STRÖMSTAD AKADEMIS FRIA SKRIFTSERIE

Lars Ingelstam

Technology as the Core Issue

On the Need to Liberate Technology Studies from Economism and Scientism

Nr 7, september 2018

ISBN 978-91-86607-43-2

Strömstad akademis styrelse beslutade 24 juli 2013 att inrätta Strömstad Akademis Fria Skriftserie med följande riktlinjer:

Ledamöter i Strömstad akademi har rätt att utan granskning få manuskript publicerade elektroniskt i Strömstad akademis fria skriftserie. Det enda som gäller är att författaren ansvarar för innehållet och för att det inte strider mot svensk lag eller innehåller copyrightskyddat material. Manus skickas direkt till webansvarig.

Technology as the Core Issue

On the Need to Liberate Technology Studies from Economism and Scientism

Contribution to the National STS Conference in Uppsala, August 30-31, 2018

Lars Ingelstam[1]

Abstract

The aim of this paper is to argue for increased attention to the defining and generic properties of technology.

Contents

Introduction and background

The aim of this paper is to argue for increased attention to the defining and generic properties of technology: what might be called its "nature". My interest in this topic can be traced back to one particular professional turn in my life – but is of course also related to many influences before and after that. What I refer to here is the creation of a research theme Technology and Social Change, at Linköping university and my role as one of two first professors in the theme from 1980.

This was a rare opportunity and challenge, given my back-ground[2] and general world-view. I had spent 15 years in a technical university (KTH). The internal culture of KTH contained very clear and visible tensions between three forces, each one with its internal advocates and outside allies: science, economics/business and technology/engineering. Strangely enough,

[1] Professor emeritus of Technology and Social Change, Linköping University and Professor of Technology and Social Change, Strömstad Academy. Mail lars@ingelstam.se.

[2] During my high-school years, my father who was docent in physics and later became professor at KTH, ran a quite successful program (1943-1964) together with a group of committed colleagues, promoting a broader humanistic outlook among future engineers. It has been documented by professor Gunnar Richardson (Richardson 1987)

the latter was the less outspoken and self-assertive among the three. In order to promote "technology" representatives of KTH often chose to invoke arguments from economy or science, or both. KTH is a "technical university" – which lately also has become a popular brand name for academic centers such as Chalmers and LTU – but then the question bounces back: what is indeed "technical" about it?

As a mathematician and physicist in KTH, I was slightly distanced from the technical core of the place, but repeatedly asked myself (and others) the question: what *is* this thing called technology? I was thrilled to find out, much later, that W. Brian Arthur (1946-) – whose academic trajectory is almost identical to mine – had asked the same kind of question already as a student but found no convincing answers (Arthur 2009; pp 1-2). Arthur's own answers, which he arrived at late in life, have impressed me, and I will come back to him.

The new theme (research unit and graduate school) Technology and Social Change started in 1980 and had been prepared in an inter-academic process (Linköpings universitet 1976). The main architects and proponents were professors Torsten Hägerstrand (cultural geography, Lund University) and Nils-Erik Svensson (education, CEO of Riksbankens Jubileumsfond) together with historians Sven Tägil and Göran Graninger. They stressed the "very high societal relevance" of research on the interaction of technology with social development and living conditions of individuals. These founding fathers were careful not to prescribe any theoretical basis for the theme: they laid emphasis on cross-disciplinarity and held it to the researchers to secure scientific quality and inter-academic relevance.[3]

During more than two decades this was my almost daily challenge. The following remarks should be understood not only as recommendations to younger colleagues, but also to no small extent self-criticism for omissions and lack of consistency during my active years.

I will attempt three things here:

1 Reflect on the way technology is dealt with in economic thinking, in particular in neo-classical theories of growth and in the currently popular approach *systems of innovation*.

2 Problematize the way in which technology and science are often treated as one and the same, or at least so similar that social research on them could be seen as almost one discipline (STS).

These are somewhat polemical positions. The first is linked to very strong forces in society, the primacy of economic thinking; there is inevitably an elephant in the room, which has to

[3] Since the theme (together with three others, with similar structure) were to be added to an already existing academic organization in Linköping, some tensions similar to those mentioned above immediately became visible. Local economists claimed, quite emphatically, that they were already on the track and were fully prepared to do what was required. Scientists in general welcomed the initiative, with the understanding that here was a non-competing net addition to "their" field. The large Faculty of Engineering was basically skeptical, partly on the (perfectly justified) assumption that research in the new theme might cast some doubts on the thesis that technology offered only blessings to the rest of society. However, the Faculty was welcoming to History of Technology as an addition to its own knowledge base (see also *A forward-looking culture*, below).

be recognized as such. The second is more academic in nature: do science and technology fit together like a happily married couple, or are there significant differences that make them somewhat problematic as bedfellows? In order to transcend pure polemics, some more assertive reasoning is needed.

> 3 Deal with the question: What is the true nature of technology? A young W. Brian Arthur asked what "technology-ness" is all about (Arthur 2009)? If technology is not "applied science" (Simon 1996), then what is it?

The literature on this subject is not immense, and I will limit myself essentially to two authors who I think have put forward the most convincing arguments. (Colleagues in the field may have other favorites, of course!) In conclusion I will put forward intellectual as well as political arguments for giving stronger emphasis to the *specific* nature and properties of technology.

A forward-looking and problem-solving culture

> "Missing Is a set of overall principles that would give the subject [technology] a logical structure."

Already in the very beginning of his book W. Brian Arthur offers us this straight and unguarded comment (Arthur 2009, p 14). He sets technology in contrast to (natural) science as well as economics and points to differences in structure and purpose. But above all he finds that, in comparison to these fields, technology lacks a clear self-understanding. Why is this so?

A possible explanation is that both science and economics somehow have higher *prestige* than technology. In the academic world, they provide relatively elegant answers to the question "what is X". The corresponding attempts to do the same for technology are fragmented and seem a bit shallow. This might explain something. A prestige gap has no doubt existed in the past (see e g Sundin 1981) but is less clear to-day and to some extent reversed. Technology is linked to progress and economic growth and as such highly esteemed, even worshipped, in the political and public spheres.

A weightier reason is found in the fact that the general questions on technology have mostly been addressed by historians, social scientists and economists. To them, technologies have by and large appeared as black-boxed, interesting and often stand-alone objects, but whose detailed properties were beyond reach for the researcher. Clearly this is a major obstacle to understanding how technology evolves. How different – asks Arthur – had it looked if engineers had been the main thinkers about the subject? How come that engineers have been reluctant to work with the theoretical foundations for what they do? Arthur quotes Walter Vincenti of Stanford university: "Engineers like problems they can solve". The problem-orientation and the future-direction of the engineering culture give little incentive to look back and stay with the "why" and the "what" questions.

I have had many occasions to observe this mind-set among engineers (from 1st year students to world-famous researchers). But there is one seeming exception. Engineers are very interested in the *history* of technology. This has, I think, two explanations, both with only a vague relation to concrete engineering work of today.

- It is nice to see that engineers of the past were smart people (and so are we: virtue by association!)
- Technologies of to-day are much better than those of yesterday, which confirms the belief that technology embodies progress.

Economics and the unexplained residual

W Brian Arthur is a mathematically oriented engineer turned economist. He makes a brilliant point about the relationship between economy and technology (Arthur 2009, p 1). He found that

> the economy was in no small part generated from its technologies. In a sense, an economy was nothing more than the clever organization of technologies. Therefore, it would evolve as its technologies evolve.

However, in the mainstream economics literature there are only weak traces of this sound observation. It is rather some “tail-wags-dog” train of thought that dominates. Theories of change and growth inside the neo-classical paradigm (which according to Paul Samuelson is accepted by 95 % of all professional economists) start out in the opposite end (money). Their assumption (or creed) is that “the economy” generates change. To the extent that they recognize the role of technology at all it is only indirectly and in an absent-minded way.

Macroeconomic theories of growth have been formulated, with a reasonable degree of mathematical sophistication, from the early 1950’s. Most influential during several decades was the Solow-Swan model (in its turn an extension of Cobb-Douglas and Harrod-Domar type production functions). In their attempts to fit models to real data, researchers found that in addition to the growth in total inputs (capital and labor) some other factor must be taken into account. This was called the “unexplained residual”. It was not far-fetched, of course, to believe that a major element in this residual consisted of (embodied and disembodied) technical change. The Solow-Swan model does not explain why technology improves over time: it is an exogenous factor (included in the so-called Solow residual). Attempts to include technological change as an endogenous element have later been made. However, they do not alter the fact that in this line of economic thinking technology appears as a poorly understood residual, although with considerable impact on growth rates.

This lack of interest, from the side of a large majority of professional economists, has, in my view, had two adverse consequences. The first is that this powerful academic profession has in effect crowded out and marginalized attempts to focus on the concrete and specific role of technology. The second is that, lacking structured ideas on the role of technology in economy and society, policy-making has been built on sweeping and ill-founded ideas, referring to the (probably!) impressive size of the “residual”. Riding the chariot and assuming that an unproblematic synergy exists between “growth” and “technology” has trivialized thinking. This has been the case in Sweden and similar countries during many decades. In following such a narrative of progress, important opportunities (not least in the long term) have been neglected, while many adverse consequences (diseconomies) such as resource depletion, environmental destruction, undignified working conditions and problematic energy technologies have remained un-observed for too long.

Institutional economics in various forms has been around for a long time, mainly as deviations (or heterodoxy) in relation to the neo-classical mainstream. In that line of reasoning more attention has been given to the specific role of technologies. Recently, institutional elements in economic thought have received more attention, in particular through approaches labeled *innovation* and *innovation systems*. Expanding research in this direction has led to an increased visibility for technological factors. On the other hand, the self-assertive theorizing around these concepts does not go well with the ambition to find the essence of technology. In innovation theories the focus is on "the new" rather than on deeper significance of technology. It is telling that neither Arthur (2009) nor Simon (1996) refer to the term innovation in any serious way.

It is tempting to also link this lack of interest in engineering and concrete change to the wider role of economic thinking in our societies. If the goal of political and social efforts is *economic growth* and the only intellectual support is *economics* (in the sense mentioned above) it follows that attention to concrete aspects of human life, happiness and the organization of daily life will be absent, or at least absent-minded. The lack of interest in things technical goes hand-in-hand with economism[4]: an ideology reducing all social facts to an economic dimension. It is urgent already from an academic point of view to problematize the relation between economic science and social studies of technology. If the research community succeeds in pulling its act together, this can also play a role for rolling back economism in general.

Technology is not applied science

> Science and technology are by no means two more or less synonymous concepts. On the contrary, they are two entirely different tracks in western civilization, fundamentally different..... These cultural traditions are at odds with each other but have by the unpardoning forces of development been forced into a symbiotic relationship, that threatens to choke them both. (Tor Ragnar Gerholm, 1978, *my translation*)

Professor Gerholm (1925-2007) was a nuclear physicist, but also a technology advisor to industry and politics and a sharp debater. He was eager to maintain the distinction. Science is driven by curiosity about the universe and our place in it. Technology, on the other hand, is inextricably connected to our lives and to human nature.

Herbert Simon (1916-2001) argues in a similar vein:

> Historically and traditionally, it has been the task of the science disciplines to teach about *natural things*: how they are and how they work. It has been the task of engineering schools to teach about *artificial things*: how to make artifacts that have

[4] *Economism*, as a contemporary and polemic concept, should be credited to US futurist and heterodox economist Hazel Henderson (1933-). In the Swedish context my own writings have played a role for introducing it in the debate (Ingelstam 1991)

> desired properties and how to design. … Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design (Simon 1996, p 111, *my italics*).

Simon does not base his argument primarily in engineering. His main area of research is the role of administrative organizations and the limits of rationality (for which he received the Prize in Economic Sciences in Memory of Alfred Nobel 1978). Engineers are professional designers: persons who devise courses of action aimed at changing existing situations into preferred ones. Simon points out that the intellectual activity that produces material artifacts is fundamentally no different from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. Simon goes on to note that those charged with the task of promoting engineering (and other forms of design) have largely deserted their task:

> In view of the key role of design in professional activity, it is ironic that in this century the natural sciences almost drove the sciences of the artificial from professional school curricula, a development that peaked about two or three decades after the Second World War. Engineering schools gradually became schools of physics and mathematics; medical schools became schools of biological science; business schools became schools of finite mathematics.

The use of adjectives like "applied" concealed, but did not change, this fact. Those topics from mathematics and the natural sciences were selected which were thought to be most nearly relevant to professional practice. But design was phased out, as distinguished from analysis. These polemic positions will be pursued in the next section of this paper, looking for the essence of technology, in part informed by Simon's key concepts *artificial* and *design*.

Looking for the nature of technology

Opening the black box

The above may suggest that very little is written about technology. This is of course not at all the case. Popular as well as scientific literature is voluminous and growing.
It is true, however, that advanced scientific literature zooming in on the broad concept "technology" is limited in volume, too little known and under-utilized in teaching and research, even in institutions that claim technology to be among its priorities. In this section I give a few hints to what I believe are some of the most useful works.

Following Arthur, I noted above that engineers in general are not strongly motivated to reflect over their own professional activity. However, some well-written texts from the inside of engineering exist and illustrate how engineers think about how technology evolves, and about its rightful place in society. In a much-read book Samuel C. Florman tries to counter the myth that engineering is cold and insensitive. He points to its vitality, sensuality and creativity, and attempts to transmit to the reader a sense of this basic mind-set, summarized in the book's title *The Existential Pleasures of Engineering* (Florman 1976, 1994). Part of his chosen mission is to refute the arguments of some well-known "technological pessimists".

The latter is an element also in a text by professor Gunnar Hambraeus (1919-) who for many years was CEO of the Swedish Academy of Engineering Sciences (IVA): "An engineers's apology" (Hambraeus 1978). However, he does not draw a line between technology and science but rather stresses their affinity, which is probably useful in order to fulfill the Academy's wish to strengthen links between high technology enterprises and big science.

Technology as an interface between the inner and outer environment

Artificial things differ from natural things primarily as they are designed (synthesized, constructed) by humans, and that they are to fulfill some specific function or goal. Hence, "doing science" on artifacts cannot be limited to description but has to cover norms and imperatives as well.

Herbert Simon invites us to look at technology as the interface between:

- An "inner" environment: the substance and organization of the artifact itself
- An "outer" environment: the surroundings in which it operates.

The laws of science impinge on the artifact through these two relations. New scientific findings can enable a different "inner" structure, whereas "nature" normally (but not always) sets non-negotiable limits in the outer environment for what can be achieved. The third element is the *interface* where the adaptation, in the form of purpose-driven design, takes place.[5] *Here human agency, not the laws of nature, prevails*. If the inner environment is appropriate to the outer environment, and vice versa, the artifact will serve its intended purpose.[6]

In line with his main line of research, Simon devotes a long discussion to the question whether a certain design is "good enough". Various techniques – such as simulation and operations research – should be used to analyze what degree of adaptation is sufficient (following his key idea that "bounded rationality" in most cases is what can be achieved).

However, Simon's concrete examples of technology are not many – and those presented are sometimes a bit weird. Unlike my other favorite author, W. Brian Arthur, Simon has not distilled his theory of design and the artificial from a large set of technological cases. Instead he has drawn sharp and useful parallels to administrative (and other) systems, where analogous problems of adaptation between inner and outer environments have to be solved

---

[5] The reader will recognize the close similarity with systems thinking, as it has developed after Wiener (1950). There the key concepts are *system*, *systems boundary* and *environment*. This Is no coincidence; systems thinking had at the time been absorbed in many branches of science as a "natural" way of formulating complex problems (Ingelstam 2012). Several references to the Systems literature, and even to Norbert Wiener, are given in Simon's book.

[6] Simon takes the clock as an example. The clock should "tell time". In a sunny environment (and with low demands on precision) a sun-dial will do. In most "normal" conditions a mechanical, electric or electronic watch will serve the purpose. In extreme conditions (high or low temperature, mechanical shock etc) different designs will be needed.

by purposeful design. It is not always possible to reach optimal solutions; they should rather to be guided by the concept bounded rationality.[7]

How technology evolves

The cornerstone of W. Brian Arthurs theory on the nature of technology is the word "evolve". His is a dynamic theory. The fundamental idea is that one technology "evolves" from other technologies plus what he calls "phenomena": a "combinatorial evolution". He bases his work on a large number of cases and examples, some of them simple for illustrative purposes, but most of them quite complex (such as modern jet-powered aircraft).

However, Arthur shares with Simon the starting point: "The first and most basic definition of technology *is a means to fulfill a human purpose* (p 28)".[8] The major intellectual effort, however, is to make clear how technology evolves as combinations of elements already in existence. According to Arthur it is impossible even to define technology in some meaningful way without taking into account how it came into being: this holds for simple things such as the mechanical lever, up to aircraft and nuclear reactors.

Arthur invites us to see the evolution of a new technology as reduced to one elementary step, combining two kinds of elements:

- **Already existing technologies**. One or more of these may be current front-line technologies, but this category also covers very basic things (nuts and bolts, sensors, feed-back mechanisms…) which remain indispensable even in the most "modern" technologies.
- **Phenomena**. In the center of any technology there is always some phenomenon which is absolutely fundamental to its working (such as leverage, combustion, gravity, nuclear fusion…). If a new phenomenon is found, or an old one improved, this can lead to a new technology. Nowadays this often happens due to advances in science (though sometimes over-sold as a factor of progress, see above). But other phenomena may have little or nothing to do with "applied science"; such as old-fashioned inventions, replacing a certain material with another, recycling of materials and energy…

According to this line of reasoning, the core of engineering work is to combine already existing technologies with phenomena (known or new) in order that they contribute to a result better suited to the *human purpose* it is supposed to serve. This is a general framework of analysis: there is no requirement that all elements should be at hand all the time. Sometimes one scientific finding is the only element needed for change, in other instances a new combination of known technologies does the trick. But Arthur's scheme makes it clear that known technologies, scientific findings and new observations (inventions, ideas) all must be taken into account as we try to understand technology and how it evolves.

[7] For a basic overview of Simon's contribution to the thinking about technology, I recommend Chapters 1 and 5 as a start. It is a shame to skip any part of this delightfully intelligent text, but I know how it is…

[8] For practical and pedagogical reasons technology may also be used to mean "an assemblage of practices and components" alternatively "the entire collection of devices and engineering practices in a culture".

This line of reasoning gives useful hints on *how* technologies evolve. But it still leaves a second question hanging in the air: *why* they evolve the way they do. As a renegade economist, Arthur distances himself from the supply-and-demand paradigm of mainstream economics. His is a much more nuanced analysis of why change happens and cannot be summarized here. He states that "people are required in every step of the processes that create technology" but chooses for his own research systemic and structural approaches rather than those that put the main focus on the actors.

Large technical systems

A great deal of inspiration for the study of technology in a social context comes from History of technology. Thomas P Hughes (1923-2014) was one of the leaders in setting this new direction with his monumental work *Networks of Power: Electrification in Western Society 1880–1930* (Hughes 1983). His intention was in part polemic: not against economics nor science but against the traditions in his own field. Plenty of history has been written, dealing with separate inventions, machines or processes (often by amateurs). He urges professional historians to set History of technology on a better theoretical footing. His expressed aim is to study in particular the development of Systems, with full attention to the cultural and societal context.

In his own works Hughes has developed a series of concepts generalizable to technical systems of similar scale as *Networks of Power* such as: ”system builders”, ”technical core”, ”momentum”, ”reverse salients” and ”technological style”. They have come to stimulate a scholarly interest that by now is a clearly distinguishable tradition in its own right. A growing number of researchers have focused on the existence and dynamics of the particular kind of systems known as *large technical systems* (LTS).[9]

Why a revival of the core properties of technology will be beneficial

From the reasoning above and my two major sources arguments have been given in favor of increased attention to overall principles and fundamental structures of technology. This would also mean liberating the idea of "technology" from unwarranted links and fetters from science, or economics, or both.

However, there are reasons to spell out the benefits of such a revival in even more concrete terms, with closer reference to groups instrumental in and affected by the tensions and contradictions discussed above.

1. **Strengthening the role, identity and self-understanding of the engineering profession.** In to-days industrial organization, economy rules. Many engineers in industry testify to the fact that "good" technical solutions will often be turned down, referring to economic considerations. Of course, the opposite cannot be argued either, but an understanding of engineering as a sophisticated and theoretically well-

[9] Among scientific works testifying to the impact and relevance of Hughes and the LTS concept, one particular book should be mentioned: *The Social Construction of Technical Systems* (Bijker & al 1987), usually referred to a SCOT. However, there is a tendency in that book to not let "technology be technology" – which Hughes' concept "technical core" suggests – but rather translate technology into other social science concepts and to some extent regard technology itself as an *agent* in change.

founded activity would give its representatives a stronger voice in intra-company and multi-professional as well as in national (see 2 below) deliberations.

2. **Correcting public research and development policies.** Simon argues the case for *design* and for the *sciences of the artificial*, against the primacy of (applied) natural science and mathematics. However, present trends in research policy clearly point the other way. The princes and stake-holders of big science have been able to convince policy-makers that "free" scientific research is not only necessary for technical progress, but also that the method of peer financing is more cost-effective than support to purposeful technological development. I think they are wrong. But irrespective of that, the lack of sufficiently sophisticated counter-arguments will allow "scientism" to carry the argument and appropriate "technology". British researcher and consultant Eric Arnold characterized one of the major Swedish research policy documents (*Forskning 2000)* "a blatant attempt from a group of physicists to lay hands on money which is not rightfully theirs".
3. **The teaching of technology in schools.** Technology is a core subject in the present curriculum for the compulsory Swedish school, from year one to year nine (age groups 6-16). It is not narrowly aimed at future engineers, technicians or craftsmen: rather the other way around. As citizens in a living democracy all must try to understand and evaluate technology and technical systems. Many of today's important social issues contain technological choices. Our society is to a great degree dependent on scientists and technologists who should be discerning, reflective and aware of important social issues. The syllabus emphasizes both scientific and social aspects, together with historical and international perspectives. The national center for technology in schools, CETIS, located in the Norrköping campus of Linköping university, is one of the focal points for understanding and disseminating the core aspects of technology. It is no secret, however, that the practice in schools falls short of the aims expressed in the curriculum. Lacking a specific teacher training in technology, science teachers (with more or less enthusiasm) take on the teaching of technology. It is to be expected that their understanding of the subject is or at least comes close to "applied science". Teachers with a back-grounds in social sciences or history lack, with few exceptions, any deeper insights into the "nature" of technology. Improved influx of core knowledge of technology into teacher training (as well as further education and in-service training) seems highly warranted if the laudable aims of the curriculum should be met.
4. **Strengthen social studies of technology in academic research.** Almost irrespective of original intentions or labels, departments and centers nowadays identify with STS: Science and Technology Studies. Is this a problem? Well, I think it deserves attention. By blurring the fundamental differences between science and technology and instead stressing their interwoven-ness (the latter is amply recognized in the literature and noted above) intellectual superficiality may be the result. The researcher might be tempted to choose some social theory with limited relevance for technological change, alternatively to fix theoretical standards on a quite modest level[10] thus returning to a "nuts-and-bolts" tradition, much-scolded in the history of technology. Everyone in the STS field should be aware of the problematic nature of the *and* in S

[10] A few years ago, I was asked by a respected academic institution to judge an applicant for a senior position, responsible for *Technology and society*. Among about 70 submitted publications only one made use of some core knowledge of technology in society. I advised the university to try again, but this was rejected.

and T. If my argument in this paper is accepted, it is reasonable to establish some sort of *core curriculum* for researchers doing social studies of technology. Good texts exist: the books by Herbert Simon and W Brian Arthur discussed above are two of these and reflect my own preferences.

References

Arthur, W Brian (2009): *The Nature of Technology* What it is and how it evolves. Allen Lane/Penguin Books, London

Bijker, Wiebe E., Thomas P. Hughes, and Trevor J. Pinch (1987*): The Social Construction of Technological Systems*. New Directions in the Sociology and History of Technology. The MIT Press, Cambridge, England

Florman, Samuel C. (1995): *The Existential Pleasures of Engineering*. London: Souvenir Press (first edition 1976)

Hughes, Thomas P (1983): *Networks of Power. Electrification of Western Society 1880-1930.* Baltimore: Johns Hopkins University Press

Simon, H. (1969): *The Sciences of the Artificial*. MIT Press London (Third edition 1996)

Solow, Robert M (1970): *Growth theory : an exposition: the Radcliffe lectures delivered in the University of Warwick 1969*. Oxford: Clarendon

Wiener, Norbert (1950): *The Human Use of Human Beings – Cybernetics and Society*. Boston: Houghton Mifflin

References in Swedish

Gerholm, Tor Ragnar (1978): ”Teknikens reifikation”, i *Attityder till tekniken*, red Per Sörbom, Riksbankens Jubileumsfond (RJ 1978:6) och Ingenjörsvetenskapsakademin, Stockholm

Hambraeus, Gunnar (1978): ”En ingenjörs försvarstal”, i *Attityder till tekniken*, red Per Sörbom, Riksbankens Jubileumsfond (RJ 1978:6) och Ingenjörsvetenskapsakademin, Stockholm

Ingelstam, Lars (1991): *Farväl till ekonomismen.* Stockholm, Carlssons Bokförlag

Ingelstam, Lars (2012): *System – att tänka över samhälle och teknik.* Energimyndigheten, Eskilstuna

Linköpings universitet (1976): *TEMA. Ny väg för forskning*. Betänkande av forskningsorganisatoriska gruppen (FOG)

Richardson, Gunnar (1987): *Tekniken, människan och samhället. Humanistiska inslag i 1940- och 1950-talens tekniska utbildning.* Föreningen för svensk undervisningshistoria, Uppsala 1987 (i samarbete med Tema T, Linköpings universitet)

Sundin, Bosse (1981): *Ingenjörsvetenskapens tidevarv*: [The organization of technological research in Sweden at the beginning of the 20th century] : Ingenjörsvetenskapsakademin, Pappersmassekontoret, Metallografiska institutet och den teknologiska forskningen i början av 1900-talet. Umeå universitet 1981