). There is thus no break between calculation and politics; calculation is just another way of doing politics.

Similarly, French engineers who have specialized in the building of bridges and roads since the 19th century are unable to separate what relates to technical matters and what relates to economics. Often isolated in rural areas, in charge of the building and maintenance of roads, canals, and then railways, they strive to define optimal solutions (Picon, 1992). Trained in high-level mathematics at the *École Polytechnique*, then in their specialized training school, they model the world they are in charge of when confronted with concrete management issues (Vatin, 2008). Their mathematical tools (differential calculation) enable them to prepare reasonable, implementable, rational and fair decisions. These help to guide policies since they reflect what is good for society. To rationalize the way the world is run, they measure what they can and in whatever whey they can, through experiments or statistics. While being fully aware of the inaccuracy, if not wrongness, of their measurements, they are convinced that measuring is a necessary condition on which decisions should be based. To assess the efficiency of their solutions with respect to a desired objective, they mathematically compare the ends (i.e. what is of social value) with the means. Hence, they link up
calculations and values, efficiency and justice. Once the debates underlying the implementation of their calculation-based approaches have faded into the distance, they sometimes lose sight of the social norms and values underlying their approaches. The level of sophistication of their calculations or their translation into algorithms sometimes transforms them into black boxes (Latour, 1989), which take on the appearance of objectivity and neutrality. In the 19th century, measuring “road wear” caused by traffic results in engineers qualifying vehicles according to their tendency to destroy the road. They then lay out technical standards (wheel width) and economic standards (different taxes according to vehicles and their loads), leading to questions about the impacts on economic life and equity (case of destructive but highly useful vehicles).

Calculation-driven thinking in engineering thus combines physical measurements and equity in the calculation. This is what can be found in the work of railway engineering (differential rates, road-rail transport), in telephony in the inter-war period (quality of lines, operator productivity, profitability of telephone circuits) (Bidet & Vatin, 2008), and, today, in aeronautics (greenhouse gas taxes and eco-design) or energy price regulation (gas, shale gas (Baudrin et al., in this edition), nuclear or photovoltaic electricity).

**The types of knowledge used**

Engineering knowledge varies according to the field. Knowledge bases are partly specific to certain specialities. The properties of wood, steel or concrete, for example, belong to the knowledge repository of structural engineers whereas, in industrial engineering, knowledge focuses more on production system dynamics. This knowledge is partly codified in text books and collections of standards. Collated and formalized through scientific research and state-of-the-art surveys, it is passed on through teaching, publications and consultants. According to Walter Vincenti (1990), it is so important that it makes teaching more important than hands-on training. Other authors disagree with this arguing that engineering above all requires practical knowledge produced through activity (Bucciarelli, 1984, 2002; Button & Sharrock, 1998; Henderson, 1999; Hutchins, 1995; Lave, 1988; Lave & Wenger, 1991; Vinck, 2003). Solving problems using repositories of known solutions underestimates the complexity and novelty of the concrete situations encountered by engineers (Schön, 1983). Labouring in situations of uncertainty, especially in the field of innovation, engineers produce new knowledge from practice as well as from exploratory and experimental work. This less formalized knowledge concerns methods of coping in situ rather than products or techniques. Engineers capitalize on this knowledge through collections of standards, archives of past works, data or case bases, and the repositories of colleagues providing useful expertise. Studying engineers at work shows that formalized knowledge represents less than half of what is used in the activity (Florman, 1997; Richardson, 1997).

Different types of knowledge can thus be distinguished according to sectors and types of activity and in relation to the ground covered in a project (Mer, 1999). In design, for example, the work is generally organized in line with the increasing level of sophistication and the build-up of details in drawings, models and calculations: knowledge relating to needs and product concepts, and theoretical knowledge...
Observation of structural engineers at work (Gainsburg et al., 2010) shows them in the process of calculating buildings (shapes, dimensions and materials), for example. To do this they use the formal knowledge documented in manuals and building codes, but they also produce sketches, put together mock-ups, consult archives of previous projects, perform tests and measurements, build models, discuss ideas with colleagues, etc. Different types of knowledge are identified: design criteria (the economic or functional objectives of customers and other stakeholders), basic design concepts (variables in relation to expected performance and requirements to be fulfilled), theoretical and conceptual tools (scientific concepts, mathematical formulae, behavioural models, sometimes integrated into software), design tools (procedures, thinking methods, know-how about how to read drawings, software knowledge and modelling strategies), data (measurements, supplier catalogues, etc.), rules of thumb (guestimates, approximate data, and shortcuts allowing the project to advance in spite of the lack of exact values), characteristics relating to structural elements (properties, commercial names, variants, etc.), data and feedback about the feasibility and ease of construction, information about the organization of work (project management tools, breakdown into phases, schedules, etc.), and knowledge about the sector's actors (companies, architects, other engineers, draughtsmen, inspection authorities, etc.).

The above authors show that engineers use much more knowledge than the scientific bases they learn. They hence challenge the representation of engineering work as a solitary activity solving problems. Walter Vincenti (1990), for example, shows that the engineer is regularly faced with substantial uncertainties, that the problems they must solve are often badly defined and that their definition has to be negotiated. Focusing on design activity, Louis Bucciarelli (1994) underlines the extent to which the knowledge used in engineering work is very different from what is taught. Engineering depends on technical acuity and tacit knowledge linked to specific contexts stemming from experience. It also demands the ability to deal with different people, problems and failures. It involves object worlds (Bucciarelli, 1994) and multiple interactions with various people (Vinck, 2003). What engineers learn during training, i.e. a world full of mathematical and physical principles, hides other dimensions of their know-how (Vincenti, 1990).

Sociotechnical knowledge

The ethnographic surveys we have performed with our colleagues in design offices (Vinck, 2003; Lavoisy, 2000; Lécaille, 2003) report on design activity and emphasize the importance of the dynamics of interaction and exchange between actors, the production and circulation of multiple intermediary objects (drawings, mock-ups, broken parts, lists of data, screen shots, etc.), and the building of compromises between actor professionals with varying viewpoints.

One of the surveys reports on the work of a young mechanical engineer in charge of designing a simple mechanical part, i.e. a shielding wall. At the start of his work, he imagines himself sitting behind a computer, using computer-assisted design software, and designing a solution based on the customer’s needs and his own knowledge of mechanics. He thinks he will be able to prove his creativeness and find a clever
solution, then study it, optimize it and validate it using drawings, modelling and calculations. He certainly does not expect to be faced with a customer (a community of several hundred physicists of international renown), who have not formalized their needs and are reluctant to do so in case they want to change their minds as the scientific project evolves. So the young engineer realizes that he will first have to form an idea of the identity and needs of this inexpressive customer. To find out what the researchers want, he starts to draw a first solution. He wants the researchers to react to the drawing so that he can at last understand what they want. He uses calculations to consolidate his arguments in order to convince his customers and gain their trust. The young engineer gradually discovers that behind each technical detail there are actors with whom he has to learn to negotiate if his technical solution is to appear consistent and relevant. Engineering work is sociotechnical work; actors and content become intertwined in the definition of problems, integration of knowledge and the search for solutions and their implementation.

Studying engineering work in situ is also a means of reporting on work practices and notably the way people think with a pencil in hand, the way they make themselves understood by pointing at a detail on an intermediary object (Adler, 1998; Henderson, 1999; Vinck, 2003), or the way they give a demonstration (Johri, 2012). Engineering work thus appears to be work involving and articulating the knowledge of multiple actors (Downey, 2009) in order to benefit from the formal and tacit knowledge of each one. James Trevelyan (2010) refers to distributed expertise. This involves building relations of cooperation, asking people relevant questions, then checking “you have understood what they want”. Engineers say that it is hard work learning to communicate. In other words, it is hard learning to understand other people’s problems and requirements, having people understand you and building satisfactory compromises (Anderson et al., 2010; Downey & Lucena, 2004).

Such ethnographic studies show that engineering is made up of multiple activities happening in specific places and at specific times. These places and times are themselves caught up in networks of relations that actors strive to interlink (Law, 1989; Suchman, 2000). Such studies are usefully backed up by an examination of the profession-related sociotechnical paths followed (cultural, economic, political and material), the representational (Alder, 1998) or experimental tools implemented (Sims, 1999), the knowledge and forms of work organization used, the professional identity conveyed (Hatmaker, 2012), but also the places where the activity is exercised and all the different artefacts mediating the activity. Henry Petroski (1995) thus shows the importance of the co-development of practices in engineering and of the materials and tools of entrenchment and persuasion (drawings, calculations, arguments).

**Work involving coordination**

Although design activity is highly valued in what is said about it, engineering in practice is also and above all made up of less prestigious activities. These are nevertheless determining for the performance of sociotechnical systems: maintenance, planning, organization and response to unexpected events (Trevelyan, 2007).

When surveys are not limited to the study of design work, they demonstrate that engineering is above all a work of coordination, linked to practice-related contingencies and to the distribution of expertise among multiple actors. This work is what the activity of engineers is really all about (Trevelyan et al., 2006; as well as the article by
Williams and Figueiredo in this edition): preparing, organizing and planning work; looking for information and procedures; drafting instructions, checking data and managing tests, etc. Although they often have to solve problems (a machine that breaks down, a supplier who has provided the wrong product, a management committee that switches strategy, a competent worker who has to absent himself/herself for a meeting, a customer who modifies their requirements, etc.), they rarely have the time to do this according to the problem-solving process taught during their training. They must above all deal with unexpected events and manage uncertainty in a rational manner, as well as deal with the interference caused by everybody else (director, supplier, customer, etc.). They therefore have to cope with several problems at once and manage several projects simultaneously, while at the same time optimizing resources and generating economic and social value.

The article by Bill Williams and Jose Figueiredo in this issue explores what engineers do in Portugal. Based on an online survey involving 177 junior engineers and exploring the time they devote to different activities, as well as 22 interviews about their work, they show that sociotechnical knowledge plays a primary role in their career right from the start. They demonstrate that the engineers’ work involves constantly looking for workable solutions while coordinating people and linking up heterogeneous pieces of information inside a complex network of interdependencies. Bill Williams and Jose Figueiredo thus show that what the young engineers believe at the end of their training, in other words that the main ingredients of their profession are linked to the physical sciences and are expressed through the language of mathematics, ill reflects the reality of engineering work. Engineers have to call on social and communication skills as well as good judgment, i.e. skills they do not learn at school.

The sociopolitical constitution of performance in engineering

In this issue, James Trevelyan queries performance in engineering. Considering engineering as a driver able to augment productivity and the social, environmental and economic benefits that can be drawn from financial investments, engineering performance represents an important stake for the populations concerned, notably the poorest. If we assume that engineering consists in applying knowledge and scientific and mathematical methods, insofar as such knowledge is widely available in the world (at least for technologies allowing the production and distribution of drinking water or electricity), the investment in engineering should produce comparable results everywhere. However, when Trevelyan compares South Asia with Australia, he observes a very different reality: engineering performance varies greatly according to region. To understand this paradox, he examines the work practices of engineers and discovers a high level of social heterogeneity (social hierarchies, management systems, representations of knowledge, development of skills, etc.), as well as how intertwined engineering is with political economics (see also Friesen, 2011).

The survey focuses on water supplies, mechanical construction and telecommunications. It brings to light social, economic and political factors that are generally not covered in training. It notably underlines that the degree of autonomy enjoyed by the engineers is much more limited by management in South Asia than in Australia. It reports on the negative influence of hierarchical managements and the positive influence of formalized knowledge and procedures.
The survey nevertheless shows that the primary influence of the local sociology and political economy is not entirely inevitable and determined by the local cultures to which the engineers inescapably belong. In reality, high-performing engineering practices exist alongside mediocre performance levels. Thus, in the telecommunications sector of developing countries, engineering proves to be capable of performance levels equivalent to those in developed countries. This leads to the question of understanding what causes these differences and whether high-performing practices can be transferred from one sector of activity to another, e.g. from telecommunications to water and electricity distribution. The challenge is all the greater given that the limited resources of these countries require engineering to be at least as high-performing as in countries that do not suffer from limited resources. The author concludes that the influence of social interactions on engineering performance levels should be taken into account by engineers. He points out that young engineers consider this to be management’s job believing that it has nothing to do with their own social role (Sainsaulieu & Vinck, 2015).

Work specifications

One part of engineering work consists in defining products, processes, equipment and working methods, in other words it involves specifying what has to be done and how. This specification work, which initially aimed to outline the work to be performed by operators (workers and technicians), has gradually been extended to include engineering and management work. In the past, innovation or production tool transformation projects used to escape standardized procedures owing to their specific nature. Project managers were free to do as they pleased, but this is no longer the case today. Now, the engineers in charge of project management must follow procedures and use certain tools (for managing technical data, for example), specified by others.

In an article published in the Revue d’Anthropologie des Connaissances, Mathieu Bensoussan (2013) analyzes the production of specifications pertaining to the work of project engineers. According to the author, this involves collecting their different working methods (experience-sharing meetings, feedback sheets or project progress reports) in order to then formalize these either as procedures or as listed cases in a data bank. The survey shows that this increased formalization of project engineers’ work limits their freedom. At the same time, however, it also enables them to benefit from the knowledge of fellow colleagues and hence extends their ability to complete projects.

Communication skills

Among the dimensions of engineering know-how, recruiters insist on the importance of communication skills. The performance of engineers depends on their ability to express themselves, to share information about and have their colleagues and partners understand the problems they are up against, the methods they use and the results they obtain. They must also be able to understand the people around them together with their viewpoints. Engineering depends on the ability to communicate but, conversely, this ability also depends on technical skills. This interlinking of technical and communication skills leads some authors (Ruiz, 2007) to say that, in the case of software engineering, women engineers will progressively have more influence than
their male colleagues precisely because of the importance of communication between experts and with customers and users.

Engineers face two pitfalls in the way they communicate (Leydens, 2012): they may consider that communication is neutral and based on technical facts alone or they may imagine that the data speak for themselves. In reality, the data are linked to specific contexts and points of view. They need a spokesperson to suggest ways of interpreting them, which is something the engineers who designed the boosters of the Challenger shuttle did not take into account. Experienced engineers, who are aware of this communication aspect, tend to examine contexts with greater attention than young engineers (Anderson et al., 2010). This is all the more important given that engineering work also entails a considerable amount of reporting (inputting information, drawing up reports, holding project progress meetings, etc.), building relationships based on trust and negotiating room for manoeuvre. Thomas Reverdy (2011), exploring the case of engineers in charge of buying energy for large industrial companies, shows that the engineers learn to manage complex situations riddled with uncertainty: erratic prices, variable availability of distribution networks, changes on markets, energy policy decisions, complexity of contracts, diversity of stakeholders and introduction of new methods prescribed by consultants. In this complex arena, they build themselves room for manoeuvre, give visibility to uncertainty, set up alliances with traders in order to disqualify consultants attempting to impose their misleading methods on them, create loyal and trusting relations with management and technical experts (both in-house and with suppliers), negotiate their own assessment criteria with their managers, build frameworks allowing them to justify their decisions, and organize a decision-making process so that decisions are firmly based on a broad consensus involving management. All of this requires developing skills that are not taught.

Communication in engineering goes far beyond work organization alone. As they design life and world-changing products, engineers have to take into account the impact of their developments and juggle with the requirements of their customers and society. They have to report back (Shrum, 2010) when they are fashioning their perception of problems, negotiate the resources they need for their work or strive to convince others of the quality of the solutions they put forward.

Knowledge that does not impose itself

The ethnographic study presented by Andrew Chilvers and Sarah Bell in this issue shows how, in practice, and using their knowledge, the engineers working in a construction industry design office attempt to act in compliance with the strategic end goals of their company (satisfying their customers and contributing to society and to sustainable development). Yet, their knowledge and the values they promote are not enough to significantly influence the projects they are working on. Their hands remain largely tied by other actors in a better position than them in the project network, notably the architect, who acts as customer’s spokesperson, for whom they are simply subcontractors. With their engineering knowledge, they are able to assess the realism, cost and consequences (in terms of functionality, structural efficiency and durability) of the solution put forward by the architect and sharpen their own arguments ready for future architectural negotiations. They never impose their knowledge, however, or use it to impose a solution or a decision. On the contrary, during discussions they use their
knowledge with parsimony, calling on it only when they are doubtful or reticent or wish to underline the negative consequences of an idea or deflate the architect’s aspirations. They never use their knowledge to corner the architect or impose a decision on him. In fact, it is quite the opposite that occurs: the architect imposes his aspirations on them and they use their engineering knowledge to come up with and assess other solutions. They thus call on their knowledge to find solutions that satisfy the architect. Instead of using their knowledge to bestow new values on the construction industry, they pay the heavy price of compromising their own corporate values. Their knowledge only allows them to dampen some of the architect’s aspirations.

This excellent study also reports on submissive knowledge and invisible work in engineering. It shows that equipping engineers with knowledge and new values is not enough for them to change the world since it is through everyday practice in specific sociotechnical networks that compromises are forged and technical developments fashioned. If these networks are not reconfigured (forms of division of work, relative position of actors), the knowledge and values of engineers alone do not allow them to rise to the challenges of society. Engineering practices are highly constrained, but less so by scientific and technical knowledge than by other actors and their position in sociotechnical networks.

Re shaping the world: heterogeneous engineering

The work of engineering goes well beyond design activity. It involves stabilizing sociotechnical systems by articulating a series of heterogeneous elements used to solve problems. In other words, it involves managing the complexity and contingency of a situation and negotiating solutions (Callon, 1986; Law, 1989), imagining, building and controlling all sorts of elements and actors and their relations, as well as deconstructing pre-existing assemblages (Goulet & Vinck, 2012). It involves convincing multiple actors (Downey et al., 2006) of the interest of something new and making sure it adapts to society and society adapts to it. But it also involves querying what engineering implicitly conveys in terms of world shaping (Nieusma & Riley, 2010).

The development of wind energy in Denmark is an excellent example of the influence of engineering communication on the success of innovation (Nielsen & Heymann, 2012). Denmark’s technical and commercial success in this field is all the more striking given that the manufacturers were engaged in a slow development process. This process involved the craftsmanship and learning of small electricity producers, and exchanges between engineers and other wind energy actors. During these exchanges, the engineers debated the energy policy and the role of technologies in society. They interacted with militants, entrepreneurs, journalists, researchers, small-scale businesses and elected officials, but they also shared their knowledge and experience without imposing any rules on the manufacturers. These multiple exchanges thus forged a shared language between the different actors, allowing them to develop and control a technology that had become a reference model.

In this issue, Matthieu Hubert and Dominique Vinck use five case studies to examine how micro and nanotechnology engineers fashion technology and society through their work in various places: international committees where roadmaps are defined, research laboratories, platforms dedicated to the exploration and transfer of
technologies to industry, research programmes where researchers and companies fashion sociotechnical infrastructures and regulate the entrenching of technical innovations in society. The article documents the mechanisms of a possible sociotechnical transition, from the building of laboratory projects through to their entrenchment in society. It also “follows the actors” and their concrete, situated practices. It shows how engineers combine market and competitor requirements, legislative concerns, consumer preferences, citizens’ reactions, the unknown behaviour of objects at nanometric scale and the strategies of research institutions. The authors underline the heterogeneity of practices (work articulating, organizing, equipping, coordinating, (re)qualifying, communicating, negotiating, etc.). Using the concept of heterogeneous engineering, they emphasize the differentiation of engineering practices and processes.

BIBLIOGRAPHY


ABSTRACTS

The article highlights the main contributions of the social studies of engineering, and reports on the historical shaping of its practices and knowledge. It then reviews the state of the art of our knowledge on the production and mobilization of formal and informal knowledge in engineering: knowledge received in training; computational, modelling and formalizing thinking; types of knowledge, including their socio-technical nature; knowledge of coordination, prescription and communication; their socio-political constitution and the challenges of innovation.

L’article rappelle les principales contributions qui relèvent de l’étude sociale de l’ingénierie (engineering studies), dont il rend compte du façonnage historique des pratiques et des savoirs. Il dresse ensuite l’état de l’art de nos connaissances portant sur la production et la mobilisation de savoirs formels et informels en ingénierie : les savoirs reçus en formation ; la pensée calculatoire, modélisatrice et formalisatrice ; les types de savoirs, dont leur nature sociotechnique ; les savoirs de coordination, de prescription, de communication ; leur constitution sociopolitique et les enjeux de l’innovation.

El artículo recuerda las principales contribuciones del estudio social de la ingeniería (engineering studies), e informa sobre la conformación histórica de las prácticas y el conocimiento. A continuación, se revisa el estado del arte de nuestros conocimientos sobre la producción y la movilización de los conocimientos formales e informales en ingeniería: los conocimientos recibidos en la formación; el pensamiento computacional, de modelización y de formalización; los tipos de conocimientos, incluida su naturaleza sociotécnica; los conocimientos de
coordinación, prescripción y comunicación; su constitución sociopolítica y los desafíos de la innovación.

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**Mots-clés:** savoirs, ingénieur, savoir informel, formation, pensée calculatoire, modélisation, coordination, communication, prescription, innovation

**Palabras claves:** conocimiento, ingeniería, conocimiento informal, formación, pensamiento computacional, modelización, coordinación, comunicación, prescripción, innovación

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