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A MACRO-ETHIC FOR ENGINEERING

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Introduction:

William Wulf, president of the National Academy of Engineering (NAE), called for a macro-ethic for engineering at the 2000 NAE Annual Meeting citing the impossibility of predicting the behavior of complex systems and the dangers that we bring on ourselves by continuing to unconsciously engineer the biosphere. As human engineered systems and their impacts on earth systems have grown larger and as knowledge has grown from research in complex systems and general systems theory, it has become clear that non-linearity, discontinuous behavior, and uncertainty are the rule rather than the exception in all complex systems including earth systems.[1] The trunk of the tree of knowledge must now be ethics, especially when designing systems that interact with natural systems. In engineering, this fundamental conceptual change can be represented as a macro-ethic.

This paper lays the foundation for a fundamental macro-ethic that can guide engineering decision making in the future. The conceptual framework for the macro-ethic is based on the work of two environmental philosophers Aldo Leopold and J. Baird Callicott. Leopold created the concept of "the land ethic" which Callicott subsequently modified and extended with his creation of the "modified land ethic."[2,3] This paper explains the macro-ethic and how it can be applied by engineers and gives guidance and suggestions to educators to help them present the concepts to students. Guidance and suggestions to educators appears as *italicized* text in the paper. The guidance and suggestions has been developed through teaching undergraduate and graduate classes on topics including industrial ecology, sustainable design and development, and complex systems study and design. The courses were cross-listed with the College of Engineering and the virtual School of the Environment. This allowed the classes to draw diverse, multidisciplinary groups of students including civil, chemical, and mechanical engineering students from the School of Engineering and MEERM students (masters of earth and environmental resources management) from diverse undergraduate backgrounds including business, geography, biology, marine science, and geology. Student evaluations repeatedly referred to the value of the critical thinking that the course format required of the students. The critical thinking component was carried out by having students read and write a critique of selected works prior to class followed by classroom discussion of the selected works and the student's critiques moderated by the instructor. This format seemed to offer great opportunities for critical thinking.

The Problem:

There are many texts and papers available that can be used to familiarize students with current environmental concerns. Some of the texts that we have used with various classes include:

- *Hawken's Ecology of Commerce (chapters 1-8)*[7]
- *Graedel and Allenbys' Industrial Ecology (chapter 1)*[6]
- *Allenby's Earth Systems Engineering*[11]

If you have any favorite works that convey current environmental concerns, use them or the suggested reading assignments above to allow students to understand the environmental problems and why the class is important.

On the most basic level, the driving force for this paper is concern with human impact on the environment. Put simply, modern human activity poses a threat to the health of the planet earth. We will not repeat the litany of environmental concerns that have already been well documented by others.[4-10] The problem of human impact on the globe can be summarized by stating that human technological systems' mass flows (especially inputs and waste products) and space requirements have grown so large, that they threaten to overwhelm the natural systems in which they are imbedded.[11]

Allenby and Graedel have created what they dub the "master equation" to help explain human impact on the earth. This equation states that a country's impact on the environment is equal to the country's population multiplied by an affluence term and a technology term. The affluence term is the gross domestic product (GDP) per capita of the country. The technology term is the amount of environmental impact per unit of GDP.[6] Put in different terms, environmental impact can be seen as the product of the number of people consuming, the amount and type of goods those people are consuming, and the impacts associated with the life cycle (creation, use, and disposal) of the goods or products consumed.

So, what can engineers do to help? Engineers as a profession are responsible for creating and maintaining the technological systems that are causing the environmental impacts. However, those same technological systems were created to deliver better living conditions for the public that they service and the environmental impacts are unintended consequences. Engineers as a profession have been guided to help the public by the various professional codes of ethics. Therefore, one way to address the unintended impacts of the technological systems is through the codes of ethics. A review of the current codes of ethics from some engineering organizations is given in the following section to shed some light on what has been the driving ethical force behind the engineering disciplines.

Engineering Codes of Ethics:

Having students locate the various codes of ethics by carrying out a web search is a valuable homework assignment. The students can be asked to review the codes *and summarize them for a class discussion. The section that follows can be used as a teacher's discussion guide for the codes.*

Before making changes to the engineering codes of ethics to address the environmental impacts of technological systems, a review of the current codes is needed. The following organization's codes were examined:

- Accreditation Board for Engineering and Technology (ABET)[12]
- American Institute of Chemical Engineers (AIChE)[13]
- American Society of Civil Engineers (ASCE)[14]
- American Society of Mechanical Engineers (ASME)[15]
- Institute of Electrical and Electronics Engineers (IEEE)[16]
- National Society of Professional Engineers (NSPE)[17]

All of the above codes contain language that very closely resembles the following two statements:

- Engineers shall use "their knowledge and skill for the enhancement of human welfare."[15]
- Engineers shall "hold paramount the safety, health and welfare of the public."[15]

Human welfare stands out in the codes. What exactly is human welfare? The American Heritage College Dictionary defines human as "a human being; a person" and further defines human being as "a member of the genus *Homo* and esp. of the species *H. sapiens*." The definition given for welfare is "health, happiness, and good fortune; well being."[18] So the current codes could be rewritten to state that engineers shall use their knowledge and skill to enhance the health, happiness, and good fortune of *Homo sapiens*.

The high standard of living of developed countries is evidence that engineers have succeeded at enhancing the welfare of the majority of humans living in developed countries. It is also evidence that a code of ethics can be a powerful normative force, thus making it seem worthwhile to use engineering codes of ethics to address the environmental impacts that are concomitant with technological development.

Two of the above organizations have altered their codes in an attempt to address the environmental impacts of engineering activities. IEEE's code asks their members to "accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment."[16] The American Heritage College Dictionary defines environment as "the conditions that surround one; surroundings." This extends the engineer's responsibility by requiring that they report factors that could endanger *Homo sapiens* or his/her surroundings. This modification stops short of calling for a change other than increasing information and awareness.

ASCE has taken their code a step further. ASCE's code asks that their members use "their knowledge and skill for the enhancement of human welfare and the environment"[14] and also that they "hold paramount the safety, health and welfare of the public and… strive to comply with the principles of sustainable development in the performance of their professional duties."[14] The code then gives the following definition of sustainable development:

> "Sustainable Development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development."[14]

ASCE has gone the furthest in attempting to address the environmental impacts of technological systems. ASCE asks their members to enhance the environment. Most engineers have no trouble with the concept of enhancing the welfare of humans. Being humans themselves, engineers intuitively know what would enhance human lives by drawing on their own experience. However, the concept of enhancing the environment is more difficult. Some humans might think that replacing a woodland with a strip mall could be considered enhancing the environment while other humans would chain themselves to the bulldozers to stop the destruction of the woodland. The key here is that we are considering environmental enhancement only from the human perspective. While humans can generally agree on human enhancements (healthy, happy lives), it is difficult to agree on environmental enhancements because the environment has no voice in the debate. While the concept of human welfare (health, happiness, and good fortune) is easily understood, the health, happiness, and good fortune of the environment is more difficult to grasp.

Environmental Ethics:

> *At this point, it is valuable to have the students read and discuss William Wulf's Great Achievements and Grand Challenges.*[1] *This is an opportunity for the class to write critiques of the paper and discuss them in class. The section below can be used to facilitate the discussion.*

Before any further discussion of the codes above or others, some discussion of environmental ethics is required. According to the Oxford Companion to Philosophy environmental ethics is "the attempt to expand the moral framework to nature and counter human chauvinism by showing that feathers, fur, species membership, and even inorganic composition are not barriers to the range of ethical consideration."[19]

There are two main branches of thought in the field of environmental ethics. One is the anthropocentric or human centered view which espouses that all that is not human can only be valued in terms of how important or useful it is to humans. Stated another way, all things non-human have instrumental value, they are valuable only to the extent that humans value them.

The non-anthropocentrists believe that nature has intrinsic value (value in and of itself regardless of the value placed on it by humans).[3]

One other point of ethics that requires discussion is the difference between micro-ethics and macro-ethics. William Wulf points out that the professional society codes apply to the behavior of individual engineers; this is the domain of micro-ethics.[1] Macro-ethics has dimensions beyond those of individual professional relations or responsibilities. Getting back to the example of environmental enhancement, let us suppose an engineer is hired by a firm to oversee the construction of the hypothetical strip mall. Half of the project's neighbors think that this is an enhancement of the environment and the other half think that putting the mall in place of the woodland is a travesty. How is the engineer to decide which group of neighbors is right and how is the engineer to reconcile this with his/her employer's views?

Wulf points out that macro-ethical concerns are very different from the traditional micro-ethical concerns and the reason lies in the complexity and the inherent uncertainty of problems with which engineers are currently dealing.[1] If the concerns of the neighbors is only noise or property values dropping due to the strip mall, then easy engineering and/or financial reimbursement solutions can be found. However, if the neighbors are concerned because the woodland is a critical wildlife habitat, is part of the shrinking aquifer recharge area, is sequestering carbon dioxide, or is damping the urban heat island effect; then there is no easy technical answer or financial fix because the true impacts of the strip mall are not understood due to the complexity of the situation. If a complex situation like the strip mall example is encountered with diverse stakeholders, then an individual engineer will not be able to resolve the issue. Thus, ASCE's code is a step in the right direction for simple situations where the potential outcomes and solutions are known, but it is not adequate for dealing with complex situations where a macro-ethic is needed.

Now that the concepts of environmental ethics and the macro vs. micro-ethics have been briefly laid out; a potential macro-ethic for engineering will be examined and discussed in the following section.

The Modified Land Ethic:

> *At this point, the students should read Leopold's A Sand County Almanac (pages 237-264)[2] and Callicott's Beyond the Land Ethic (pages 134-139).[3] The section below can be used as a discussion guide.*

Leopold was one of the first environmental philosophers. Leopold's work culminated in what he called the land ethic. Leopold's land ethic states that "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community, it is wrong when it tends otherwise."[2] Leopold's land ethic does not allow humans to disturb the environment to any extent which makes it untenable as a macro-ethic for engineering, but it is a valuable philosophical underpinning. J. Baird Callicott is an environmental philosopher who has closely followed the work of Aldo Leopold and has altered Leopold's land ethic to make it a viable option for use as a macro-ethic. Callicott's modified land ethic states that "a thing is right when it tends to disturb the biotic community only at normal spatial and temporal scales. It is wrong when it tends otherwise."[3]

The modified land ethic (MLE) allows humans to alter the environment, but places constraints on the extent of the alteration. The temporal and spatial constraints are quantifiable in terms of earth history and can be expressed as average rates of change. Implementation of the MLE can be shown by going back to the example of the strip mall. First an appropriate system boundary should be defined. The boundary should be based on pertinent landscape features. If the concern is storm water run-off and aquifer recharge, then the boundary should follow the natural aquifer and water-shed boundary. The historic natural changes in that watershed should be quantifiable. The estimated changes associated with building the strip mall can be compared to the historic changes. If the strip mall's impacts exceed the historic rates of change, then its design must be modified to bring the impacts into an acceptable range. This is the domain of the engineer. The problem is now well defined for the engineer who can modify the design to lessen the impacts. In order to use the MLE, some ecological knowledge is required. The engineer must know how the proposed project interacts with the local and global natural systems and the engineer must know the normal or historic rates of change of the key elements of the natural systems. This knowledge must come from other fields such as ecology and/or bio-geochemistry, requiring multi-disciplinary teams to carry out projects.[8] The hypothetical strip mall example is a great simplification the design problems that engineers face today, but it does give an example of how the MLE can be applied.

> *A valuable exercise at this point is to create a design problem and have the students apply the MLE to the problem. The storm water run-off example above can be used, but there are many other options such as the long-term change of the earth's atmospheric composition. The students can gather information detailing the constituents of the atmosphere, their change over time, and strategies to correct any human induced changes. To close the course, ask students for feedback detailing the strengths and weaknesses of the MLE and their opinion of the value of the MLE as a macro-ethic.*

Conclusion:

As human engineered systems continue to grow larger and the inter-relations with natural systems increase in strength, the need to develop a macro-ethic for engineering grows greater. The inherent uncertainty involved with dealing with complex systems, such as natural systems, prevents exact knowledge of the impacts of engineering systems. In these situations, engineers cannot rely solely on traditional design methodologies, but must also use a macro-ethic to inform their designs.

One such macro-ethic is the modified land ethic which requires that human activities not disturb natural systems at rates greater than average changes in natural systems on spatial and temporal scales. Using this macro-ethic requires that engineers know which natural system parameters will be affected by the engineering project, how much those parameters will be affected by the project, and the average rate of change of those parameters. In order to integrate this new information, engineers will have to have an understanding of complex systems theory and access to ecologists and experts from other disciplines who can supply the required natural system information.

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