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IS THERE AN URGENT TASK OF EDUCATING ENGINEERING STUDENTS TO BECOME 'REFLECTIVE PRACTITIONERS'?

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Abstract

Societal dynamics recently undergoes deep stuctural changes. Integrative differentiation and commitment to 'innovation society' are becoming main overarching characteristics. Acquiring and widening core competences for sustainable applicability in work more than enhancing the knowledge base, new capacities have to take the central position. Experiential learning and (computer) modelling get new importance alongside the traditional way of developing theories and their application. Capacities of interpreting and 'framereflection', instead of routinized problem solving will get central position, not only in epochal issues but also in the issues of everyday life and production. All this puts emphasis on a new type of master and apprentice relation. Further, because the growing role of expertise reproduces the growing role of participation in a society where service gets the new central role instead of producing things adequate communication with experts and clients gets central role. To solve the task of becoming competent in a 'service society' needs enormous efforts in engineering education too.

To become a co-evolutionary partner, education, including engineering education, has to proactively accomodate to these changes. In its essence this restructuration of engineering education needs to put back the inclusion of it into real practice. The article makes some comments on the basic reasons of why and how this putting back may be made when basic new requirements to engineering activity and its mental tools are emerging with an emerging 'innovation society'.

Keywords: structural changes in societal dynamics, integrative differentiation, engineering education, reflective practitioner, self-reliable labour, acquiring tacit and codified knowledge, social accountability of engineering work.

1. Introduction

Societal dynamics recently undergoes deep stuctural changes. These changes firstly mean that the overwhelming tendency of progressing differentiation in modernization is about turning to the opposite and the integrative differentiation takes over the leading role. Dealing with complexity, the integrative differentiation does not undergo essential reduction but taking it as some sorts of irreducible complexity it will be the basic social phenomenon (including interaction with nature) to live together with and learn about appropriately. Two ingredients of the new process are of greatest importance. First, social value differences are irreducible up to a great measure and values are needed to be able to realise any menaningful action. This is equal to say that a pluralistic society is the only really possible adequate answer to that complexity. Second, instead of reducing them to the known, as certain or probable, rational understanding and management of uncertainty become overall requirements. Uncertainty is both a steady threat and innovation resource that also is partly to be produced consciously through tehnological and other sorts of innovation in a type of society committed to be 'innovation society'. All this requires appropriate accomodation too, partly by ourselves consciously produced, uncertain situations. Main tools of this accomodation are interpretation capacity and capacity of 'frame-reflection'.[1] Hence, reflectivity, including interpetation capacity, has to become essential part of succesful life, work and labour as well as it needs to be integrated into a new type of governance.

With the deep structural changes in societal dynamics education also gets challenged to undergo approapriate changes that can make it a co-evolutionary partner in changing societal dynamics. Engineering education needs to follow the requirements of the changing nature of typical work and labour. Among other characteristics, its penetration through research and the enhanced requirement for public accountability set on them belongs to this. Involving students into real practical work in industry, involving them in research work as early as possible during their education and teaching them the contextualized tasks they will meet in their profession, may help to involve education in a co-evolutionary process with society and to educate students 'reflective practitioners'. This needs a comprehensive effort to reverse the main direction engineering education has been following for more than a century by striving to realize an abstract and hierarchical way of education. In its idealtype this was conceptualized as a theory-led praxis with universal validity. The new type of engineer is context-sensitive, is engaged in mutually discursive relation to society, is armored with simulation tools (both by mathematical models and experimental capacity) to be able to provide socially robust engineering knowledge and artifacts even in lack of theory. To solve this task is urgent, for, if, as it seems, we are entering a Mode2 society, any change in engineering education will only show its first results in a half decade.

Recent overwhelming changes in societal dynamics include an urge to a basic rethinking of emerging educational tasks. In this rethinking one has to start with basic models of social change. It should immediately be emphasized that even when there is a widespread feeling of basic changes the models of recent profound changes in societal dynamics are only very rough and much contradictory. Hence even when the educational tasks seem to be very urgent these models only lead to rather uncertain and different educational consequences partly. Nevertheless, the tasks are urging. In this article, we concentrate on engineering education. Why do we concentrate on engineering education? The reason is rather evident. Beside arguments from the cv, namely that the author is professor of innovation studies at a university of technology, the publicly acceptable reasons are, that first effects of technological change in society are much more important than it still seems

[1] The use of the term see in [27].

to many, including its many analysts. Second, that as it seems, an engineering education, sensible to the changing social context of engineering, could much do for developing socially responsible technologies.

To understand the technology-society relation, two basic characteristics are, first of all, to be put in the centre of considerations. First, that citizens of recent modern societies, in an accelerated way, 'live their lives through technology', even the most intimates of our relations get profound technological mediation. Second, that introducing any new technology is equal to making an ill-structured social experiment. It must be added to this, that societal dynamics seems much more complicated than it could be well expressed by such sort of reductive conceptions as 'societies based on technoeconomic paradigms' (as 'information society' or 'knowledge society' conceptions mostly try to express the relation) and by their quasi naturalistically induced changes and the subsequent accommodation of the social superstructure to these challenges, including education. To put it differently: the technologization of society follows first a much more complicated scheme than the one usually expressed in a 'driving force' metaphor, i.e. in cause – effect relations, as 'the emergence of new, breakthrough technologies and their effects'[2] and second, with any epochal renewal of technology guidance in society the problem of democracy gets new challenge and importance: technological development as social experiment is also experimenting with democracy. All this makes social reflection on the reflexivity of engineering practice immensely important. It is important, both to be able to be responsive to the new needs for flexibly accommodating to evolutionary environments in terms of effectivity and to do this for emancipatoric interests.

Flexible accommodation needs steady reflection. To understand this reflectivity need one can depart from the models of the most characteristic epochal societal changes, of 'information society', 'knowledge society' and 'learning society', from 'network society', all being in some way, even more complex different conceptualizations. It is typical that the emphasis of basic changes in the technological level is narrowly conceptualised and the idea of a 'post-industrial technological system' frames the approaches through which one looks for the changing role of (technological) innovation in an emerging 'new economy'. 'Economy of globalization', and the need for 'reflexive modernization' can be added to the list of reductive conceptualizations. It is important to see that considerations may be made from a reductionistic efficiency perspective or from its abstract opposite pole, the 'risk society' perspective. It seems that the very first task is to try not to get trapped in these reductionistic perspectives. Committing to some sorts of co-evolutionary perspective and approaching chances of technological development from a perspective that is committed to looking for developing and utilising possible technological alternatives for emancipatoric interests may prove a more balanced view.

To repeat it, one can formulate as a common denominator of the many, several times diverging views that technological research and expertise are guessed to be-

[2] This 'driving force' metaphor may be changed e.g. from 'information' to 'knowledge'. This is an important advance in one relation but the linear causal structure of the metaphor is not changed with it.

come much more important than any time earlier. One can find different models of this quickly raising importance and the changing nature of technological research and expertise in literature. It may be expressed by formulating the idea of an autonomous innovation system and its interaction with society, or the 'triple helix', or the Mode2 hypothesis [12].

2. On Network Society

All the following will somehow be about networking, and co-evolution, and its consequences in societal processes, including accommodating research and higher education processes under preconditions of some sorts of a 'network society'. Manuel Castells claimed to observe a special type of linearity in societal dynamics: basic changes of the technological-economic system challenge the 'superstructure' for death and life, [3]. Economy changes into network economy. As he put it in a more recent lecture: "The 'new economy' is not the Internet economy, or the dot-com companies. It is the economy of business, of all kinds of business, built around Internet and networking, which means potentially all economy", [5]. According to him, "the 'new economy' puts different social and institutional requirements than the 'old economy'. Hence societies need to reconstruct their social, economic and political institutions, in ways appropriate to specific national and local cultural contexts" [5].Characteristics of the 'new economy' seem to be new forms of productivity gained through its global networking character. The networking within and between companies is the new organisational form, new rules will be set by these dynamics for capital, labour and management and its development requires certain social and institutional conditions. One can say that the 'new economy' can be characterized on one side by what may be called the comprehensive 'innovation challenge'. The 'new economy' is 'innovation economy', as it is claimed, it is a totalizing system, continuously producing and reproducing the 'innovation challenge'. Concerning the reproduction process it seems to be worthy to emphasize the evolutionary nature of structural characteristics of basic societal changes. It is not only essential to speak about the steady 'structuration' and 'restructuration' process, but also to highlight the evolutionary irreversibilities as main feature of recent structuration processes. Innovation is evoked by and evoking irreversibilities.

In this short introduction I just intend to re-emphasize that facing rapid epochal changes now, we do only have very vague models of them. Let us take as starting point that somehow there is a rapid emergence of something new either as a new type of economy, or economy of innovation, or networking economy or globalization or knowledge economy or learning economy or whatever else as their combination and so on. In this new type of economy, this seems the least contested, labour is not strategically based on the forced division of labour into creative and deskilled work anymore, as it was earlier. The tendency is rapidly changing and labour may typically become 'self-programmable', to take the term of Manuel Castells and, together with it, co-ordinated decentralization will be another organizing principle [6]. Both self-programmability and co-ordinated decentralization are essentially connected to the spread of computer modelling and informational networking possibilities as their basic precondition. Robert REICH, 1991, was perhaps the first who coined the term of 'symbolic analysts' who, as the coming typical working force in 'information age' are able to identify and solve non-routine problems and broker solutions to them [25]. This is a claim about ability to access and manipulate information in novel ways (in a back and forth of formulating and reformulating problems and their possible solutions, configuration and reconfiguration) and transform it for use in dealing with the non-routine tasks at hand, mostly in (flexibly changing) teams – but less under bosses. This formulation of the new happened nearly 15 years ago. Needs seem to be emerging on the market and society begins to require even more. What Reich conceptualized was a reflection on labour based on the 'information age' type conceptualization. The new challenge at the peak is more, something that is called by Donald SCHÖN, 1997 in a partly different context, the context of political discourse, as 'frame reflection' capacity and that, maybe, will rapidly be included into the labour process for the most innovative fields. Work and labour are changing and these changes require the renewal of higher education. The emerging recognition of new tasks partly leads to the multiplication of institutes providing post-diploma education. Recently, in many cases they underestimate the structural characteristics of their educational tasks by concentrating on delivering some (or even unbelievable much) missing new information and typically some missing knowledge how to use ICTs. The new task on a deeper level is to help to acquire the capacity of doing self-reliable labour and working in heterogeneous teams by identifying and realizing contextually interpreted engineering tasks. And it seems rather evident that education, in order to be able to realize this sort of engineering activity, should already begin at the undergraduate, bachelor level. With this I already want to indicate what is at stake in turning a century long tendency in engineering education.

Even when refresher courses became already normal parts of working of both universities and firms it seems rather certain that higher education of engineers realized by higher education institutes should preserve a main role in preparing the appropriate engineers in the future too. The industry or anything else cannot take over this main role, and perhaps for good reasons, should not do so either. The new engineer generation has to acquire competencies that scarcely can be in the immediate focus of any industrial player. Some sorts of division of labour in educating new engineer generations seem to remain essential. It is important to emphasize this, for a main intended say of this paper is that, turning back the long trend we still are in, the production sphere should intimately be involved into developing a new type of higher education – from the very beginning of the education of engineering students. This requires some sorts of basic restructuring of the education and working of these higher education institutes. To indicate the opinion of us, we think real practice in life, such as working at a working place, should and will necessarily get more and more educating role, already during the basic formation period, in the changing recent societal, economic, technological conditions. It will be the one side of the interaction: the other side develops by invading the universities through research charges by industry. To form a new basic professional attitude industry should have an effect integrated in the dedicated education and not only after it. Of course, in a somehow moderated way it has always been so and 'real life' had its basic, correcting role on dedicated education already during the formation period. But some recently emerging peculiarities seem to be distinctive. One of them is becoming more and more typical, namely that any agent in the recent production processes, working in a quickly changing environment, to which he himself continuously contributes, has not only to produce the needed products but also has to learn continuously, reflectively in the production process for enhancing its survival chance. It will be an important task to investigate the possibilities of how this spontaneous learning process, a 'learning in context', a 'situational, experiential learning' can be connected to, and widely utilised for developing dedicated higher education, by a basic structural change of higher education, by delegating and immersing higher education into the production process 'outside', much more, and qualitatively differently, than the already existing modest forms do.

It seems most important to immerse students in real working practice and to bring this immersion as close as possible already to the first higher education immatriculation. And this task may extend from multiplicating simulation tasks of the real production process in industry, of 'real life' in the higher education process, for acquainting this way with problems really set and solved by the industrial and commercial life, to immersing students onto the real practice already as early as possible in their education process, for part-time of their education. Introducing part-time reality-near practical education from the very beginning of the training process to develop a flexible practical enframing capacity may fruitfully help to acquire that type of enframing that is needed for a more and more typical working and labour process, during the higher education process.

Until now the dominating model of teaching is based on following the opposite way. Students of technological universities acquire the capacity of setting and solving abstract problems and they are instructed to look at the real life problems as if they were nothing but imperfect realizations of the ideal case. An artificial demarcation is constructed between education and practice with the expectation that education, in its highest form as educating theory, will lead to an armament providing in principle for the basics of a practically successful deductive approach in practice. But more and more one may observe an unbearable gap between a still overwhelming purist education process, and the real practice earlier is developed in the belief that supreme knowledge as pure science can be acquired at universities, to apply it later in the, at least somewhat, backward real practice. It seems we have to get rid of a demarcationistic idea that led higher education for more than a century. Part-time, reality-near practical education may help deconstructing the time demarcation of higher education and working. The labour process can and should be utilized for higher education purposes. It helps, among other things, to prevent the development of a one-sided purist attitude. Students, acquiring knowledge of real industrial problems can steadily confront their studies with the real problems. Fortunately it is a trend that becomes less and less typical that one begins working only when having finished the official formation process.[3] ‘The network generation’ seems to begin to declare its new orientation.[4] Doing some sorts of expertise, establishing and working firms, already at a quite early age by this generation may be signs calling for anticipation of a new period. This may have a very important consequence for higher education. These students will continuously reflect on their work through their study process, but mutually, not only on their work, also on their education process, based on their experience in life. One advantage of this will be that they will be stimulated to a sort of ‘speaking back’, from a realistic position, to their higher education.[5] And this may be integrated in, as it is to expect, many, fruitful ways into higher education, which are yet to explore, from the very beginning.[6]

It seems, this ‘speaking back’ will more and more move to undergraduate education too, and will change its role and character. It will be a part of a process in which the whole education is about getting back its discursive character. It is to guess that the educational situation that is now special for post-graduate-education as lifelong learning, i.e. inclusion in education of those who are already in working life will be somehow similar to the whole higher education process. Of course, like something new, it seems to have its opportunities (and it is the purpose of this sort of articles to argue for these) but it needs its profound SWOT analysis. One potential strength of this early inclusion which may develop under appropriate conditions is that it naturally brings with it a ‘real life context’ that may get in fruitful dynamic with the education process, by bringing higher education into a discursive context, notwithstanding to perhaps many differently oriented educators. It is also to expect that lifelong education also will be much less lifelong passive learning, as it became the typical institutionalisation. It will be a more important task to renew the competence base more than the knowledge base and a process of encouraging and managing creativity for setting and solving reality-near problems. My guess is, that, provided the labour process will rapidly develop in the direction that self-programmable labour will be the typical form, continuing higher education will more and more take over characteristics of learning from research work.)

It is important for engineering education not only to involve students in work under real conditions but the best students, into research, as early as possible. Either at the university or at firms employing students in research should be a further tool of developing creative engineers. Apprenticeship in research teams (with a view on

[3]I do not think of waiter or night porter positions just to earn the money needed for education or anything else but of working preparing the profession.

[4]The term comes from Don TAPSCOTT, [31].

[5]‘Speaking back’ is one of the essential categories of the group of scholars working on the ‘Mode2’ conception. It is used now in a more narrow meaning. We will come back to the fuller meaning later in this article, see Helga NOWOTNY, Peter SCOTT and Michael GIBBONS, [23]

[6]Just as for one case: practising students bringing their best examples into the discussion over innovation management at the university course can make the education process more symmetric and ‘densely interactive’. One can experience this at ‘refresher courses’ for post-graduates but much speaks against the practice which allows this only for ‘refresher courses’.

educating students to become a master, not simply accepting them to do a low level simplistic work without enlightenment of its sense, following the old principle of division of labour into a creative and a deskilled part) should be much more typical than now, when it is rather occasional. Not only reconfiguration of tools in a 'fixed' problem space, but also re-contextualisation, frame-reflection capability and capacity seem to be, at different levels, much sooner needed in productive practice than earlier. 'Reprogramming him/herself toward the endlessly changing tasks', as Castells formulates in his famous book, CASTELLS, [4] needs developing the capacity of frame-reflection. This is to say in terms of problem-solving behaviour that, according to this guess, even construction, and re-construction of the problem space will be rather regularly required also in the labour process, i.e. some sorts of genuine research activity included in concrete labour, when looking, because they are bound by the objective(s) of the work-process, for some local solutions to satisfy the changing needs. Farewell to the dominance of the stability of mass production is behind it.

Could this mean that the demarcationistic understanding that sharply differentiates between /repetitive/ work and research will have to be mitigated? I think, it could. And it also means that it may be advisable, taken into account some additional considerations, to prepare students to a type of context-bounded creative, research like top-labour process, to immerse them in the real research process, made within or outside universities, as apprentices, from the very beginning of their education. Let me make a very short remark on the possible ethos of the reorganization of higher education in the 'Bologna process'. The main ethos of this process should be the conscious turning back of the earlier tendency that the higher education process simply provides for appropriate higher educated working force for an industry based on simply hierarchically divided labour in which application of theory is dominant. But this turning back can only be a real re-structuration of education following and preparing for a new typical type of labour.[7]

3. Infosociety, Knowledge Society, Learning Society

If somebody begins to speak about 'network society', the reader is suggested to think of connectedness, non-linearities, synergies, virtuous, vitious circles, downward, upward spirals, non-equilibrium processes in general, with all their 'effects' on working life, leisure time, economy, politics, and culture, also of, among others, changing productivity and competitiveness, or, just to mention a political dimension, 'inclusion – exclusion' relations.

Let us put emphasis on some characteristics of the emerging 'network society'. One of them may be that it is obviously better to characterize it as 'knowledge society', than as 'information society', i.e. emphasize that any investigation into

[7] One often observes, at least in Hungary, that instead of this restucturation a fight for dominance appears. In this fight universities argue for more theory for the earlier college education and colleges argue for extending their practice-near view.

the revolutionary development of ICTs should be subordinated to investigation into the development of knowing, if we intend to understand their real social role. One can further try to express the obviously accelerating interactive changes in society by compressing them into the term of 'learning society' (a term that expresses an intrinsic dynamism). 'Learning society' may be something that includes 'learning economy'.

To put an emphasis on it, repeatedly, one can say that, under increasing systemic integration, many signs show that labour becomes self-reflective, i.e. in some ways labour more and more creates its own object of study. After a Fordian period, labour comprehensively gets the task of checking, improving and regulating itself to guarantee its own quality and efficiency. 'Self-programmable' labour is to realize more and more, in rapidly developing and changing team co-operations. This requires a constant and comprehensive monitoring of the behaviour of others, to be able to fit, and a capacity of making, keeping and solving connections. This is something of an element LASH (1994) calls: 'structural reflexivity' in the time of 'reflexive modernisation' [18]. Requirements of 'reflexive modernisation', in some possible interpretation of the term, among other things, emphasize the importance of communication among disciplines, in transdisciplinary contexts, among professions, with the users, the everyday life etc. These requirements of 'reflexive modernisation' give a frame to set tasks for changing engineering education in general.

One has to try to connect this reflective modernization to 'globalization'. Is it then about emerging new strategies of comprehensive interactive networking world-wide, not only connecting but mutually pervading the differentiated social institutions of economy, science (to call more correctly 'research' in its new forms), technology, culture and politics? Is it then more about a new type of institutionalization in which earlier differentiated institutions begin to comprise each other or about simply the new domination of the capital through financial capital? Does it bring with it such structuring dynamics as the simultaneous mechanism of 'pluralization of innovations instances' and 'individualization' of the paths of innovation? How, what is called 'research' will look like? And what are the educational challenges?

Just to jump over to some consequences of highest importance for engineering education: if the whole life will more and more be mediated through technologies (think of genetic engineering and psychiatric techniques), and any engineering work is ambivalent, has a double potential of being a chance and a danger simultaneously (this ambivalence is now appearing on quite new, profound levels of the capacity of breaking through the nature given) will the education of engineers need deep transformation not only for enhancing some instrumental rationality (mainly through the enhanced computer simulation capacity), to be able to manage the heterodox problems by new instrumental forms of labour, but a problem of deepest moral responsibility? The answer seems to be obviously yes. And it shows some very basic wisdom that public opinion gets very much interested in the possible life models mediated to, or perhaps constrained on people, by forefront research and technologies, challenging them for better or worse, to prepare themselves to change their social and individual identity. All this new interest of the public is partly about the needed rethinking of the relation of research and ethics in its focus and partly about social accountability by involving public discourse over high-tech research. After all, developing of new high-techs through forefront research is about enforcing changes in social and individual values too by ways of social experimentation where the outcomes are partly unknown or uncertain and their desirability is certainly the matter of democratic negotiation. Coming scientific researchers and engineers are to be prepared to this 'social context' of and responsibility for their doing and to the typical public debates. (NB. Public debates should develop to natural milieu of learning about social viability of technologies.)

Let me shortly turn now to some characteristic of globalization that may get importance in preparation of future engineers. This is 'glocalization', i.e. realizing globalization through mobilizing local capacities as innovation sources. In a world of glocalization the multicultural foundation, the localities in the network will be a rich source for globalized, networked economy.[8] I personally believe that it brings yet unforeseenable new development opportunities for a globalizing economy and life, not only through the rich factual resources, the emphasis is, onesidedly put on in literature, but also the value and contextualization challenges local milieus express for any universalizing tendency. Globalization seems to necessarily be more and more realized through glocalization.

Successful glocalization needs utilization of an especially high amount of tacit knowledge. In relation to this it is a very misleading conceptualization of the role of the tacit dimension in cognition when it is identified with 'know how'. This misleading identification is partly the result of a theoretical reconstruction of the typical innovation processes of the industrial period, reducing tacit knowledge to a 'remaining factor'. The main problem is with this limiting usage of the term 'tacit knowledge' that it comprises a profoundly misleading assessment of the cognition process, and especially in conditions of networking. I shall come back to this.

If universities begin to do more research appropriate for the interests on the user side (the industry, public political institutions, etc.), then it seems rather natural to utilize these interfaces to teach students how to make research in application context, under conditions of trying to produce as much 'marketable' knowledge as possible. One of the usual objections to this aspiration is that undergraduates first need to acquire the toolkit in a purified milieu. This is an objection mainly based, I think, on an idea of bureaucratic systematization of the needed scientific knowledge for an 'ideal researcher', who, having got his/her diploma, in principle would be able to do his work, measured on his amount of decontextualized knowledge on 'knowledge base'.

Getting involved into practice and communicating with other students also involved can help raising creativity by the students. Not orienting to the possible early development of the creativity of the student but toward an abstract idea of systematic and theoretically oriented knowledge is still in the centre at many ed-

[8] The term comes from OECD, 1991. My interpretation bringing 'intrinsic complexity', a term taken from phyics, and 'glocalisation' in connection is in Imre HRONSZKY: Growth in 'intrinsic complexity' and 'glocalisation', in: [32].

ucation conceptions. This makes a real difference in the issue how to involve the student into the practice. While a, from research separated teaching lab, with its fixed criteria what to perform, made formally well comparable what the mechanistic replication performances of the students were, it scarcely contributed to develop their creativity. A clear alternative would be to include the fresh students in research labs as soon as possible and to work out them pathways for how their actual level of working capacity can be fruitfully utilized for the research objectives and be made into a starting point for reaching higher levels. It is not to be thought that any type of inclusion would be useful. I do not speak about repeating the idea of mechanistic division of labour for the inclusion of students into research teams by trusting them only with repetitive works but, from the beginning including them as (at the beginning attentive but more quite) reflective participants. Their inclusion should also be into project tasks to regularly connect to their courses, so that their projects get a double enframing through the research group and the course level they have, requiring their, on the given level possible independent reflection.

A false attitude with the overemphasis of the role of basic research for engineering work is widespread now. Recently, a movement of engineers and engineering historians began to help to restore the balance in this issue. I think of authors like VINCENTI or BUCCIARELLI, [33], [2]. As an important engineer, VINCENTI turned in the 70s to the history of his own profession with the determined view of demonstrating the falseness of the applied science conceptualization of engineering inventive work. I utilize his ideas when I try to formulate the following: Engineering education should be able to form students able to acquire real engineering capacities as transforming and integrating sorts of engineering research, a complex mixture of science and even technological empirical approaches, into the emerging new type of self-programming labour.

But what about *scientific* breakthroughs? And how is the old classification from ‘small innovation’ to ‘radical innovation’ still applicable? One has to recognize that scientific breakthroughs are more and more important for radical changes in technological systems. It seems true, notwithstanding, that many alleged scientific breakthroughs proved to be mainly inventive engineering work, on closer view, becoming much more departure points for feverish scientific research, than the opposite way, as it was with the relation of the transistor and the solid state physics. But, as mentioned, all these scientific breakthroughs are only starting points in a complexity and the work still to be done until innovation products are realised is a typical empirical developmental work, that is in no way correctly to characterize by any sort of application of science ideas, even when much science is utilized in the development process. Still, engineering students, if they hear any historical remarks at all, will mostly get a demonstration of what can be called the ‘applied science bias about the nature of technology, even technological research’. To repeat it, the cultural preparation of engineering students certainly needs historical introduction based on profound historical research. The lesson from history is that radical innovations come from different corners: application of a scientific breakthrough, breakthrough in engineering research, breakthrough through networking, and what I would especially like to emphasise: merging of many smaller breakthroughs. The overarching lecture from history is that technological innovation is a complex interaction process between research, design, production and marketing, and it takes place in a complex interacting learning process, as Lundwall formulated in 1992. In this complex interacting learning process multiple sources of information and pluralistic patterns of interaction prove to be useful. Changing teaching should help students to make conscious that especially modern innovation, as Gibbons and his co-authors formulate in 1994 against the linearizing idea, turns from a 'relay race' to a 'soccer game in which the university is a member of a team' [12]. To help students to understand this complicated 'soccer game' seems the best way to immerse them in this game, parallel to their basic disciplinary studies.

4. On the Role of Tacit Knowledge

One of the main recognitions that should lead to basic rethinking of engineering higher education is about the role of tacit knowledge in cognition. 'In the learning economy crucial elements of knowledge remain specific and tacit, and rooted in specific organizations and locations' states the report on a research performed by a group led by A. LUNDWALL, 1997 and supported by the EC's 4th frameprogramme, [20]. 'In contrast to codified knowledge, tacit knowledge is the knowledge, which cannot easily be transferred because it has not been stated in an explicit form. One important type of tacit knowledge is skill. The skilled person follows rules not known as such even by the person following them. Another important kind of tacit knowledge is implicit but shared beliefs and modes of interpretations that make intelligent communication possible.' …'According to Polanyi, the only way to transfer this kind of knowledge is through a specific kind of social interaction similar to the apprenticeship relationships. This implies that it cannot be sold and bought in the marketplace and that its transfer is extremely sensitive to social context.'[9] Something important is said about work and research with the above text, decisively important for educating the students especially through including them in real work processes and research work. It is about the essential relation of apprenticeship. Understanding the role of tacit knowledge invalidates the prevailing model of including students in research. Namely, the prevailing rationalistic model falsely presupposes that inclusion into research should be done through previously acquired codified knowledge and perhaps through the conscious overview of the research situation, somehow 'from above'. According to this false presupposition tacit knowledge, apprentice relation will only be needed for recognizing the local elements of the situation. But if anybody gets first of all overarching tacit knowledge of the situation in research, s/he is put in, then immersion in real practice would be the easiest way to be able to acquire command of it. But introductory university teaching concentrating on basic codified disciplinary knowledge only, (and accompanied by some sorts of lab practice in which one can acquire the most simple elements of practice, mechanistically), still follows the nearly hundred years old idea that

[9] At the same place.

a higher engineering practice can best be learnt through first getting a codified overview of it and then identifying the codified elements in real practice. This is a misleading way to let acquire engineering capacities, and also probably develops an attitude of alienation in the students toward real practice, to overcome only at least with some difficulties, later. The suggested basic way through this simple consideration is to develop a two tiered way of educating beginner engineering students, a parallel way of which one element is the traditional one, of teaching codified disciplinary knowledge (connected to, or more mostly realised through its own practice of solution of examples and learning some elementary laboratory skill first) but the other one immersing the beginners in real practice, either inside the university or 'outside', in the industry, through a special approach to it, through project work and conscientious accompanying. Strength of this method would be keeping the relation to real life natural.[10]

One can not emphasize enough that the tacit dimension is not only a limit to explicit knowledge but much more its basic source [29, 35]. On a higher level of education the task of reproduction of the acquired tacit knowledge appears as advancing codification. Knowledge gets codified this way as one characteristic of the research process. The other part is that every codification, through its application possibilities reproduces a systemic basic field for developing tacit knowledge. It seems that a two tiered higher education system may be based on its basic level, on the development and exploitation of an immediate acquaintance with the working of the machines, while the 'higher' level should develop a practical capacity of scientific modelling of the real issues, developing, through practising, a wide tacit knowledge of how to connect these models to the experimental practice of working with the real research objects. (This ramification does not involve that computer modellization does not have its basic place on the lower level too.) The overall end for educating engineers should be to educate social-practical capability of realizing socially acceptable, contextualized innovations. Just teaching them narrowly instrumental functioning, even when it will be based on high level theoretical knowledge, deprives them to learn to form a needed social-practical attitude as natural through the education process. To put students in all those 'communities of practice' (E. WENGER, [34]) that are relevant for their profession, including putting some of them into 'communities of practice' striving for high level theoretical knowledge as soon as possible beside the traditional way is a very urgent requirement [34]. Through an overall practical, design approach students would get in a dialogical relation to the analytic-synthetic, formal knowledge of their profession, a dialogical relation throughout their education, which will be the overall frame of their real life practice.

[10] How far a similar way of education at lower levels of teaching learners already from elementary school should be the necessary basis is not a question to put here, even when it is of highest importance.

5. Extending the Functioning of a Researcher to Give Expert Advice, on Participation in Expert Advice

It seems obvious that expertise is getting more and more important in our time. One can say we live more and more through expertise. If so, and also scientific and technological expertise and its special form, advice becomes more and more important, students must be prepared for this role as far as possible, they should be acquainted with this task during their higher education. Even a very rough overview of the task of providing technological and scientific expert support that enables society to make 'good decisions' stimulates a couple of remarks. One deals with the paradox, that the growing role of expertise induces the growing role of public participation, a point I shall touch later, and vice versa. A second remark deals with the role of what is called 'expert opinion',[11] a third with the tightly bound problems of high social consequences and uncertainty of expert advice (!) and the subsequent high moral responsibility.

Next I shall make some remarks on the responsibility of making expertise. The lesson to draw from these types of mistakes of the expert advises brings, among many other things, into the forefront a layer of the thinking of Michael Polanyi. This has not found its way into considerations over expertise, differently from the recognition of the considerations by Polanyi of the tacit layer of cognition. It is what is called by Polanyi 'personal knowledge', the unity of knowledge and moral. I am sure that discussions with students about the importance of 'personal knowledge' for orienting experts and its interiorization by future experts would greatly help in getting back more trust in expertise. Teaching real cases, e.g. Ford Pinto, Seveso, Yucca Mountain should be included into the preparation of future experts.[12] Further, in connection to this it would be essential to speak about the place, for science and technology students, about the problem of and solution to expert advice set by the notorious Funtowicz-Ravetz model of decision making [11] but I turn now to the problem of public participation in enhancing knowledge in 'issue driven research'.

[11]Expert opinion, a deeply tacitly based but outspoken knowledge, steadily accompanies any research process, but in ideological reports on expert activity more often than not it is put back through the requirements of codified knowledge to the private sphere of the researchers. It can have a role for directing further research, but should not, in principle be included until certified scientific knowledge is at stake. All this should be different with issue driven research where any type of knowledge should be taken into account to reach the best available result, to be able to give the best advice. Students, if the education is determined to really prepare them to their later social roles should learn to make this difference conscious and, possibly students should be able to get involved in the process of practising 'expert opinion'. The medical profession preserved this inclusion in hospitals, at least in form of accompanying and observing the professor when visiting the patients. As far as we know it was some surprise for students of economic research to learn that many big firms regularly utilize expert opinion to judge predictions by codified models of processes like selling goods in extreme situations.

[12]Technology assessment should be an integrative part of any engineering education and should involve moral considerations. [15], compare also [17], [16], summarized by [26] as contribution to announcing a 'third generation approach'. Participative Technology Assessment is controversially discussed in [24].

The necessity to turn away from the one way communication model as basic communication relation of experts to the public is slowly becoming evident for many types of professionals. It is still much less evident for engineers and natural scientists. Important policy making institutions have already made steps to encourage the change of this attitude. The participation by the public in the assessment processes is given a very high importance, among others, by the Science and Society action plan prepared lately by the EC [28].

Why should the public already participate on the assessment level and not only on the evaluation and management levels of expertise? The dominating view strongly protests against participation in assessment (description and analysis) of issues. It identifies participation in assessment processes as nothing but an attack on sound science. But the dominating view does not recognize some things. These belong to the distributed nature of knowing. The public has an essential role in issue-driven, policy-relevant research, in assessment process, because it knows local values, and has contextualized factual knowledge, and, first of all, it has a special practical relation to the problems to be investigated, it looks at them from everyday life practice.[13] The place of this special practical relation can especially well be seen in cases of uncertainty and what I would like to term as 'undeterminatedness' in expert assessments. So to speak, the task of handling uncertainty brings this onto the surface and enlarges its importance. Concerning uncertainty, one can turn to the Funtowicz-Ravetz considerations, concerning both, and so what I call 'undeterminatedness', to the problem of valuation, frame reflection. Stirling and his research fellows, 1999 point to the essential role of the public in setting the frame for expert calculations [30]. Concerning the essential role of the public participation in dealing with risk issues perhaps it is the most important thing that they demonstrate that a risk assessment which includes public participation at this systemic place, at the foundation laying process of framing of expert research will be more scientific, i.e. less decisionistic, than the one, where the framing is simply left to the experts. That is why there are ways in which participation in expertise leads to a raising scientific level of expertise, to its less decisionism, dogmatism. I am scarcely wrong by telling that the typical way of referring the public opinion in the courses at technological universities is concentrating often on stupidities, ignorance in scientific and engineering issues. Students of natural sciences and engineering should learn about the essential role the public opinion will more and more occupy in the process of realizing research and engineering work [7].

This changed understanding of how uncertainty should rationally be explored has very much to do with educating science and engineering students. Teaching experience shows that they find it difficult to acknowledge the argumentation for the essential place for the public in assessment processes of uncertainty. And the

[13] The transdisciplinary approach, i.e. utilizing interdisciplinarity for issue-driven problems, is mirroring this practical relation to the issues in science. Any transdiciplinary approach realized in real practice easily shows how much local knowledge, systematically including local knowledge of 'residents', is indispensable to be able to give an answer for practice. This expresses the 'tinkering nature' of cognition in this special case.

argumentation may quickly fall in a trap, at least for a while, for the essential role of the public in setting the framing for expertise is in real cases contrasted, mixed with ignorance, ‘amplification’ on the side of the public, etc. It is very important to prepare students as far as possible to be able to develop an alliance of expert and participatory knowledge. Once again, involving in practice and interpreting the experiences through modelling them may be the best way. Teaching assessments of real uncertainty cases runs against two cultural habits of engineering. The first is that an engineer may be inclined to deal with real situations through their definitions and the task of providing for definitions is seen as a single task of the researcher, leading to the definition of the uncertainty through the framing of it by the researcher and very often also reducing it to the quantifiable. The second is that an engineer is par excellence somebody who believes that s/he can fully reconstruct processes of nature for human purposes, at least in ideal case. In case of uncertainty management an engineer may be inclined to believe in the overall capacity of developing safe science.

6. Mode2 Research in Mode2 Society?

I want to make some more systematic remarks on the educational consequences of changing research relations and engineering activity by using one theoretical model as background. It is the Mode2 hypothesis, both in its original expression of 1994, and in the later one, that emphasizes an intrinsic relation between the alleged Mode2 production of knowledge in the alleged Mode2 society. This model is offered to this task for several reasons. Some of these are its very comprehensive claim (compared to the triple helix conceptualization it vindicates to get recognized much deeper, epistemologically relevant layers of change) and its unifying approach. I will just give a very short summary of some Mode2 considerations themselves. I think the most important is its co-evolutionary approach. One can approach the problem of alleged emerging new type of research (M2 research) from the hypothesis of alleged emerging new type of society (M2 society). Mode2 society, so the thesis is in co-evolutionary relation with Mode2 cognition [10].

The question from the point of view of complexity theories is about ‘intrinsic complexity’ and integrative differentiation. One can contrast in this way a type of society, based on progressive differentiation of functional subsystems, as Niclas Luhmann did, and speculate about the ‘logic’ of the process of progressively differentiating subsystems and how they communicate through incidental communications. Then a basic problem will be to show that these, allegedly closed through their ‘codes’ but differentiating subsystems produce and reproduce society through themselves and their incidental communications. [14] These two types of approaches realise two contradicting types of structuration. One has to make the first choice and one can take also simplicity, isolation, progressive differentiation and interactions by chance or complexity, integrative differentiation, essential interaction as basic

[14] On a profound criticism of Luhman’s starting points see [22].

stylized facts for starting with the explanatory model. (The explanatory position of the two approaches is only seemingly symmetric.) In the second case a progress of integrative differentiation occurs recently as the basic social fact.

'Speaking back' to each other by the subsystems of society and with society itself, as it is put metaphorically, becomes the main issue in Mode2 type of interactions, and context sensitivity will be the most important characteristic. There is no pure economy, politics, science anymore but strongly interacting subsystems of a whole, itself steadily producing and reproducing through the interactions of its subsystems among themselves and with the whole (NB: including the interaction of society with nature). This mutual inclusion of each other has at least two important consequences. One is that any 'logic' of the development of subsystems becomes mediated in multiple ways through its multifaceted dynamic connections, second is that approaching objects of research through trying to input universals (decontextualization) prescribes very strong preconditions for the possible existence of such systems that allegedly would obey to the determination by universals.[15]

GIBBONS [13] puts emphasis on the idea that the main thesis developed in 1999 (published in Nowotny 2001) by the Mode2 authors is '*that Mode2 science has developed in a context of Mode2 society.*' [13]. That Mode2 society has moved beyond the categorizations of modernity into discrete domains such as politics, culture, the market, and, of course, science and society. Consequently, 'under Mode2 conditions, science and society have become transgressive arenas, co-mingling and subject to the same co-evolutionary trends.'

In a Mode2 society context-sensitive science (Mode2), as claimed by the authors, is produced in a more open system of knowledge production. Beside different degrees of 'openness' Gibbons differentiates between 'kinds' of openness too.

1. Multiple interactions between the number of experts and sites of expertise.
2. In each context of application, more than scientific and technical expertise is involved, other, social and personal, perspectives also enter and it is these non-technical communications that are contributing to the production of context-sensitive knowledge.
3. The sites of problem formulation have gradually moved out from their traditional institutional domains in government, industry and universities into the market place. Now, in Mode2 society, the marketplace – a type of new market – becomes an essential component in establishing context-sensitive science.
4. People feature in more and different ways in the research process. In Mode2, people and their interests, concerns and perspectives enter concretely in, and in some cases provide essential data for every aspect of the research process.

[15] It is important to emphasize that it has just been the historical success of Western type science and technology which is able to demarcate such sorts of systems. Standardization with its normative precondition, for closeness is essential to these types of – in this relation simple – systems.

5. Participation in the market place is reflexive, that is, the interaction of the scientific and social perspectives not only affects research priorities but also modifies scientific beliefs about what research to do, how to do it, and with whom. This means that the reverse communication between society and science is transforming science in fundamental ways. In the market-place conditions are created for the reflexivity that have been identified as one of the key attributes of Mode2 knowledge production, this is enabled by the parallel emergence of Mode2 society.'

Two essential remarks: First that Mode1 science has a homogeneous criterion for quality management: it aims at (let's call it, to be able to symmetrically compare with Mode2 science, (or research)) 'disciplinary robustness', i.e. scientific reliability based on replicability, and approaches it through the invariance requirement in ideal case. Mode2 science (or research) is contextualized, heterogeneous, bricolage is typical in it. Because it is issue-driven it puts together all sorts of knowledge that make it available that a transdisciplinary, social issue relevant knowledge ensemble can be developed. Its quality requirement is not, and mostly can not be 'disciplinary robustness', only in a very special case, for in typical cases there is not enough disciplinary science available to develop the needed level of the interdisciplinary integration, for transdisciplinary objectives. There is no motivation to do it either. Formulating the problem from a language committed to the ideal of developing scientific account of an issue 'shortages', time shortage, all the other possible shortages of resources (money, equipment, personal, etc.,) may make it urgent that, through a 'bricolage' an available best transdisciplinarily relevant knowledge ensemble will be developed. Its quality criterion will be its 'social robustness', its applicability to a wide variety of individual situations. NB. Mode2 approach is not only not to identify with a special type of RandD research approach to problems of practice but it does not even discourage to follow a further disciplinary-based research direction at any transdisciplinary result either. What is essentially different to the evaluation of a research taking disciplinary orientation is, that in Mode2 this requires reasoning. (To contradict to the verdict of Arie Rip (in [21]) Mode2 is not an expelling approach, but a special type of mediating, which applies 'context relevance' as the overarching point of view, whatever this more exactly may be.)

Approaching real complex problems in life may happen from the disciplinary perspective or from Mode2 perspective. Their comparison helps to formulate a general paradox. This is the paradox of giving an exact but irrelevant or a relevant but fuzzy report. (It is very clearly shown on the example of risk research by Arie Rip (in [30]). It follows that nothing prohibits in Mode2 research that the elements of the ensemble brought into it through bricolage would not be changed for science, if it seems to be needed. And this, in time T1 missing science may be reached through any stimulation, among them through stimulation by experiencing its lack in an existing Mode2 knowledge. (I have no place to speak about the problem that one can not require without many further reconsideration that from any piece of, let us say, bricolaged knowledge a universally valid scientific knowledge can be developed. Universal validity, once a general ideal for science, may not only not be needed but also demonstratively impossible.) I shall mention some relevant considerations by DOSI about models of economics, [8], [9].

Let me turn now to a different problem. Successful technological research was always in some way context-sensitive. That means a type of Mode2, trans-diciplinary knowledge ensemble got together through bricolage, even in its most standardized form, just because they have to really function, not only in their idealized models. Taken this into account, the conclusion for higher education in engineering is obvious. Students must acquire the essential capacity of bricolage, as the other side of learning about how functioning of 'natural laws' can be built in into their 'machines'. Understanding the making of Mode2 research this way, the answer is partly trivial. This is what good engineering schools always make. Important is that it can first of all be developed in practice and acquired as tacit knowledge (method in a flexible sense). On the higher level it can and should be reflected with the idea in mind of codifying the tacitly already known, for reaching all the advantageous codification offers. (Speaking about the bricolage technology of engineers, about the Mode2 approach to their problem, I have to remember my brother in law, who shows even wonderful frame-reflexive, not only combinatorial capacity on the tacit base acquired in his earlier practical work, without the slightest codification capacity (for this lack one has to remember his very bad lecture marks in maths and theoretical physics at the university). For me, to whom opening a door may already be a stimulation to develop a theoretical problem, it is a steady challenge to understand how much I have to respect his 'higher technician' Mode2 way of approaching practical problems through tacit knowledge. His descendants learnt this practically from him, just as he from his father, through material practical apprenticeship, utilizing also much law knowledge acquired at the university and later profession. But they already acquired a computer modelling practical capacity as 'higher technician' capacity, and practical knowledge, capacity of utilizing it.) Enriching practical, tacit knowledge acquired in and through practice by computer modelling support, allowing a special type of Mode2 research, is something what can be a basic objective for the undergraduate research work at the coming bifurcated universities. (By the way, computer modelling supported practical work is not to mistake for scientification of research, for it does not need any scientific codification capacity.)

Mode2 ideas provide for the most comprehensive assessment of changes in research processes, in my opinion. But Mode2 ideas are in my understanding promising 'monsters'. They are strongly challenging for intending to go deep, deeper than the 'triple helix' approach to mention one alternative. It is not simply about changing organizational relations, but showing a comprehensive claim: about methodology, epistemology, normative authority, social legitimization. But, yet, it is not clear at many places, and entails a huge amount of very controversial theses, some of them seem to me not tenable.

To mention another monstrous promising idea, it is that an 'agora' has developed a thesis really essential to Mode2 society and Mode2 cognition too, also for giving place to emancipatoric interests. Rare forms of reflexivity, empirically identifiable feedbacks on the market etc. seem only uncertain empirical signs for an ‘agora building’. Visions about ‘agora building’ would be the most important to develop and put to ‘cross-questioning’.

A third one. Even when the authors of the Mode2 conception do send us the basic message that Mode1 and Mode2 are not seen as mutually excluding, as a main message by them, themethodological position, not well cleared, of the Modes conceptualization helps itself to misunderstand them. To be able to argue that even in the high time of Mode1 cognition reality was much richer, it is a rightful argumentation if Mode1 is not only an idealtype but also claims to be empirical reality of some historical period. Something else with Mode2. Is it intended with its introduction to conceptualise a descriptive or/and a normative term, an idealtype description or an empirical one? If the intention was, what I doubt, just to formulate an empirical thesis, then Mode2 now is near to something where short range application orientation is dominant, a period where the ‘exploration – exploitation dilemma’ is sharply moved in direction of exploitation, hence a dangerous tendency. If it is not intended to be the descriptive conceptualization of the processes but just pointing to a possible direction in which the ‘exploration – exploitation dilemma’ itself will be overcome, then it has a more normative status, a pro- and prescriptive one.

Something about the historically renewing craft characteristic of cognition in Mode2. Mode2 knowledge may not be codified into general law statements about its object, at least in its main part. So, it is essentially tied to persons, groups. These agents have steadily got the task at any new case of essentially utilizing some tacit knowledge of similarity, a relation that is not formally transitive. So, the success of knowledge transfer is essentially tied to a person’s never fully formalizable capabilities, even when computer support can be developed to it. As an exchange one gets appropriate solutions for individual complex cases, even for, for human measure, unbelievably complex cases. Computer-supported craftmanship relation to the subject of cognition brings back, on a different level, of course, the main role of rule-production. Rules are always, in principle, subject to unexpected falsification, meanwhile preserving the behaviour of insisting on the preserved validity of the rule. Educating for expertise in computer supported modelling for rule development repeats the tasks of earlier apprenticeship, differently and on a higher level. Will Mode2 research quickly disseminate, it will be more urgent to change for practical, apprenticeship based education technologies.

I think, Gibbons appropriately comprises the basic changes occurring in society at large and its subsystems when he formulates, I guess, exemplarily for science, that “(J)ust as Mode1 was the form of knowledge production appropriate to a world in which boundaries of the state, the market and science were more clearly delineated, so Mode2, because of its more open and reflexive attributes, is a form better adapted to our current more open institutional environment. That environment is ‘speaking back’ to science, demanding innovation in a variety of ways. Typically, the way forward is uncertain, and society is looking for leadership in production of context-sensitive science.” To approach the same issue from a different angle, would be to point to the ‘intrinsic complexity’ of the nature of these processes.

Gibbons summarizes the challenges for universities as follows:

> 'Universities need to adapt themselves to this new environment. As we have seen, moving into the market place and participating in the production of context-sensitive knowledge implies a more-or-less continual expansion of research practices which will have the effect of altering what it means to be a good science.' [16]

Neither GIBBONS, nor NOWOTNY or other persons of the same point of view formulate the abundance of requirements that actually can mean changing of the university. They do not show how education can adapt itself to the needs of the emerging Mode2 society. I shall try to drop some hints in this relation in the part Consequences for higher education, by dealing with the utilization of merging research places at universities for already introducing novices in Mode2 research, made either outside or inside the university, by suggesting a systemic way of developing research careers in first practical knowledge of doing researches in Mode2, getting 'tacit' forms of cognition through practice, then helping to learn to codify the acquired practical capacities on a higher level. The reform should include the strengthening of the capacity of reconstructing problems, up to 'frame reflection' as focal place for typical innovations for a 'new economy' and also for emancipation. That is why systematically including humanities reflection into curricula of engineering students and systematically introducing them to a capability of critically reflecting the special ethos characteristic of engineering became a urgent, with the emerging new needs in Mode2 society.

Concerning the ethos: Ability to weighing the values of accessible knowledge with social robustness makes the basic value for social context sensitive science. Here would have been a place of some further development of the idea of 'personal knowledge' developed by Michael Polanyi for scientific attitude. 'Personal knowledge', integrating the factual and the value part, is the appropriate overarching term to formulate the basic requirement for a committed person, so for engineers, with the appropriate specification, too. (Personality education, education to facilitate teamworking gets here its emancipatory, not only effectivity requirement and possibility.) **(**Flexible personality, able to engage endlessly in the reconstruction of the self, but not on a one dimensional way, only for effectivity reasons. Ability to develop adaptation not only to heterogeneous social roles, 'creolisation', but also to its changes in short time, developing a capability of differently experiencing and ability of joining to others with different experiences, culture.) Any move that deconstructs the artificial demarcation between university and life can only help in this respect.

There is much ado and enthusiasm nowadays that project-based learning, involvement in research should be brought back into, enhanced for teaching. We see already how narrow requirement it may be. Recently, there are lots of efforts to do it for Mode1. i.e. developing discipline based projects, and research and inclusion of the students into it. If it is true that Mode1 and Mode2 differ as all the 'worlds', in their idealized forms, and there is, or should be a move toward realizing

[16] see GIBBONS [14].

more Mode2 research and that the recent students may find jobs later much more than until now in workplaces and research institutes appropriate to Mode2 society then the task is not only to reconstruct teaching on practice and project base without any further qualification. But much more emphasis has also to be given in integrated teaching with institutions of Mode2 research, so that they may practically acquire capability of appropriately moving in this type of context of research, practically acquiring an adequate behaviour.

Let me make a cycle of repetition. Arie Rip wrote recently, I think something of most importance for the conclusions for changing university education, in [21]. His way of looking at Mode2 cognition formulation is mainly rejecting, at least warning. In his reading, and many formulations by the Mode2 authors are near to it, is the formulation of Modes dichotomizing. He puts emphasis on a basic richness of the possibilities of knowledge production, providing it is not disciplined, as it became by the emerging new science from the 17^{th} century. He identifies this development as a lock-in. With the emergence and stabilization of this type of science a type of wave of 4–5OO year length can be identified: from the renaissance richness of approaches emerged a Western type of experiment based on science and got retained. This development as a special disciplination of cognition led to a lock-in. He contrasts it with a new natural history approach, best exemplified in geology and environmental science. Obviously Rip recognizes some richness of new requirements for cognition, as, beside the traditional experimental scientific approach, the development of a new natural history. But he identifies any Mode thinking as dangerously reductionistic.

This contrasting is the most important, I believe. For it is only one task to enhance the effectivity of the research system for practical exploitation. The other most important task is the engagement in environmental issues, and then the synthesis of the two in an environmentally sound engineering. This task is the balancing of the preserving of the evolutionary capacities of natural environment and its engineering for human purposes, or at least an accelerating process of diminishing the recent clash between these two basic human aspirations.

Rip draws the conclusion that capacity and competence building for the future is the basic task, exactly when we face the unpredictability of the evolution of the cognitive system. His conclusion is nurturing varieties and a precautious practical approach.

Mode1 model may have been, as up to a high degree really has been, an ideology and formal organizational principle to bureaucratically arrange the quickly growing flow of knowledge. Mode1 model provided for an applicable method of distributing the financial tools, gave some rough directions how to make and control research, and it provided for a bureaucratic arrangement of higher education, which, among other things, based on a realistic interpretation of the world, was able to give a classified survey of the knowledge to be acquired by the student. (Everybody knows how provisional all this always has been. Any new result made demarcation and inclusion problems and the historical pathway of problem setting and solution had its strong effect on the further development.)

Some basic characteristics of the higher education system have to be mentioned. One is that the arranging of higher education in the 19th century was made in a hierarchical society, insisting on types of knowledge as of higher rank, because of being theoretical. Theory was of higher value than knowledge attached to laboratory practice, and the whole had a higher value than knowledge of the material, as industrial practice. This got connected to a belief in a linear model of innovation 'from above', innovation as theory guided. Education was science and theory biased. If higher teaching was oriented toward prelegating knowledge and not centred around the creativity of the learning subject, as it mostly was, a good systematization was only good. Looking back to the origins one can only estimate Justus Liebig, a famous chemist of the mid-19th century who included his students in the creative work, as soon as possible, into a laboratory work that was planned to serve for his scientific purposes as well, not only for education of students. Because he had the highest interest to exploit his students in exchange for educating them he soon understood that the most important capital for him is their creativity to form and meanwhile exploit for his purposes always on the possible level. It is also well known that earlier students of the Liebig school had a very disproportionately high effect on developing chemistry in the second half of the 19th century.

But this was the very beginning of modern laboratory teaching. Later, even laboratory teaching began to be oriented toward providing for a systematic catalogue of practical capacities to be acquired during the laboratory teaching, with the dawn of mass education, in chemistry and electricity in the second half of the 19th century, when higher education in chemistry or electricity got its form, preserved through a long century further. This has been a type of lock-in in its most bureaucratic form. One can play with the analogy and say that the generations of engineers, through their education became good bureaucrats of their profession.

7. Once Again: How to Educate 'Reflective Practitioners'?

I began to develop already earlier the suggestion of including the students into real practice, both industrial work and research work in industry or at the university possibly from the very beginning of their studies. It would go parallel to teaching them the basics in academic science terms, as maths, physics, chemistry, or biology. It seems most important to develop a sense for practical issues, knowledge of it and what seems even perhaps more important, a committed attitude toward them. With this type of education students would not loose innate contact to practice neither get simply a type of surrogate for it by only studying the analytically cleaned practice in laboratories. Additionally it could provide for one criterion for the selection of students at the two-tiered education system. So it would easily be imaginable that somebody with very good practical affinity got a best way to building his/her capacities when continuing education on a graduate level when already got a good practical basis. It is interesting what will happen with the Bologna process, with generally introducing the two levels diploma education. Certainly, if the selection criterion for the first level diploma education will be the bad capability of acquiring abstract codified knowledge (bad lecture marks in maths, etc.), then a decisive element of the old type hierarchical worldview will be preserved.

Engineers are and should be major agents in a sustainable development. Keeping their position apart of praxis in education prepares them to a 'remote adviser' role, both in the informational and the emotional part of their later profession. What is required for natural science and engineering researchers too is to develop a type of participatory research engagement similar to interactive social sciences. The users, the industry, the public get a parallel, structurally symmetric role of engagement in the research process. Doing participatory research may have different forms, from including into the formulation of research problems, through contextualization as the researcher visualizes it, getting in consultation with those who will be the possible users of knowledge, including them into research. Having never got in touch, through education, with possible dangers of the technological development, it would be easier possible that they will be neutral agents. They do not develop then either an overarching orientation toward successful working of engineering as consultancy in our time, and especially less responsibility feeling for giving bad advises in issues of natural, technological hazards, public health hazards, social exclusion, pressure on natural resources. Developing advice in co-operation with the 'lay' people, in direction of cTA (constructive technology assessment) may show some fruitful ways how both types of knowledge can be integrated. Even much less than really participating in cTA can give an impetus for raising already responsibility. As an example: One can simulate in the classroom a comparative visit to the two big technology museums in Germany. In one, in Munich, the emphasis has been put on 'technological progress', on the 'good' side, while in Mannheim on the concerns. One may also remind them to Gaspard Monge, who regularly called his students to think of engineering work not only to make labour more efficient but also easier for the workers. All the types of social responsibility framing the already existing topics, as environment protection, orientation to health issue consequences, etc. can quite effectively be built in higher education through demonstrations. Experiencing the 'remoteness', inadequacy for, even hostility of some sorts of engineering work against life could be an important element in personality development, in accelerating the development of 'personal knowledge' in the sense of Michael Polanyi. One element of educating responsible engineers could be to involve engineering students into the public discussion over leading edge RandD and technology in their early phase of development. Together with discussing technological visions of society and nature they may orient students toward their proscriptive tasks. In reality the educational situation is now rather the opposite.

The self-accelerating move toward utilizing creativity in the labour process, that labour becomes less based on its separation of creative and de-skilled components, gives a first overarching, but abstract framework for realizability of utopias of emancipatory education of technological students. Developing the capacity of 'reprogramming him/herself toward the endlessly changing tasks': this is what seems to be a typically new way of reflective development, of medium level innovation possibilities in computerbased industrial work. Practical experiencing by engineers of their own creativity should be brought in unity, through education, with responsibility for others.

I want to make a short excursion to describe a trial of turning over traditional engineering education. I want shortly mention the experiments initiated by a group of engineering professors in the US. I mean the work of the ECSEL group, reported by BUCCIARELLI, [19]. Buccarielli contrasts the view of practicing engineers and engineering educators. The one looks for social-practical capability to realize real world tasks, the other aims at instrumental, classificatory knowledge. While for the practicing engineer design task makes the overall frame, for traditional teaching the analytically decontextualized elements step in its stead. The result is a highly reductive analytic student experience, while 'engineering is about creative exchange and negotiating meaning within a social milieu, about uncertainty and ambiguity and multiple framings, approaches and conclusions as much as about solving for the forces or displacements in a complex or simple structure.'

One element of his considerations motivated me to think further. It is about the knowledge, evident for practicing engineers that a realized design unifies for different competencies, the whole will be formed from the different analytical competences either made through autocratic, decontextualized decision or through negotiations leading to some closure. His example of constructing is a simple diving-board and teaching the task through contextualising or de-contextualising way shows how much decisions are made until a task of constructing a such simple thing as a diving-board will be transferred 'into the problem' for a mechanical engineer. One of the important elements of their future practice engineering students have to acquire is to understand that all their calculations include a huge amount of decisions through making closure (including e.g. assumptions about way of life) and have to suit into other decisions, that are, for a democracy, instead of making one-sided decisions by the experts, and even more, having proudly undertaken or covered this decisionismus by them, to change into closures, through negotiations that adequately account for the needs of all 'stakeholders'. [17]

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[17] This article goes back, concerning its interest in 'educating reflective engineers' to the task, participation in the high level EC DG Researchs STRATA-ETAN expert group On Forecasting Changes in Research and Higher Education Relations (set up 2001) gave me. The very preliminary ideas were developed in a manuscript written to the group discussions. The results of the group are to see in [1].

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