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Strategic competences for concrete action towards sustainability: An oxymoron? Engineering education for a sustainable future

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ABSTRACT

In the current discourses on sustainable development, one can discern two main intellectual cultures: an analytic one focusing on measuring problems and prioritizing measures, (Life Cycle Analysis (LCA), Mass Flow Analysis (MFA), etc.) and; a policy/management one, focusing on long term change, change incentives, and stakeholder management (Transitions/niches, Environmental economy, Cleaner production).

These cultures do not often interact and interactions are often negative. However, both cultures are required to work towards sustainability solutions: problems should be thoroughly identified and quantified, options for large change should be guideposts for action, and incentives should be created, stakeholders should be enabled to participate and their values and interests should be included in the change process. The paper deals especially with engineering education. Successful technological change processes should be supported by engineers who have acquired strategic competences. An important barrier towards training academics with these competences is the strong disciplinarism of higher education. Raising engineering students in strong disciplinary paradigms is probably responsible for their diminishing public engagement over the course of their studies. Strategic competences are crucial to keep students engaged and train them to implement long term sustainable solutions.

Contents

1. Introduction

In 1959, C.P. Snow lamented the great divide between ‘science’ and ‘the arts’: *‘intellectuals often proudly proclaim that science isn't their thing, almost as a badge of honour to indicate their cultural bent’* while ‘*scientists being blind to the fact that live is not just about optimisation but also about the values behind that: we have to develop compromises between various, partly contradictory and overlapping, partly qualitative and emotional, demands’*. Snow argued that practitioners in both areas should build bridges, to further the progress of human knowledge and to benefit society [1,2].

Although Snow's analysis triggered lots of reactions, especially regarding its message to create more understanding for science

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among literary intellectuals that dominated the British elite, it hardly affected the phenomenon it described: Today we can observe a gap between the 'sciences' and 'the arts' that, in the industrialized world, has probably widened instead of having been bridged [3,4].

A powerful explanation for this gap was soon after provided by Thomas Kuhn. In his ground breaking "The structure of scientific revolutions" he introduced the concept of 'paradigm': the set of concepts, practices and heuristics that defines a scientific discipline [5]. Paradigms define what is of interest to a discipline, what counts as proven knowledge, and what the legitimate questions for further research are. Paradigms can be divided in categories according to the rationality that is applied:

- Scientific paradigms apply a rationality that aims at establishing truth, i.e. at creating expressions that match reality [Cf. e.g. [6]].
- Technological paradigms apply a rationality that aims at obtaining useful results, i.e. in obtaining results that fulfil practical demands [7].
- The arts apply a paradigm of beauty, i.e. it aims at results that are original, provocative, tantalizing.[1]
- Law applies a paradigm of justice, i.e. it aims at creating an institutional structure that produces 'just' decisions to resolve conflict [Cf. [8]].

A main part of Kuhn's history of science legacy establishes the point that in a scientific revolution, a paradigm changes. However, contrary to the self-image of scientists, this is not a cognitive process based on the introduction of new concepts and/or the discovery of new facts. A paradigm change often raises controversy as contestants are unable to grasp each other's arguments as the arguments refer to incompatible frameworks. A paradigm change is a social process in which generally young scientists, attracted to the new paradigm, take over power from the establishment.

The aim of this paper is to show that the challenges of the future requires changing the discipline based higher education system of industrialized countries. Future experts should learn to think and act change. This paper will focus on engineering as engineers are the experts that design and operate the main metabolic systems of the industrial society. Similar changes could be described for educating managers, lawyers, civil servants, etc.

Educating a new type of engineer requires a paradigm shift in engineering. The future requires an engineer that combines the usual scientific strengths of engineering with strength in managing change and innovation in order to deliver systems level innovation. Innovation is still promoted as if the world is still an almost barren place to be filled with new ingenious products and systems. However, modern innovation is taking place in a context of various other capital intensive systems [Cf. [9]], and in a far more participative society than the 19th century society that created the engineering profession [Cf. e.g. [10]]. Technological change requires thoughtful planning and dialogue, not just to introduce the innovation that was conceived in the laboratory, but to conceive the technologies that might survive the innovation process and deliver the changes that are required for sustainable development.

The paper will first examine how two paradigms regarding environmental issues entered the academy and will argue in favour of an understanding of both paradigms in order to be able to create change. Afterwards, the paper goes into the insufficient educational responses to the sustainability crisis. It develops an argument to restructure engineering education in order to make contributing to sustainable development the leading principle of engineering education.

2. Two paradigms in developing solutions towards the environmental crises

The first wave of environmental awareness developed in the 19th century. In 1848, Thoreau's classic work Walden was published that contained a message of respect for nature. It was a reaction to the tremendous damages that the rapidly developing mines, industries and infrastructures, as well as the growing population, inflicted on natural systems [11]. Nature had to be protected and hence the impacts of human activities upon natural systems were targeted by conservationists. Environmental sciences gradually started as ecology and toxicology to study nature's balance and the impacts of various man-made disturbances.

Meanwhile, environmental engineering started in the cities of the industrialised world. It was not related to any thoughts about nature but to a pressing need for public hygiene. Sewage- and drinking water systems were created as a counter measure to infectious diseases and poisoning. Tall chimneys and the first environmental regulation aimed at protecting the health of citizens [12].

2.1. Analysis of metabolic systems

In a second wave of environmental awareness, the focus of attention shifted from the decline of nature and natural systems, to industrial production as the cause of environmental degradation [13] and the limited resources available for the rapidly expanding industrial society [14]. Especially after the Brundtland report made clear that global poverty reduction and improvement of the metabolic efficiency of production and consumption were two sides of the same medal, the metabolism of human society received far more attention. Thereby the focus of the environmental problem definition shifted not only from emissions to metabolic processes, but also to global equity and issues of socio-economic development [11]. A new scientific research paradigm aimed at analysing complete sequences of metabolic processes of human society in order to assess the combined impacts of providing a product, a service or a material, and to identify the causes of these impacts. It utilised quantitative analysis, and aimed at analysing (global) flows and stocks of resources. Each unit consumed could therefore be connected to flows of resources, emissions and wastes. The combined environmental impacts of any consumption of products or services could therefore be established, although some environmental impacts (like wildlife disturbance), and some causal factors (like risks) were hard to quantify. Methods based on this paradigm are Life Cycle Analysis [15] and Mass Flow Analysis [16].

2.2. Analysis and management of change

Ever since the Enlightenment, science has been regarded as an important cultural activity that could help people understand reality. However, in the course of the 20th century, science more and more became a source of technological innovation. Hence it was a source of national strength and economic success [17]. Especially in the 1980s, historians and sociologists of science and technology started claiming that new technologies did not emerge by 'discovery' of the 'facts of nature' but as a result of economic [18] and social forces and their dynamics [19]. Technology is not prescribed by (perhaps still unknown) facts of nature; its' developers aim at serving specific goals. Hence, actors can develop strategies to try to influence, or even manage, processes of

[1] The Golden Ratio has been suggested as an explanation of beauty in arts, and as a tool to achieve it. However, the aim of arts is not to represent any formula.

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technological change in such a way that the new technologies serve their interests or worldviews. These interests/worldviews are different for actors and change over time. Hence, technological innovation cannot be separated from processes of social change. The publication of the Brundtland report, in 1986, almost coincided with this changing perception of science and technology. As sustainable development became a major policy goal, many scholars of innovation addressed sustainability targeted innovation. The most far reaching claim that some academics made was the claim of 'transition management', which assumed that encompassing technological and institutional change could be managed [20]. In transition management mechanisms and interventions are sought, developed and evaluated that can initiate and/or propel encompassing change, or create a bootstrapping change process.

2.3. Sustainable development between two paradigms

These paradigms (of environmental systems analysis and of management of change and innovation) hardly interacted. Sharp debates took sometimes place within the paradigms. For instance within the environmental systems analysis paradigm there were famous debates on Life Cycle Analysis results, like the debate on what should environmentally be preferred, reusable cloth diapers or disposable diapers. These alternatives caused rather incomparable environmental impacts. Several debates focussed on packaging [21].

Within the management of change and innovation paradigm, there was a distinction between scholars that argued for a more supply driven innovation approach (strengthening the innovation system for specific sustainable innovations), [22,23] and scholars that argued in favour of more encompassing intervention in the change process [24]. However, signs of a debate between these paradigms can hardly be found.[2]

Although these paradigms hardly interacted, there were strong informal judgments between them. For example in the paradigm of 'analysing metabolic systems', Life Cycle Assessment was a core method. Its' complicated procedures and the unreliability of various data triggered strong criticism regarding the precision of final scores in millipoints. In my personal experience of 20 years visiting various international environmental and sustainable development conferences and seminars, I heard LCA partisans sometimes being called '*hair-splitters*' that were engaged in *'futile analysis of marginal change'*. Such criticism was published in more academic and eloquent wording: *"a narrowly set question in LCA can lead to narrow, mechanistic and sometimes inappropriate conclusions."* [[25] p. 35] In the paradigm of 'management of change and innovation' LCA types of analysis were almost completely disregarded as transitions were claimed not to be measurable by the LCA method as too many of the background systems were supposed to be affected by the transition. The main criticism towards LCAs was that their large specificity and depth were not balanced with comprehension and applicability, requirements that were crucial for developing an effective strategy to deal with major problems [26]. In response, some scholars aimed at making LCAs a tool to analyse more encompassing change [27] but without much recognition from the *management of change and innovation* paradigm adherents.

For many science scholars, managing change or managing transitions was too much a qualitative approach that should be left to politicians. Plans aimed at creating 'transitions' were often accused of being a banner to cover politically motivated action, not aiming at sustainable development but at supporting various interests.[3] Some scientists combined their academic position with activism. Hence '*management of change and innovation*' academics were informally blamed as being too 'political' although not in official publications. In such situations scientific contestants realize that it makes no sense to show conflict in public as it weakens the entire discipline. [Cf. [28] for similar situations in physics in Austria during the controversy on nuclear power.]

In the beginning of the 1990s, an issue emerged that showed that there could be interesting cooperation across these sustainability paradigms. The issue was whether to use ceramic coffee mugs or disposable plastic cups. LCA analyses showed that not primarily the materials, or the wastes were most important, but the cleaning habits of the users [29,30]. In fact, this LCA example showed that real improvement in environmental performance takes an encompassing *management of change and innovation* perspective, and that broadened LCAs that encompass both behavioural and material elements might be tools for problem analysis and evaluation.

LCAs are in fact a snapshot of the environmental performance of a product/material/system. This triggered the criticism that foreseeable improvements in background systems should be taken into regard in an LCA (e.g. greening of the electricity grid as a major factor that determines whether electric vehicles can be considered 'green'). To account for the improvement potential due to background changes, the dynamic LCA was introduced which aims at being far more useful in strategic decision making as it shows how LCA outcomes might change if key external parameters change [31]. Especially for artefacts that are supposed to last long, a dynamic LCA might sketch the dynamics of its environmental performance in a scenario-like manner [e.g. [32] shows how this works out for an institutional building]. Dynamic LCAs might therefore gradually resemble scenario's that are a main tool in the management of change and innovation paradigm [33].

3. The professionals of tomorrow need thorough analysis to be agents of change

The changes that are required will not only be made by the current generation of experts, the next generation will be of far greater importance as they are the ones that have to introduce the changes that go 'beyond the low hanging fruits'. Crucial to teaching the next generation of experts is that they learn to think and act longer term change: develop the competence to think and act strategically and to interact with others in order to implement a sequence of changes that produce transitions. The future engineer will not only need to be successful in designing this process but also in implementing change and that requires really convincing arguments. Quantification helps recognizing targets and progress and is thereby a mobilising force in the process of change. Regarding environmental issues, the absence of quantification sometimes makes things worse: For instance, many people have misconceptions about environmental issues (such as 'air travel is always worse than car travel' [34] or 'ceramic coffee mugs are better than disposable plastic cups' [30]). Without proper quantitative analysis/evaluation, change and even transitions could make things worse. And even in situations where the environmental merits of technical alternatives are clear, clean technologies might

[2] Naturally, the absence of a phenomenon throughout the world cannot be established.

[3] Cf. the controversy that was ignited by plans of the Netherlands government to allow exploration of shale gas in the transition process to renewable energy. Government reports: https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken/documenten/kamerstukken/2013/08/26/brief-aan-de-tweede-kamer-schaliegas-resultaten-onderzoek-en-verdere-voortgang [accessed 01.03.16].
Criticism of its scientific merits by transition professor Jan Rotmans: http://www.stopwarming.eu/?news&id=1080 [accessed 01.03.16].

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trigger changes in consumer behaviour that might annihilate the benefits of these technologies. For example the option of cleaner private transport might sometimes cause public transport commuters to switch to this option, which might cause a deterioration of the quality of public transport. This is in fact an example of the Jevons paradox [35].

But foremost, the next generation should learn to think and act large change; whether it is a factor 4 [36], 10 [37] or 20 [38] is not really relevant. Long term strategies, and methods to develop these strategies like scenario analysis and backcasting, are required for success [3]. Students should for instance learn

- that technical and social change interact [19],
- that choices lock technologies into specific pathways of development and these choices cannot be undone over time [39], e.g. they lock out renewable technologies [40],
- that engaged champions are required to make things come true [41], and
- that incentives should direct people towards the more sustainable solutions.

4. 25 years of sustainable development education

The Brundtland report [42] implied an important change in education. Hitherto, 'the environment' had been a side-issue for many academic disciplines, a nuisance that had to be dealt with by engineers, economists, lawyers, chemists, … but it did not affect the main orientations of those disciplines. The Brundtland report made sustainability core business: products not just had to be manufactured in a cleaner way, but they also should be more resource efficient in use and providing opportunity for development. Education had to play an important role in societal change that aimed at bringing material and energy consumption within the limits of the carrying capacity of our planet [43]. Many academic disciplines embraced sustainability as their new legitimation. There were only few outspoken critics that opposed sustainable development [Cf. [44]] but they were considered charlatans. In engineering implementing sustainable development was often regarded as just an issue of developing add-on courses and programmes to train the next generation of technological leaders. That turned out to be somewhat naïve.

Recently, American sociologist Erin Cech published a longitudinal study regarding the question whether '*engineering education was succeeding at nurturing students' sense of professional responsibility to the welfare of the public*' [45]. She observed engineering students' support for four public values at regular intervals:

- Professional and ethical responsibilities.
- Understanding the consequences of technology
- Understanding how people use machines.
- Social consciousness.

Four US engineering programmes participated in this study: MIT, Olin College, Smith College and the University of Massachusetts. The survey results presented a consistent image: over the course of their engineering education, students' support for these values all declined, independent of race, ethnicity and the programme that students were attending. The results suggest that as students are further integrated into the culture of their engineering programmes, their public welfare beliefs decline. This decline even occurred at programmes that explicitly aimed at nurturing public engagement, although the support for professional/ethical values dropped less rapidly than it did at other programmes [45].

The phenomenon that engineering education produces a declining support for public values can in part be explained by the fear of programme managers for not meeting the established learning outcomes. '*Even programmes that explicitly attempt to create a structure and culture that diverges from historical norms have difficulty doing so because of the need to be recognized as legitimate purveyors of engineering knowledge (e.g. through accreditation).*' [[45], p. 64]. Former Netherlands prime minister Wim Kok emphasized the same point: '*….Engineering Education for sustainable development is OK but we don't want our bridges to fall apart*' [46].

However, the falling support for societal values among engineering students is perhaps not just an issue of institutional pressure. In general, young people are very enthusiastic regarding more environmental education [43]. For engineering freshmen, this situation is not different; a survey among Delft UT freshmen in 2000 showed that there was an overwhelming engineering student interest for more sustainable development education [47]. However, in the following years no large increases were observed in student interest for SD related electives. It seemed that SD interest had decreased among the students of this cohort.

As engagement with public values declines over the course of engineering education, it remains questionable if this pattern is unique for the development of engineering students; do preferences of students of non-engineering programmes develop in a similar way? Does this pattern also apply outside the USA? An appropriate hypothesis, in accordance with my personal 20 years of sustainable development teaching to engineering students, seems that the engineering students are gradually drawn into a technocratic paradigm. In such a technocratic paradigm, decisions should be based on quantitative data, qualitative data are disregarded, and solutions for problems should be based on expertise, not on values.

A technocratic identity of engineers supports an analytic SD paradigm, as it is in line with the quantitative modelling approach of engineering, and is at odds with a strategic SD paradigm, as it does not take into regard the preferences and behaviour of other actors and the long term impact of engineering decisions.

Such a technocratic worldview can easily be observed in day to day engineering. Engineers are for example not very well equipped to have a productive relation with local community energy initiatives [48]. As illustrations I include a number of quotes from various engineering educators that I personally gathered in the past 20 years. These quotes are not representative for all engineers but are illustrations of an important strand of thinking among engineers on their identity: that engineers understand their piece of the world, besides other experts that understand their own piece. Other stakeholders are in general irrational and should be ignored/opposed.

Lecturer Electrical Engineering:

'SD is none of our business: the shaft is the divide. In generating electricity, the fuel consumption and emissions are from steam production which is Mechanical Engineering'

Lecturer Physics Engineering:

'We don't want our engineering students to do assignments in companies/agencies. These organisations are methodological too unscientific'

Lecturer Maritime Engineering:

'Can you believe it: Government sent a sociologist over to interview me on green shipping policies…… A sociologist for God sake …!'

Lecturer Civil Engineering to his students:

'Don't engage with politicians, avoid it if you can and disregard their comments, because you know better than they do.'

Lecturer Aerospace engineering when discussing development in Africa:

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'How my designs might help reduce poverty in Africa? Well, Africans are welcome to learn from my work too.'

5. The strategic sustainable development paradigm is missing

In the past decades, successful training modules have been developed to train engineers to contribute to sustainable development [49]. However, this does not imply that graduating engineers are well equipped to deal with sustainable development. Engineering curricula may even tend to create a more disengaged engineer, even if the curriculum aims at more engagement.

For sustainable development, committed engineers are crucial. However, for the engineering profession, contributing to such a tremendous societal challenge is also a 'must', as an indifferent attitude would not be understood by the societal stakeholders of engineering education. This does not imply that engineering students should just learn 'sustainable development': it implies that contributing to sustainable development should be the leading principle for organising any engineering curriculum. Hence the arguments of Corcoran and Wals, that a complete reorientation of a curriculum is needed in order to contribute to sustainable development, might also apply to engineering. Instead of creating a curriculum for a discipline based on the 'basics' of the discipline, and add some 'sub disciplines' or 'specialisations', a curriculum should be built on the question 'what could our knowledge base contribute to sustainable development?' [50]. This contribution to sustainable development always means 'strategy': not just designing something sustainable, but designing and implementing it.

Instead of teaching basics and applications in engineering, developing the strategic and analytic capabilities to contribute to sustainable development should be leading the engineering curriculum design: Systems analysis, technology history and future studies could be fundamental in developing techno-strategic competences. The issue is not replacing science, modelling- and design courses; it is enabling students to connect science, modelling- and design work to the main challenges of society. The additional capabilities that this requires could also help students in developing their own curriculum. Far more individualized curricula might help students acquiring the capabilities that fit to their own future. Of course a far more individual curriculum does not imply far more individualised education, on the contrary. Problem based and project based learning have proven their value to engineering education [51].

Thus far, the changes that are proposed here have only been applied in a few specific engineering programmes with headings such as Industrial Ecology,[4] Sustainable Technology[5] or Sustainable Energy Technology.[6] These programmes have been increasingly successful. This success might be a stepping stone towards more encompassing and lasting reform in engineering education, if these programmes are able to increase their success and challenge the established programmes. Under those conditions, a major reform of education might become an issue of survival for engineering institutions.

Such change in engineering education is worth a trial, but the results are by no means certain. The resistance of the long established paradigm might be strong, and this resistance might easily spur suspicion among the stakeholders of engineering education that normally take trust in engineering design. However, the change is worth a try.

[4] E.g. Chalmers UT, UPC Barcelona, TU Graz, TU Delft/Leiden.

[5] E.g. KTH Stockholm.

[6] E.g. TU Eindhoven, University of Twente, TU Delft.

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