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# The practice of engineering and the idea of justice: concepts and challenges illustrated by the development of membrane desalination

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ABSTRACT

All engineering activities have the potential to profoundly affect the wellbeing of persons and the communities in which they live, both beneficially and deleteriously. Hence, in addition to technical challenges, professional engineers are presented with a major ethical challenge: can the great technical innovation of engineering be matched by a corresponding innovation in the expression and acceptance of ethical responsibility? This challenge is explored using key concepts provided in the work of two leading contemporary philosophers: the concept of a *practice* in the work of Alasdair MacIntyre and the concepts of the *obligation of power* and *capabilities* in the work of Amartya Sen. The application of these concepts is then illustrated by consideration of the engineering work of the desalination pioneer Sidney Loeb. The article concludes with a challenge to today's practising engineers, giving particular reference to desalination and water treatment.

*Keywords:* Agency; Capability; Desalination; Engineer; Engineering; Loeb; MacIntyre; Practice; Sen; Membrane; Peace; Poverty; Wellbeing

## 1. Introduction

When asked to describe their work, individual engineers tend to focus on the technical aspects of their activities. Indeed, the opportunity to work on the development of sophisticated technology is one of the attractions of engineering as a profession. However, engineering activities, whatever their level of sophistication, have the potential to profoundly affect the wellbeing of persons and the communities in which they live, both beneficially and deleteriously. Hence, in addition to technical challenges, professional engineers are presented with a major ethical challenge: can the great technical innovation of engineering be matched by a corresponding innovation in the expression and acceptance of ethical responsibility?

Even so, the engineering profession as a whole has generally given a high priority to technical ingenuity whilst giving only more muted attention to ethical responsibility. This is reflected, for example, in the almost entirely technical content of many university engineering courses and the highly technical focus of many commercial engineering enterprises. Such prioritisation has become mirrored in public perception: engineers are often perceived as being primarily technically ingenious nerds or geeks. As a result, their positive contribution to the wellbeing of persons and communities is often poorly appreciated.

However, there is an increasing awareness that professional engineering may be enriched by paying more attention to ethics, with corresponding benefits to the public and ensuing changes in public perception. Achieving such enrichment can be aided by careful consideration of the nature of engineering as a professional activity. One such approach will be outlined in the present article, drawing on key concepts provided in the work of two leading contemporary philosophers: the concept of a *practice* in the work of Alasdair MacIntyre and the concepts of the *obligation of power* and *capabilities* in the work of Amartya Sen. The application of these concepts will then be illustrated by consideration of the engineering work of the desalination pioneer Sidney Loeb. The article will conclude with a challenge to all practising engineers, giving particular reference to desalination and water treatment.

## 2. Ethics: persons in communities

The origin of the word "ethics" lies in the Greek *ethikos* referring to ethos, that is, distinctive character, spirit or attitude. For more than 2500 years, the documented quest of ethics has involved philosophical activities such as careful conceptual analysis and contemplation. However, ethics is not just an apparently arcane theoretical aspect of philosophy but rather a vitally practical activity, for ethical decisions, how we choose to live and act, may have significant consequences for human wellbeing[1].

At the core of ethics lies an awareness of the uniqueness and value of every person. This leads to our sense of compassion and responsibility for those with whom we come into contact, especially those in need. In simple terms, we hear (literally or metaphorically) the voice of others saying, "It's me here, please help me!", and to such persons we can reply, "Here I am! How can I help you?". Proximity in place and time is necessary for such an ethical response, and hence we have a special and immediate ethical responsibility for our families, friends and immediate neighbours.

Mention of families, friends and neighbours reminds us that we live in communities and that each person's wellbeing depends on the wellbeing of the community in which he or she lives. In practice each person belongs to several communities of different sizes which may be categorised in different ways, for example, a local neighbourhood, a city or a nation. Hence, each person's wellbeing depends on the wellbeing of each community to which he or she belongs. Further, in the modern world, each person's wellbeing also depends on the wellbeing of communities to which he or she does not belong: poverty and deprivation are major causes of conflict within and between communities of all sizes.

Until modern times, only a few very exceptional individuals could influence the lives of those outside their family and local community. In sharp contrast, it is possible today for most people in the more affluent parts of the world to influence, consciously or unconsciously, the lives not only of those close by but also of others far away, through activities such as international trade, international travel and electronic communications. Achieving a balance of proximate and distant ethical commitments is especially challenging for professionals such as engineers whose actions may have substantial influence far beyond proximity in both place and time.

## 3. Engineering as a practice

The overall nature of engineering may be clarified by considering it as a *practice*, "a coherent and complex form of socially established activity", of the type first proposed by MacIntyre [2,3]. The UK Royal Academy of Engineering (RAE) has provided a cogent and challenging description of what might be considered *the practice of engineering:*

> Professional engineers work to enhance the welfare, health and safety of all whilst paying due regard to the environment and the sustainability of resources. They have made personal and professional commitments to enhance the wellbeing of society through the exploitation of knowledge and the management of creative teams [4].

Practices have a number of key features, here defined using MacIntyre's terminology with descriptions of their engineering application:

(i) *Internal goods* – For engineering these are particularly those associated with technical excellence: the accurate and rigorous application of scientific knowledge combined with imagination, reason, judgement and experience. Such goods are best recognised by participation in the practice and characteristically benefit all who participate in the practice, and less directly all those affected by the practice.

(ii) *External goods* – For engineering these include considerable economic benefits to society, but more particularly technological artefacts. Such goods are typically the possession of an individual or group.

(iii) *Ends (or goals)*[2] – For engineering this may be described as being to contribute to the flourishing of persons in communities through contribution to material wellbeing.

(iv) *Virtues* – These facilitate the success of a practice, and those particularly necessary in the case of engineering are: accuracy and rigour; honesty and integrity; respect for life, law and the public good; responsible leadership – listening and informing [3,4].

[1]There is a huge ethical literature. An excellent introductory work has been provided by Graham [1].

[2]Philosophers use the term "end" to describe what an engineer might describe as a "goal".

(v) *Institutions* – These sustain practices and in the case of engineering include university departments, professional associations and commercial enterprises.
(vi) *Systematic extension* – Successful practices will seek to continuously develop their internal goods, external goods, ends, virtues and institutions.

Two characteristics of the practice of engineering are especially noteworthy in the present context. Firstly, the practice is described as being concerned with the welfare, health and safety of *all*. This is a very demanding aspiration, which includes communities beyond our usual boundaries and the individual persons in those communities. Secondly, a successful practice pays appropriate attention to *all* of its key constituent features. A cautionary note is required here. MacIntyre noted the dangers of too great a focus on external goods such as wealth, fame or power. In the case of engineering there is an additional and particular danger of focusing too greatly on the external goods of technological artefacts. Too great a prioritisation of the development of technically ingenious artefacts can lead to mistaking the external goods of the practice for the real end of the practice. When engineering is considered as a practice, technological artefacts are only contingent products, external goods, in the pursuit of the flourishing of persons in communities.

## 4. The obligation of power

The technical aspects of engineering are can bring great intellectual satisfaction. However, as has been noted, this leads to the danger of becoming lost in "the labyrinth of technology"[3], of becoming so absorbed in the technical aspects that the ethical dimension, the effect of the technology on others, is neglected or lost. The avoidance of this danger can be stated in terms of a positive challenge to engineers: *can the great technical innovation of engineering be matched by a corresponding innovation in the expression and acceptance of ethical responsibility?* That is, can engineers adopt a truly aspirational approach to their work? A possible aspirational approach may be based on aspects of the work of the philosopher and economist Amartya Sen, as most recently expressed in his book *The Idea of Justice* [6].

Engineers have at their disposal a range of knowledge, skills, techniques and technologies of uniquely powerful potential. So the first concept that engineers could adopt from Sen is the *obligation of power*:

> ... if some action that can be freely undertaken is open to a person (thereby making it feasible), and if the person assesses that the undertaking of that action will create a more just situation in the world (thereby making it justice enhancing), then that is argument enough for the person to consider seriously what he or she should do in view of these recognitions [6].

[3]The title of a book by Vandenburg [5].

This obligation could be considered as a generalisation of the "rule of rescue": the powerful motivation to save endangered human life wherever possible. The obligation certainly refers to a type of situation in which many engineers may find themselves. It should also be noted that this obligation is practical rather than idealistic, for it concerns the serious consideration of feasible options and thus recognises that there may be situational constraints on the action (at least in the first instance).

Sen further considers an approach to social justice in terms of *capabilities*, the various things that a person manages to do or be in leading a life. Such capabilities he describes in terms of both *wellbeing* and *agency*, the latter being the possibility to advance whatever goals and values a person has reason to advance. Wellbeing is particularly useful in assessing issues of distributive justice. Agency gives attention to the person as a doer [7]. The specific inclusion of agency is a characteristic feature of Sen's work and allows for a much richer description of benefits than consideration of wellbeing alone. For example, a person may have reasons for pursuing goals other than personal wellbeing or individual self-interest, including promoting the wellbeing of others and respect for their agency.

Sen further characterises wellbeing and agency in terms of *achievement* and *freedom*. Freedom refers to a person's options and opportunities, and may have a plurality of expression, including basic aspects such as freedom from hunger and higher level aspects such as developing self-respect or creative fulfilment. He notes that such freedom has not only instrumental but also intrinsic value, and may be directed to the benefit of others.

Taken together, this analysis yields four concepts of benefit to a person:

(i) *wellbeing achievement*,
(ii) *agency achievement*,
(iii) *wellbeing freedom*,
(iv) *agency freedom*.

This fourfold classification of advantages seems particularly useful for thinking about the benefits of an essentially *enabling* activity such as engineering. Further, the approach is general enough to allow for a great range of specific circumstances. For example, persons in poorer communities may particularly benefit from provision of necessary basic goods, such as clean water and sanitation. These may already exist in wealthier communities, where wellbeing and agency may be further advanced by additional consideration of how such goods are provided.

A central feature of Sen's approach is that it does not seek to identify some ideal state, a task adopted by many philosophers. Rather it seeks to further *practically* the wellbeing and agency of persons in whatever circumstances they find themselves. Most importantly for engineers, consideration of *the obligation of power* and *capabilities* provides powerful motivations for giving ultimate priority to persons in communities rather than technological artefacts. Even so, it might be considered that such an ethos sets goals that are too high. Thus, the next section will give a specific example of how an aspiration to fulfill such opportunities has already been achieved for a type of engineering.

## 5. Sidney Loeb: the engineering work and an ethical analysis[4]

Separation from liquids of small entities such as colloids, macromolecules and simple ions (salts) requires a type of advanced filter known as a membrane that contains appropriately sized pores, typically in the range 100 nm to less than 1 nm (a simple ion is typically ~0.5 nm in diameter in solution). This raises a number of initial issues, two of the most important being: (i) How can large areas of membrane containing such pores be fabricated? (ii) As the hydraulic resistance of a pore increases very rapidly with decreasing size[5], how can a practically useful membrane be fabricated? These issues became particularly important in the middle of the last century when new ways of producing drinking water from saline water were being sought.

The key to solving these and other issues was the invention in 1959 by Sidney Loeb and Srinivasa Sourirajan of polymeric anisotropic membranes, that is, polymer membranes in which a thin porous layer (say ~1 μm thick) with the required separation properties was supported on a thicker layer with much larger pores. If such a structured membrane (comprising both layers) is then itself appropriately supported, it can withstand the high pressures (up to as much as 80 atmospheres in some cases) required to remove salt from water at a useful rate, thus allowing the production of drinking water from brackish water and even from seawater. The first Loeb and Sourirajan membrane was what is now termed a reverse osmosis membrane, and is the prototype of a family of membranes, also including nanofiltration membranes and ultrafiltration membranes, with pores in specified segments of the range from sub-nanometre dimensions to about 100 nm.

Sidney Loeb was known as a man of great ethical integrity, much concerned about human wellbeing. He was thus motivated to play a key role in applying his invention through the development of the world's first commercial reverse osmosis system in the town of Coalinga in California, a development that required the ingenious solution of several practical engineering problems. The process at Coalinga provided 19,000 l of drinking water daily for the residents; there was a special need for such provision as the local water was so high in minerals that potable water was previously transported in by rail tanker. He subsequently moved to Israel, and worked on that country's first reverse osmosis plant in Kibbutz Yotvata, which used locally manufactured membranes to produce 150,000 l of drinking water daily. This installation was important as the local water was sufficiently brackish to pose a serious threat to health when consumed. Throughout his life he continued to support the commercialisation of membrane based water treatment processes throughout the world.

The reverse osmosis business that Sidney Loeb pioneered is now worth many billion euros annually. Installed reverse osmosis processes produce about 13.5 billion cubic metres of drinking water annually and are now the leading desalination technology on a world basis. About another 17,000 small industrial, ship-mounted and household reverse osmosis systems are also in use. Further, the closely related processes of nanofiltration and ultrafiltration are very widely used throughout the manufacturing industries, including pharmaceuticals and food production. Such membrane processes also have important medical applications[6].

It is now possible to consider Sidney Loeb's work in the philosophical framework described earlier. Thus, in terms of MacIntyre's description of a *practice*:

*Internal goods* – Discovery (with Srinivasa Sourirajan) and recognition of the importance of membranes with an anisotropic structure; ingenious solution of practical engineering problems in the design, construction and operation of the world's first commercial reverse osmosis plant in Coalinga in California.

*External goods* – Successful operation of the plant in Coalinga and the subsequent plant in Kibbutz Yotvata, both meeting essential local needs; continued support for commercialisation of membrane-based water treatment processes to billion-euro status.

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[4]A number of readers of this journal will have had the pleasure of knowing Sidney Loeb, who died in December 2008. The outline of his work given here is provided for those unfamiliar with his achievements.

[5]Assuming constant fluid viscosity, hydraulic resistance is directly proportional to the length of a pore and proportional to $(1/\text{pore diameter})^4$. A further increase occurs due to the increased viscosity of water in pores of nanometre dimensions.

[6]For further details of Sidney Loeb's life and work see [8,9]. His co-inventor of asymmetric membranes, Srinivasa Sourirajan, was subsequently very productive in membrane research and development during a long career. His different, but very effective, approach to technology could form the basis of a further case study.

*Ends/Goals* – Sidney Loeb was known for his compassionate concern for the welfare of those within his community and outside the boundaries of that community.

*Virtues* – The key engineering virtues were apparent throughout the development of this work: accuracy and rigour; honesty and integrity; respect for life, law and the public good; responsible leadership, listening and informing.

*Institutions* – Many have arisen to support the practice: research centres (including Srinivasa Sourirajan's), journals (including this journal), commercial companies.

*Systematic extension* – Development of all of the key features of the practice continues.

Further, examples of the benefits to persons may be made clear in terms of Sen's concept of *capabilities*:

*Wellbeing achievement* – Improved health due to the provision of high-quality drinking water.

*Agency achievement* – Improved health allows adults to take a fuller part in society and ensures that children are well enough to attend and fully benefit from school: these are just an indication of a multitude of such benefits.

*Wellbeing freedom* – Benefits continue to increase as membrane engineering provides for the growing worldwide need for high quality water - much of the world's population lives within a few kilometers of the sea which thus provides an accessible large resource.

*Agency freedom* – Options and opportunities continue to arise due to the use of membranes in a multitude of processes including pharmaceutical and food production.

Thus, MacIntyre's and Sen's concepts provide a good framework for the consideration of the engineering development of membrane desalination and related membrane processes. The *agency* benefits are particularly worth noting as these are often neglected in ethical assessment of engineering: even the previously quoted and challenging RAE description refers only to welfare, health and safety. It should also be noted that Sidney Loeb's work was quintessentially that of an engineer. If he had been a scientist, he might have been content with acquiring further knowledge of the properties of anisotropic membranes. If he had been a technologist, he might have been content with the invention of ingenious laboratory devices incorporating such membranes. However, as an engineer he acted on what we could now express as an *obligation of power*[7].

## 6. The ethical challenge to today's practising engineers

The development of synthetic membrane processes demonstrates that enormous benefits can result if great technological innovation in engineering is matched with aspirational acceptance of ethical responsibility. Many have contributed to develop membrane engineering to its present state, but all build on the pioneering work of Sidney Loeb and Srinivasa Sourirajan. The same challenge of matching technical innovation with a corresponding innovation in the expression and acceptance of ethical responsibility continues to apply to all of today's practising engineers. The possibilities depend on context, but those with skills in the matters which comprise the scope of this journal, *Desalination and Water Treatment*, are fortunate to have the ability to contribute to many of the major issues confronting persons and communities in the contemporary world. Three such issues that have particular importance are: promotion of sustainable peace and security, reduction of infrastructural poverty, and the development of engineering with a human face. Possible contributions to these may be summarised as follows:

(i) *Promotion of sustainable peace and security* The greatest tragedy of modern engineering is that for generations many of the most technically ingenious engineers have been employed in the design, development and use of weapons of indiscriminate and huge devastation potential. The resources used are enormous: annual global military expenditure reached at least $1531 *billion* in 2009 [10], with almost a third of engineers in the US being employed in military-related activities. However, due to a combination of perceptive analysis by NGOs and the global financial crisis, governments are now realising that a better approach to peace and security is to tackle the root causes of conflict [11,12]. One of the most important of these root causes is competition for essential resources. Water is one such resource and competition is already a source of intra-state violence in several places in Africa, including Darfur, and of tension between a number of states, including: Israel, Jordan and Palestine; Syria and Turkey; China and India; Egypt, Sudan and Ethiopia; Angola and Namibia. The challenge to engineers is to work to ensure the equitable distribution of water in these and other such places so as to promote sustainable peace [13].

(ii) *Reduction of infrastructural poverty* The developing world suffers from infrastructural poverty. Like war, such poverty particularly devastates the most vulnerable persons, families and communities. Indeed, it has been referred to as "institutionalized violence" [14].

[7]Scientists and technologists can, of course, also make valuable contributions to wellbeing and agency. However, the balance of goods and ends/goals within engineering, science and technology differs. Elucidation of these differences is outside the scope of the present article.

One of the most serious types of infrastructural poverty is the lack of clean water and sanitation. It is estimated that 884 million people do not have access to a reliable source of clean drinking water and that 2.6 billion people have inadequate or no access to effective sanitation, a number which is currently increasing [15]. The consequences are enormous. For example it has been estimated that 1.4 million children die each year from preventable diarrhoeal diseases (almost 4,000 *every* day) and that 50% of malnutrition is related to repeated diarrhoea or intestinal nematode infections as a result of unclean water, inadequate sanitation or poor hygiene [16]. A study for the World Health Organisation has shown that universal provision of clean water and sanitation could be provided at modest cost, in the range 1–10% of global military expenditure over a period of fifteen years [17][8]. Here the challenge is to work to ensure that the relatively simple engineering required is made available to those in need.

(iii) *Engineering with a human face* In both developing and developed countries, concerns can arise about the effects of water treatment and desalination on the environment, and issues regarding the effect on local communities of large facilities for the storage and processing of water may also occur. In such situations it is particularly important for engineers to remain aware of the value of all persons and that respectful dialogue, listening and informing, is an essential part of their work. Attention should be given wherever possible to ensuring that facilities are on an appropriate scale, not necessarily the "small is beautiful" of the seventies slogan but at least sized with sensitivity to the location and local community. More generally, we as engineers need to make known our human face in words and deeds: demonstrating our professional ethical concerns through a balanced *practice*, through accepting the *obligation of power* which arises from our knowledge and skills, and hence promoting the *wellbeing* and *agency* of persons and communities. This we can do with imagination and generosity, bearing in mind Levinas' evocative definition of an ethical act as "a response to the being who in a face speaks to the subject and tolerates only a personal response" [18]. We may then be fortunate enough to follow, in some small way, the example of Sidney Loeb, who in the words of an appreciation in the *Jerusalem Post*, "enjoyed the satisfaction of knowing that he had contributed so much to the welfare of so many, now and in generations to come" [8].

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