On Defining Engineering Ethics: A Challenge to the Engineering Community

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Introduction

When the Accreditation Board for Engineering and Technology (ABET) established Evaluation Criterion 3: Outcome #f, it signaled a renewed interest in instruction in ethics at colleges of engineering in the United States.[1] Outcome #f states that "Engineering programs must demonstrate that their graduates have an understanding of professional and ethical responsibility." As a result, all colleges of engineering have an obligation to document their instruction in ethics for accreditation.

Everyone wants the engineer to do what he or she ought to do, but *ought* implies ethics, and the study of ethics is in a mess. Is the state, the existing situation, the individual, a religion, or some absolute standard to be the final arbiter of the good and the ethical? The engineer seeking professional guidance is quickly drowning in a sea of "ist." Should he or she believe the intuitionist, the empiricist, the rationalist, the hedonist, the instrumentalist, the situationalist, the pragmatist, or (if this is an acceptable word for one who endorses Ayer's emotivism) the emotivist?[2] Recent books on ethics for engineers provide different guidance to ethical conduct.[3,4] One bases the study of ethics on the classical virtues; another one, on *utilitarianism*, rights ethics, and duty ethics—each with passing glances at competitive systems such as pragmatism, situation ethics, and the theories of Rawls. The problem is that the most candid authors admit that the choice of underlying assumptions about which ethical system to use determines what is to be taken as ethical behavior. For example, the authors who wrote the first book cited above remind us that "After this selection [of principles and methods], a specific range of right action appears . . . Different sets of principles and methods yield different ranges that often overlap only partially."

More disturbingly, there are significant omissions in recent books on engineering ethics that must confound the well-read engineering student. Seldom do we find Ludwig Wittgenstein's position on ethics discussed in the engineering classroom, for example. This is ironical because Wittgenstein is one of the best known modern philosophers and, most notably in the current context, he was, at one time, also an engineer. Through his work on language, he ultimately held the position that the claim of an *absolute* ethical system (the position of most, if not all books on engineering ethics) is impossible! To quote Arto Tukiainen, "Wittgenstein thought that if we wish to speak of ethical value . . ., our sentences cannot be anything but nonsense."[5][1] Instructing engineering students about ethics and omitting the position of one of their brethren of the stature of Wittgenstein, who specifically feels that the fundamental basis of our study is flawed, does not seem very ethical.

Thesis, Background, and Organization

The thesis of this paper is simple. Although the engineering community should certainly become knowledgeable in the state-of-the-art (sota) of classical ethics and—teach that, the engineering community must also contribute to the continued development of ethics based on the unique characteristics of modern engineering and—teach that.

The term *ethics* is used in different ways in the literature. Borrowing from reference [9], we limit our discussion to only one meaning of *ethics*, so-called *philosophical ethics* or *meta ethics*, since that is the approach that seems to be emphasized in courses for engineering students. Ethical philosophy began in the fifth century b.c., with Socrates. Simply stated the central questions of philosophical ethics are: What do we mean or what should we mean by *good*? and What are the right standards for judging things to be *good*?

Our initial volley, two volleys really, is to demonstrate that the two concepts, *good* and *truth*, so dear to the hearts of all ethicists, are treated quite differently by the traditional philosopher and the engineer. During the discussion, we will have occasion to give a definition of what the engineer means by the two that could be examined with profit by all conscientious ethicists. In passing we note two additional engineering terms that may be profitably used by modern ethicists. Next we consider the ethical system *utilitarianism* that is often associated with engineering ethics and show why it must fail in its traditional formulation to be convincing to the engineer. Other ethical systems such as *pragmatism* and *situation ethics* could have been chosen to make this last point, of course, but due to its current vogue, *utilitarianism* will be sufficient to demonstrate that systems of the past are often wanting when it comes to describing ethical behavior for the engineer. As a result, engineers should be motivated to create our own, new ethical system compatible with modern engineering.

Disparate views of ethics: terms and theory

Engineers use terms such as *good* and *true* differently from the traditional ethicists; they employ terms for determining what is the good course of action in a specific situation that are unknown to the traditional ethicist; and they are often confused by traditional ethical theory. Each of these categories will be examined separately.

The nature of the good

Quickly now, from an engineering perspective, which is a better automobile, a Mercedes or a

[1] The word "nonsense" is being used here in a technical sense. See references [6], [7], and [8] for Wittgenstein's views in his own words.

Mustang? In over 30 years of teaching a course to an equal mixture of engineering juniors and liberal arts honors students, this question has been consistently answered differently by these two groups of students. The different answers depend on two dissimilar definitions of *best*. First we examine the concept of *best* due to Plato that is probably operative for most people, and then we consider what *best* means to an engineer. It is hard to see how we can make much progress in our quest for engineering ethics if we do not know what the nature of the good is to the engineer.

Plato's Best or Ideal Form

As I understand it, Plato held that there was an ideal form of, say, beauty, justice, and so forth towards which we approach as we go from good, to better, and to best along a single dimension. Most people use this formulation every day in all manner of argumentation, although they do not know to whom they owe the debt. Thus in English we have the conventional comparison of adjectives: good, better, best; pretty, prettier, prettiest; happy, happier, happiest; tall, taller, tallest, etc. Using Plato's view of an adjective, it seems so obvious that a Mercedes is a better automobile than a Mustang. In fact, it is even difficult for the philosopher to conceive of an alternative to Plato's linear progression toward the ideal form. Given the option, I'm convinced that both the engineer (hard-hat removed) and the non-engineer would choose the Mercedes offered a choice of either automobile for free. Our interest, however, is how he or she would answer as an engineer.

Engineer's Best or Optimum

The engineer, hard hat firmly in place, will answer that both the Mercedes and the Mustang are probably the best (or optimum) automobile given the specific design specifications with which each design team had to work. Given the design criteria, the resources, the knowledge base, and the market considerations available to the team creating the Mustang, it would have been very, very unethical if it had even tried to create the Mercedes which had a completely different set of criteria. In fact, if the design team had tried to do so, no final automobile would have probably been produced due to a lack of resources and if, perchance, one had been produced, it would not have been what the customer wanted. No creditable engineering ethicist would accept either of these alternatives as very ethical.

Since the engineer defines best by using optimization theory,[2] a short digression is necessary at this point to ensure that we agree as to what it is. The time will be well spent, because it will allow us to advance more rapidly when we contrast the philosopher's notion of *truth* with the use of *truth* by the engineer, and when we later examine the failure of *utilitarianism* in its defining formulation as a valid ethical system for the engineer.

Engineers want the best solutions to the problem they are is given to solve, but then who wouldn't? Surely supplying the best product for the client given the available resources is the ethical thing to do. The difficulty is that the engineer's notion of *best* represents a surprising departure from the standard concept as endorsed by most western philosophers and described

[2] This analysis and the figures first appeared in references [10, 11] and they will appear in an expanded form in [2]. They are reproduced here to emphasize the extension of this earlier research to engineering ethics.

above. What we now seek, therefore, is the engineer's notion of a best solution or what is technically called the *optimum* solution. What we will find is a new, radical concept of *best* little used in Western, Greek-based philosophy. This adventure will carry us into the heart of an important area of engineering called *optimization theory*, which is familiar, at least in outline, to all engineers but relatively unheard of and more challenging to the philosopher and non-engineer. Ironically it is totally ignored by the engineering ethicist who makes his or her living telling the engineer what the good, right, ethical thing to do is.

Saying that a Mercedes is a better automobile than a Mustang is nonsensical (this time from the point-of-view of the engineer) if *better* is being used in an engineering sense. As stated above, they are both optimum solutions to different specific design projects. It does make sense to prefer one design project over the other. An engineer could conceivably argue that designing an automobile similar to the Mercedes is a better goal than designing one similar to the Mustang because it would last longer, conserve natural resources, promote national pride, or whatever. And, of course, a second engineer may feel that he or she could have produced a better final product than the first engineer given the same problem statement. But for the engineer who designed the Mustang, the automobile you see before you is that engineer's best solution to the problem.

Recalling the technical terms used in optimization theory will help to make this point. Consider a television set with one control. We will assume that turning this knob to a higher number will produce a better picture but at the same time worsen the sound; turning the control to a lower number, on the other hand, will worsen the picture but improve the sound. Confronted with such a device, it would be relatively simple for you to adjust it for your personal preference as you balance the relative importance of picture and sound to you. The engineer's job, however, is not only to please you, but to find the best permanent adjustment of this knob to please society. Let us see how this is done theoretically. The setting of the knob is called a *manipulated variable*. One can set it to a lower or higher number as desired. The quality of the picture (say, sharpness) and the quality of the sound (say, fidelity) are the *criteria* in the problem. It is against these two characteristics that a judgment is made as to whether or not the control setting is best. In general, the criteria are conflicting in that an improvement in one implies a worsening of the other. The criteria taken together make up the *optimization space* or *axis system* of the problem. Figure 1 is a graph that shows how the sharpness of the picture might change with the position of the knob. As the number on the horizontal axis increases, the sharpness, shown on the vertical axis, is improved. The dotted line indicates that a setting of four corresponds to a sharpness of eight. The sharpness of the picture is higher for a setting of six than for one of two. For no compelling reason this curve is often called a *return function*.

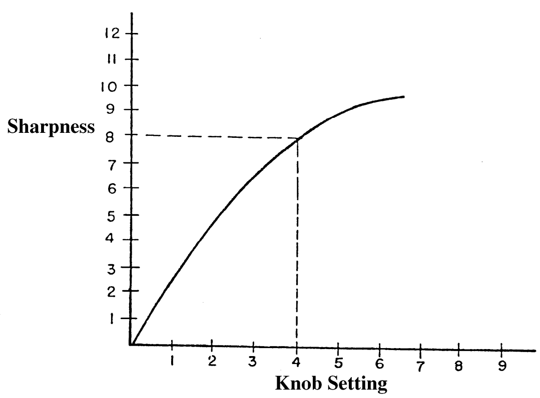

Figure 1: Sharpness vs. Knob Setting

A different return function, Figure 2, exists for the sound. Turning the knob to a higher setting decreases the fidelity of the sound. When the control knob is set to the value four, the value of the fidelity is also four as can be seen on the graph. To represent pictorially what a person does instinctively when he selects his preferred setting, the two return functions must be combined or superimposed on the same graph; they must be put on the same basis; or, technically, they must be made *commensurate*. This requires that a *common measure of goodness* be found for picture and sound. What the engineer seeks is the relative importance of sound and picture to the owner of the television set. A ten-percent increase in the sharpness of the picture is worth what percentage decrease in the fidelity of the sound? This relative importance is expressed by the *weighting coefficients* of the two conflicting criteria.

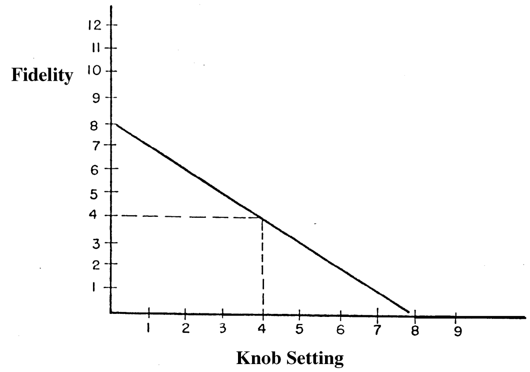

Figure 2: Fidelity vs. Knob Setting

Another term used for the set of weighting coefficients in the *value system* of the problem.

To simplify the analysis, let us assume that sharpness and fidelity are equally desirable. That is, the relative *weights* in the two cases are equal. Stated differently, the values of sharpness and fidelity to the owner of the television set are equal. The resulting combined graph is given in Figure 3. The bottom two curves are the return functions for the conflicting criteria that were shown in Figure 1 and in Figure 2. The upper dotted curve is the sum of these two under the assumption that an improvement in picture and sound are equally desirable. Verify that this combined dashed curve with a value of twelve at setting four is equal to the sum of our previous reading of eight and four at the same point. This dashed curve is the common measure of goodness for the problem. It is sometimes called the *objective function* or *measure of system effectiveness*. We want the largest or maximum value of the objective function. This number is called the *optimum* or *best value*. For our television set, the optimum setting corresponds to a control setting of the knob or manipulated variable of four.

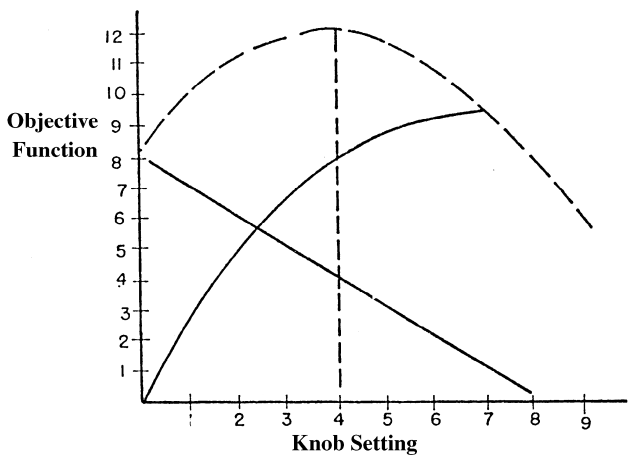

Figure 3: Objective Function vs. Setting

Best for the engineer is not the good, better, best of the sound; it is not the good, better best of the picture; it is not even the good, better, best of the objective function measured against some external, immutable, true, ideal form or standard. It is simply the maximum value of the objective function once the optimization space consisting of its criteria and their relative weights has been chosen. *If the criteria have been ethically chosen, if their relative weights have been ethically chosen, and if all ethically important criteria and weights have been included, the best or ethical solution is guaranteed in principle, although it may not be easy to find in practice.*

The design of an automobile will have an optimization space with a much larger number of conflicting criteria such as fuel economy, power, safety, comfort, and style, and it will have more complicated return functions and weighting coefficients. In this analysis we insist that the relevant axis system for ethical engineering design must also contain axes that capture the ethical components of the design. As a result of the large number of criteria in a typical project, seldom does the engineer try to find the optimium mathematically. Instead, it is found based on intuition and experience solving similar engineering problems in the past. The important point is that evaluation of *best* for an engineer is a well-understood operation, one at variance with the dictates of Plato. *The engineer looks for his or her best in a multi-dimensional space instead of the one-dimensional one of Plato.*

The Nature of the Truth

From the preceding discussion, it is obvious that the classical ethicist and the engineer treat the important term *good* differently. Attention now turns to a second term that is likewise treated differently by the ethicist and the engineer. Unlike science, engineering does not always claim to model an assumed, external, immutable *true* reality. Instead it seeks society's perception of reality including its myths and prejudices. If a nation feels that a funeral pyre should be aligned in a north-south direction to aid the dead person's journey into heaven as is true in some cultures, the model to be optimized by the engineer will incorporate this consideration as a design criterion irrespective of the *truth* of the claim. In fact, even if the engineer is sure in the strongest technical terms that a better fire is possible or pollution minimized by another orientation, it will not be insisted upon. The engineer could stop, of course, and philosophize about the truth of the religious doctrine that dictated the north-south alignment before beginning the design, but what is to be done with the corpse in the meantime.[3]

As a result, the optimum obtained from an engineering model does not pretend to be the absolute best in the sense of Plato, nor the true solution in some eternal, absolute sense. Instead it is only the *best*, the *true*, relative to the society to which it applies.

For the engineer, *truth* is often just one more axis to be taken into account in the optimization process—and in the case of the alignment of a funeral pyre, it is to be given a very small weighting coefficient. Of course, at times even the engineer must use *truth* in its conventional sense.

The engineer's notion of truth as one more variable to be appropriately weighted instead of an eternal characteristic of the universe is not as strange or rare as it first seems. There are

[3] This abbreviated analysis seems to lurch perilously close to *ethical relativism*, but a deeper analysis avoids this pitfall. Again, see reference [2] for a view of the epistemological status of the word *relativism* consistent with one prevalent view of engineering practice.

other situations where *truth* is undeniably being traded-off against variables thought to be more important. Consider three examples: the Quaker's balance between personal truth and group truth in achieving consensus; the Japanese's balance between truth and harmony; and the engineer's (and others) concept of "mobile truth."

For the Quaker religion, consensus before action is more important than an individual's personal view of truth. During a Quaker meeting everyone is free to stand up and contribute to the debate on either side of the question, but an individual does not belligerently insist on his or her own view to the exclusion of all others. Once a personal view has been articulated, if the "sense of the meeting" is otherwise, a person defers to the group's opinion in the interest of consensus.

For the Japanese, harmony is all important. In fact the name of their country comes from an ancient word for harmony. A Japanese person has two versions of the true world: a personal one (*honne* or real feelings) and a public one (*tatemae* or official stance). In Japan, harmony is a more important criterion than is their personal version of truth. They feel that in the long run, they lose more by insisting on their personal version as opposed to their public one in the trade-off with harmony.

The last example of the variable nature of truth has been called "mobile truth." "Mobile truth" is evident among politicians, laypersons, and engineers. When an engineer works for, say, Company A, he or she naturally feels that the products it produces are the best and would defend them in testimony before congress, with friends, and in the press. Changing jobs to join a competitor, say, Company B, results in an overnight change of opinion. "Mobile truth" dictates that Company B be now defended as the best before congress, with friends, and in the press. Clearly, the engineer is trading-off some variable such as "company loyalty" against some assumed objective feeling of truth.

"What is truth?" This question has been asked since philosophy began and still we have no answer. Since even a cursory glance at the voluminous literature shows that philosophers cannot answer that question themselves to everyone's satisfaction, we should feel free to supply our own, at least when it comes to engineering ethics. *Truth* is often nothing but one more variable in engineering design—desirable, useful, helpful, but unjustified, unjustifiable and potentially fallible. We might say that *truth* is just one more engineering heuristic among many other important ones.

Additional terms

In the preceding sections, we considered two concepts *good* and *truth* that, at the very least, require reexamination, redefinition, and reinterpretation, if not complete elimination from the engineer's lexicon as absolutes. They are not the only contributions engineering can make to a more modern analysis of ethics. In addition, engineering can contribute additional terms and procedures to the debate on ethics that were unknown to classical philosophers. For example, Seebauer and Barry augment their analysis of ethics with the engineer's event trees and risk-benefit theory [3]. The first of these has been extensively used in the evaluation of the safety of nuclear reactors and the second even more widely used in engineering decision theory. The differences in the use of the terms *good* and *truth* and the addition of these two last concepts support the view that the key concepts of the classical ethicist and the engineering ethicist are, at times, fundamentally different. Not only the terms, but entire ethical systems, appear quite differently to the engineer as we shall now see.

Utilitarianism

Let us focus on one prominent ethical system often applied to engineering called *utilitarianism* to show why traditional ethical systems cannot be taken over into engineering without carefully analysis.

To avoid the accusation of misrepresenting *utilitarianism*, we begin with its definition by two acknowledged experts in the history of philosophy [4]:

> Utilitarianism: the doctrine that all actions are to be judged in terms of their utility in promoting the greatest happiness of the greatest number.

And again [5]:

> Utilitarianism: the moral philosophy that says that we should act in such ways as to make the greatest number of people as happy as possible.

The formulation, "the greatest good for the greatest number," is, of course, due to the inventor of this ethical system, Bentham (although it is frequently associated with the name, John S. Mills), and often quoted without attribution in books on ethics. It is difficult to explain how strangely this definition sounds to an engineer. When the engineer hears it, he or she feels as though he or she has fallen down Alice's rabbit hole where the very laws of nature were suspended. In this case, it is the laws of engineering and mathematics that are being ignored.

The problem is that *one cannot optimize with respect to two or more variables at the same time.* One simply cannot seek to have both the *greatest good* and the *greatest number*. To claim to do so, is equivalent to solving the television problem examined above without any weighting coefficients at all—a truly curiousier and curiousier position for an ethicist who has studied engineering to take. In fact, the well-known biologist, Garrett Hardin, reminds us that the phrase "the greatest good for the greatest number" violates the principle of D'Alembert which is at the heart of the theory of differential equations [6]. Until presented with a commensuration or at least a way to commensurate the two variables *utilitarianism*, the thoughtful engineer is left shaking his or her head.[4, 5]

Consideration of the impossibility of finding the "greatest good for the greatest number" was not meant to imply that utilitarianism is unworthy of study by engineer ethicists or that other ethical systems of the past are without merit as guides. They are all valuable for sensitizing the

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[4] Optimization theory is an active area of research in engineering and has been simplified here. None of the recent advances in optimization theory such as Pareto optimization, iso-resource-cost analysis, etc. refute the results given here. In any event, it is highly unlikely that Bentham or Mills had any variation of optimization theory in mind in defining utilitarianism.

[5] Others have recognized the problems caused by these matters for utilitarianism, at least in small part, as evident in the discussion of utilitarianism and its connection to game theory in reference [9 (Volume 7, pg. 210)].

engineer, administrator, and the public to the importance of ethics based on the best thinking of the philosophers of the past. What it does suggest, however, is that ethicists coming to instruct the engineer on how to behave ethically should define their systems and terms within the domain of the engineer and give the engineer the right to modify these systems in return.

One cannot deny the value of the ethical systems of the past. It would be a very poor engineer who designed a project without knowledge of the current ethical sota as well as the current technical one. Still our present experience with engineering ethics and the yawn of disinterest by most engineering students, professors, and practitioners suggest that we should try to define engineering ethics anew.

Challenge to the Engineering Community

The central claim of this paper was that engineers have a contribution to make to the grand conversation on ethics that has been going on since the dawn of Western philosophy—and that they have a moral obligation to engage in it. The engineer's notion of the *good* derived from *optimization theory* contrasts sharply with the Platonic notion of the *good* that colors our daily lives. Other important concepts essential to the practicing engineer are ignored by most ethicists. And, finally, the ethical systems such as *utilitarianism* of the past are inadequate for capturing the ethical behavior of the modern engineer.

This paper is a companion piece to a paper entitled *On Teaching Engineering Ethics: A Challenge to the Engineering Professoriate* submitted to the Educational Research and Methods division of the American Society for Engineering Education.

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