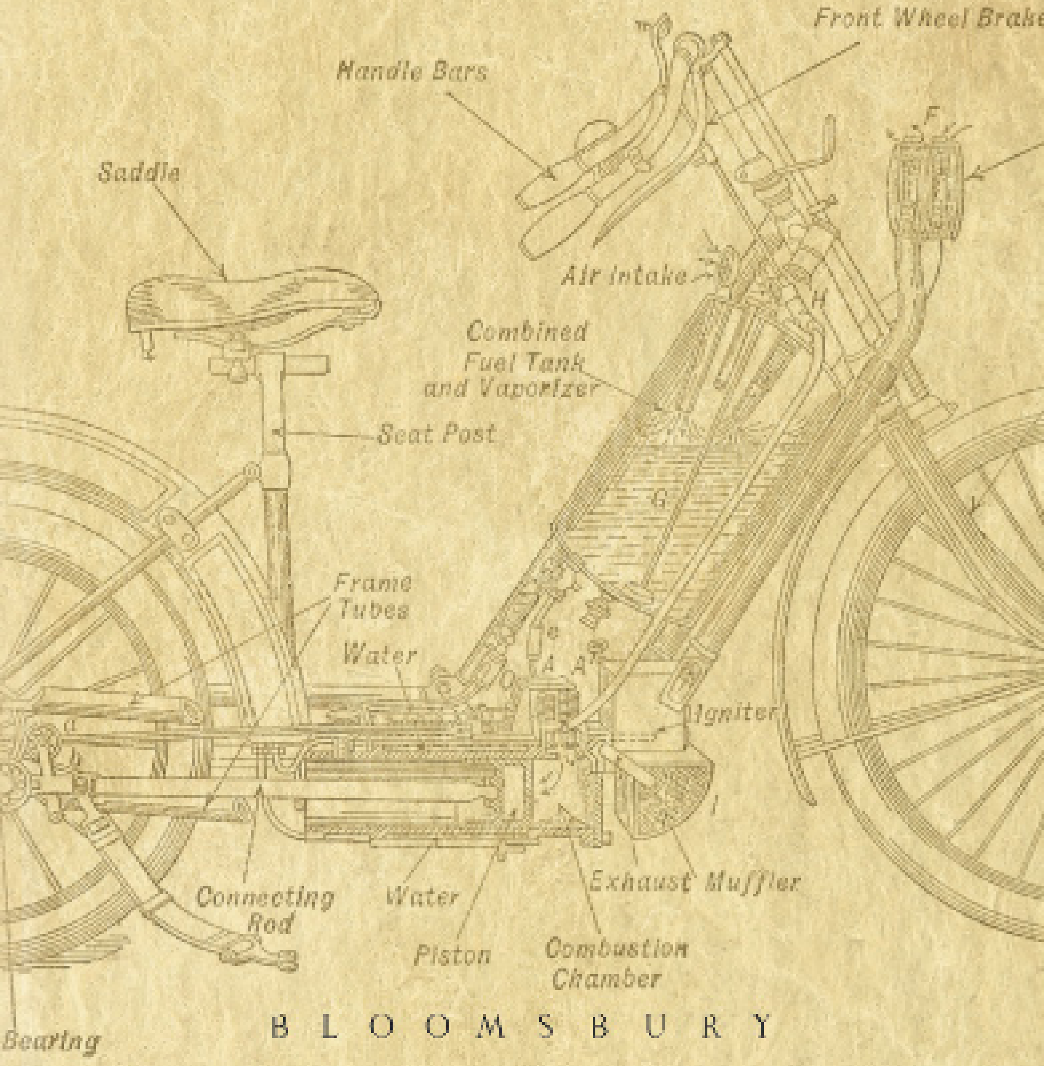
WADE L. ROBISON

ETHICS WITHIN ENGINEERING

An Introduction



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WADE L. ROBISON

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To Christina

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PREFACE

When I came to the Rochester Institute of Technology as the Ezra A. Hale Professor in Applied Ethics, the Provost suggested I visit the Dean of the College of Business to see if I could help with business ethics. The Dean said, in dismissing me, "We're all ethical here." I was amused, but went next door to the College of Engineering. The Dean there, Paul Petersen, welcomed me, but told me that if I was going to have any street cred among engineers, I needed to take their senior design course, the capstone of the five-year program. So I did, and I learned an immense amount working with a group of students designing and making a self-propelled colonoscope. I learned more about the workings of the colon than I ever wanted to know.

I then started teaching with Jasper Shealy in the Department of Industrial Engineering, an association that continued for four years or so, and afterward lectured on ethics in engineering to the students in the capstone course, telling them something I thought, and think, they needed in their first year.

I cannot thank Paul and Jasper enough for their kindness in letting a philosopher into their midst and to Jasper in particular for letting me teach with him. I found him a wonderful teacher, and I learned far more about engineering than I did about colons. They have my thanks. They would probably think I did not learn enough, but I certainly cannot hold them blameworthy for what follows. They did their best with the material they had, with me, that is.

I also want to thank all my students through the years and especially those to whom I have explained the idea of an error-provocative design. The idea itself seems to provoke example after example, and much of what I have been given by them has found its way into this book. I am particularly indebted to my colleague, David Suits, both for the surfeit of examples he has provided and for his having read through the manuscript and made many a helpful comment.

I am also indebted to Adam Potthast at Park University and Mark Vopat at Youngstown State University. They each used drafts of the book in classes, and I have learned much from their responses and their assessments of where students had problems understanding the text. Just as engineers need to test their design solutions, so writers need to test their creations. Some may decide the book needed more testing, but I alone am responsible for the errors that remain.

My wife, Christina, has been a godsend, helping me talk through problems I ran into as I tried to put my thoughts into words uncluttered by philosophical jargon. I also owe a special thanks to our companions—to my beloved Scout, the wonder pup, now gone after our affectionate fifteen years; to our beloved and much missed Mangia and Gus and Tess, the fierce kitty, who came with Christina; to Raven, our live-in crippled bantam rooster, also now gone, for the companionship he gave us all as well as the insights into just how bright a little rooster can be; and to our new kitty, Peaches, and the pups, Laddie, Gage, and Sunny.

FOREWORD

An interest in engineering ethics has generated an enormous amount of scholarship over the past few decades. So anyone who writes on how ethical considerations enter into engineering owes much to many. But though I have learned much from those who have written on the subject, I will cite few because I will be concentrating on a way in which ethics enters engineering practice that has been downplayed, if not downright ignored, in the vast literature we now have.

I will concentrate on how ethical considerations enter into the intellectual core of engineering, the solution to design problems. Engineering begins with a design problem—how to make occupants of vehicles safer, settling on the interface for operating an X-ray machine, designing more legible road signs. Any design problem leaves much room for creativity and innovation, and so the range of possible solutions to any particular design problem is broad. We can see how broad by looking at the various kinds of cars, or toasters, or coffeemakers, or computers: each artifact marks one design choice over another.

In choosing any particular solution, engineers must make value choices, and, obviously, as we again know from looking at engineering artifacts like cars, not all design choices are equal. Each reflects a particular configuration of values with a particular set of effects, the effects ranging from those produced by obtaining the material from which the artifact is to be manufactured, to those produced in the manufacture, to those produced in moving the artifact to market and storing it until it is sold, to those produced by those who use the artifact, to those produced in disposing of or recycling or remanufacturing the artifact once its useful life is completed.

The easiest way to understand how ethical considerations enter into engineering is to focus on design solutions which cause problems for those who use the artifact embodying the design, and the clearest examples of those are solutions which provoke even the most intelligent, well-trained, and most highly motivated into making mistakes and sometimes causing great harm—by designing an X-ray machine that can easily over-radiate patients or a car or truck with a high risk of exploding if hit.

Everyone is subject to the minimal ethical principle: do no unnecessary harm! Engineers have special obligations to take care not to cause unnecessary harms because they can cause a great deal of harm by virtue of being engineers and are best positioned to choose design solutions that minimize harm.

The intellectual core of engineering, the source of the intellectual joy that animates it, is the working through of various possible design solutions and settling on a particular design that solves the original problem and perhaps pushes the envelope of design. At its core, this is an ethical enterprise since the particular configuration of effects of each design solution will cause more or less harm and so will be, all else being equal, more or less ethical.

These ethical issues are internal to the discipline of engineering. An internal ethical issue is one that arises within a discipline. No one can be an engineer without solving design problems, and so no one can be an engineer without making the ethical decisions we must make in solving those problems. We should presume that every discipline has its internal ethical problems. A physician, for instance, cannot practice without treating patients in one way or another—with respect as a person, or as a piece of machinery to be fixed, say—and those are radically different ethical views to take of a patient.

Such internal problems are distinct from what I call external ethical problems—an engineer who, as a buyer for a company, faces requests from a supplier to let through somewhat questionable parts; an engineer who is upset to find himself working under a younger female boss when he thought he was going to be promoted; an engineer who, as a manager, is ordered by someone farther up the chain to get a product done by a certain time when the testing will not have been completed. These are problems that arise because the engineer is not working just as an engineer, but as a buyer, employee, or manager—positions any professional could hold and problems any professional may face.

Internal ethical issues are those that only someone within a discipline will face, and they are, to my mind, the most important ethical issues engineers will face. Yet, as I say, they tend to be ignored. This book is the antidote to that. I will generally ignore external ethical issues to concentrate upon internal ones.

That is not to say that external ethical issues are unimportant. It is to say that we need to pay at least as much attention to internal ethical issues as the current literature on ethics in engineering tends to pay to external ethical issues.

I came to see the value of thinking of design solutions as embodying ethical choices when I took the Senior Design class at my university. I worked with a number of engineering seniors from various departments in the college, and we had a contract with two internists from the Strong Memorial Hospital in Rochester, New York to develop a self-propelled colonoscope.

The standard way of inspecting for cancer in a person's colon is to insert a stainless steel articulated endoscope with a lens, a hook for grabbing suspect tissue, and a small hose for cleaning off tissue that needs detailed inspection. The endoscope has to traverse the colon and make two sharp turns where the colon attaches to the rib cage on either side, and the risk of harm is high because cancer makes the lining of the colon friable and easily penetrated—especially by a steel endoscope with the circumference of a small pencil. It takes great skill to maneuver the endoscope, and the internists were looking for a device that would significantly decrease the need for a specialist taking extreme care. An endoscope that would propel itself through the colon and do so without touching the colon walls was the goal of our engineering group.

What I noticed was that the engineering students and I were looking at the problem in different ways and so focused on different aspects of our project. The engineering students were intently concerned with getting something that would work. "How do we get it to move through the colon?" I found myself thinking about how the endoscope would be used and so focused on what could go wrong. Since not touching the colon walls was part of the design problem, the students considered that, but failed to consider what would stop this motorized endoscope if it took off up the colon. When that concern was raised, a student said, "Ah, good point," and the group proceeded to ensure that the endoscope could not take off. Their focus put to the periphery of their vision, unnoticed except when drawn to their attention, concerns about the harms to be avoided.

If we focus not just on whether the solution solves the original problem but on whether it solves the problem without causing any unnecessary harms, we make explicit what is implicit in any choice of a design solution: we are making an ethical choice no matter what we choose. Once realized in an artifact, each choice carries with it a set of harms, and except choices with only minor differences, those sets are going to differ from each other. We do not need to provide a formula for weighing those harms against each other or against the benefits that may also be realized to see that, whatever the results, we would be putting on the scales what has moral weight.

Engineers distinguish between what they call the hard and soft, or professional, skills.[1] The former are what students learn from STEM courses, the latter supposedly the "extra" stuff like an ability to communicate effectively. There is a movement afoot to make these skills part of the engineering curriculum.[2] Among these skills, listed in the ABET criteria for all engineering programs, is "an understanding of professional and ethical responsibility."[3]

It turns out that in making use of their hard skills to solve design problems, engineers cannot help but make use of that so-called soft skill. They cannot help but make an ethical choice in choosing one solution over another, I shall argue. So moral considerations are already embedded in the intellectual core of engineering, the solution to design problems.

I shall make this point as vividly as I can by focusing on what I call error-provocative designs to illustrate that ethical considerations enter into design solutions. These are design solutions that provoke errors in even the most intelligent, well-trained, and highly motivated operators in the most pristine circumstances. When an accident occurs, we properly blame the artifact, I shall argue.

Using error-provocative design solutions to illustrate how ethical considerations enter into design solutions may mislead readers into thinking I am writing a book to warn engineers not to pick such terrible design solutions. But I am not looking at what goes wrong, the disasters to be avoided, in order to tell engineers to avoid them—but to illustrate most clearly how any design solution embodies ethical choices and how engineers need to make explicit what they are already doing implicitly in solving any design problem.

The aim of this book, in short, is to show that ethical considerations enter into all design solutions and thus are integral to the intellectual core of engineering. They cannot be avoided. The aim is to make explicit how those ethical considerations enter.

The ultimate goal is to change the way in which ethics is taught in engineering. It is now either an add-on to existing courses, generally discussions of cases, or a separate course called Engineering Ethics. Both alternatives send the message to students and faculty alike that ethical considerations are not integral to engineering practice. I shall argue in what follows that they are.

I obviously do not expect this book to change a long-standing practice, but do hope that once the idea is given a hearing, it will win adherents and ultimately change the practice. That change will require pushing back against the quantification of ABET criteria, but also, in the meantime, providing a numerical weighing, however artificially determined, for the various harms that may occur with various measures of risk for each of them. Engineers are certainly more competent to do that in the detail required for any particular design choice than anyone outside the discipline.

1

Introduction

Morality permeates our lives in the artifacts we use, for they reflect our moral choices. The intellectual core of engineering is the solution to a design problem, and those problems always leave room for creativity. In choosing among possible options, engineers are also necessarily playing off one value against another, and the choice of what to create will necessarily, once realized in an artifact, have effects—some good, some bad. In addition, once the solution is clearly articulated, the artifact that is to realize it follows, and that artifact may incorporate, intentionally or not, new features that cause different effects—some good, some bad. It is a basic moral principle that we should cause no unnecessary harm, and so, in making a choice, an engineer has a moral obligation, at a minimum, to ensure that none of the harms likely to ensue from the artifact are gratuitous.

The most striking examples of how moral considerations enter into design solutions come in error-provocative designs. These are design solutions which are going to provoke errors in even the most intelligent, well-trained, and highly motivated operator in the most pristine of conditions. Since neither the circumstances nor the operator can be at fault, the artifact must be, and we are all familiar with such objects—

doors that appear to open one way but open the other way, for instance. What error-provocative design solutions illustrate is how essential moral judgment is for an engineer engaged in the intellectual core of the profession.

Our moral world

Engineering artifacts permeate our lives—from cars and iPhones to bridges and planes. We are all familiar with things so badly designed that they cause us to make mistakes: doors that look as if they open one way when they open the other way; control knobs that look as if they are to be turned to operate, but must be pushed in or pulled out instead; "DO NOT ENTER" signs on entrance ramps misplaced so they seem to tell us not to enter where we must. It is unfortunately all too easy to find such designs.

We can always find news of them in the headlines. The crash of the Virgin Galactic SpaceShipTwo killed the copilot, who caused the crash when he "prematurely unlocked a section of the space plane's tail used in braking."[4] What is more disturbing is that the company that did the hazard analysis failed to consider "pilot-induced" errors.[5] The company concentrated on the plane and failed to consider how hazards could be introduced through how it would be flown.

The copilot's error was presumably not induced by the plane's design, but it is easy enough to find designs that provoke errors. The worst are those that provoke mistakes for even the most intelligent, well-trained, and highly motivated operator, in the most pristine of circumstances. We can find such designs in even the most mundane artifacts. We need look no farther than our toasters.

One comes packaged with a slip of paper saying, “WARNING! To interrupt toasting, turn toast color control to off/cancel. Do not push the toast lever manually. Internal mechanism will be irreparably damaged.” As someone asked, “What kind of toaster is ‘irreparably damaged’ by using the LEVER to remove the toast?” We use the lever to push the toast down, and levers generally work in both directions: what goes down comes up.

The toaster mechanism will be irreparably damaged by many users who failed to see the warning or, having seen it, pulled the lever up out of habit while hurriedly trying to save the toast from burning.[6]

That toaster is an accident waiting to happen, an unfortunate solution to part of a complex design problem: how can we toast bread and yet interrupt the toasting? Perhaps the solution was driven by considerations of cost or a change in the internals of the toaster, but to the extent that engineers designed the toaster and signed off on the final design, they are responsible for the results—for the predictable harm of customers breaking the toaster, for instance.

A toaster that can be irreparably damaged by lifting the lever up is an artifact whose production was a waste and whose quick end is waste that we must put somewhere. We have in that artifact a set of unnecessary harms—those that come from getting the materials to make it; those that come from squandering the energy required to make it; those required to package it, ship it, store it, and use it until it burns our toast and we break it; and those required to rid ourselves of the trash it has become. These are harms because they set back interests we have in, for example, not wasting our money on something that will quickly break and, for another example, in not polluting our air and groundwater any more than necessary. For engineers to choose that particular toaster design from all the possible designs is to make a moral choice, one that will produce more harms, and worse harms, when realized in an artifact than other choices that could have been made. We live in a contingent world that reflects moral choices we have made.

We each no doubt have our own favorite examples. They seem to be object lessons in the frustrations of life, things we have to live with. But there is no necessity that toasters be designed that way or that "DO NOT ENTER" signs be so placed as to mislead drivers into thinking they are on the wrong ramp or that doors look as though they open one way when they open the other. These examples come about because of the choices people made. They are artifacts, designed and created by us.

If it seems puzzling that ethical considerations enter our lives even in the artifacts with which we have populated them, think of how ethical considerations enter our lives even in what we might consider the most mundane of circumstances because of choices we make. If we choose to pick up and answer our cell phone while driving, we have chosen to increase the risk of our having an accident as well as the risk to others. Increasing the risk of harm is itself a harm, and so, in choosing to answer the cell phone, we have chosen an option that is more harmful than the other option, immediately available to us, of not answering the phone.

We have few better examples of how our lives are shaped by such decisions. Few, if any, who drive have escaped having to shape their driving by another driver's failure to signal because preoccupied with a cell phone and without a free hand or by the slowing down and speeding up as the driver gets more or less animated while talking. The list is long, but the point is short: the way we move down the highway is no different from the way we move through the world. We move in a world created and shaped by moral decisions.

So we should not be puzzled that morality permeates our lives through the artifacts of our lives—from the toaster we face in the morning to the ramp on the thruway with the "DO NOT ENTER" sign. These artifacts are the result of choices made by those who designed them.

The path from a design problem to its solution to its realization in an artifact is a complex one, with many a possibility of error along the way and many a way for the initial design solution to be altered by someone other than the designer in order to save costs, for instance. I will concentrate not on the path, but on the initial step, the solution to a design problem.

We find in such a solution the intellectual core of engineering, and although it is often claimed that engineering is a purely quantitative discipline, it is not. Ethical considerations are at the core of engineering. They are essential to engineering practice. Remove them, and we cannot have engineering.

Design problems

A condition of our doing something moral is that we could have done otherwise.

When toddlers trip and fall, we comfort them; when they throw themselves on the ground in a temper tantrum, we at the least look askance. Engineers can make a moral choice in picking a design solution because there is no single way to solve any design problem. A statement of a design problem, however detailed, does not necessitate any one solution.

We need only consider toasters and the myriad forms they can take or, for that matter, toothpicks.

The initial statement can be sparse: design a pick to get food and other such things out of your teeth. "Ah, a toothpick! What could be easier?" We may well wonder how there can be much room for creativity with such a design problem. How many possible different kinds of toothpicks can there be? And how could any value choices influence the answer, especially moral values?

We can see an answer to that question in the toothpick given in Figure 1.1:

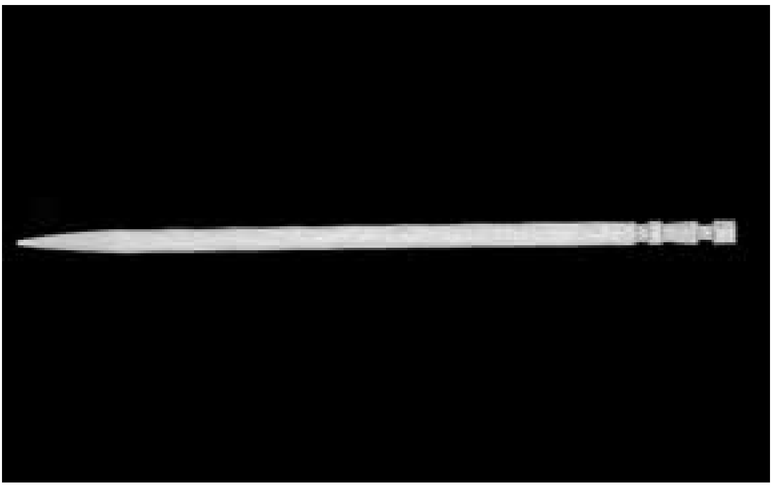

FIGURE 1.1 ***Japanese toothpick.***

This is a Japanese variation of a toothpick, pointed at one end with "a series of grooves encircling the toothpick" at the other end.

Once you use the toothpick, you are to break off the end at one of the grooves. You then place the end, like a Japanese pillow, on the table, with the rest of the toothpick resting on it, pointed end up. That way others can see that the toothpick has been used—a health benefit—and with the used end up "what had been in the diner's mouth does not touch the common table." The design is thus not just decorative, as we might assume, but a clever solution to ensure that a used toothpick is no risk to anyone's health.[7]

This Japanese variation solves a problem not in the design problem with which we began this section: what are we to do with the toothpick after it is used so that others will not use it? An easy way to transfer disease from person to person is to use a common toothpick. So ensuring that a toothpick is used but once is of some importance.

The design does waste wood, however. It will take two of them to provide two pointed ends for picking. But the value of not spreading disease was judged of more value than making full use of a piece of wood for picking. That is arguably a moral judgment since the aim is to mitigate the harms that come from spreading germs through using someone else's toothpick. The design thus expresses a set of values.

The design is also an example of another feature of design problems. As it turns out, initial statements of design problems inevitably go through a transformation as engineers work out what might and might not work, what causes additional problems (such as puncturing your gums or damaging the enamel on your teeth), what can be readily manufactured, what can be manufactured cheaply enough to make it commercially viable, what problems are missed by a design, and so on.

In *The Toothpick: Technology and Culture*, Henry Petroski details a variety of transformations of the design problem. That initial sparse description for a toothpick ends up including something like this:

> These areas between adjacent contacting teeth, i.e., the interdental spaces and the interproximal tunnels, are actually like a passageway with a somewhat triangular cross-sectional shape. The base of the triangle is the gum or gingival tissue; the sides of the triangle are the proximal surfaces or side walls of the contacting teeth; and the apex of the triangle is the incisal or occusal contact area of the two adjacent teeth.
>
> Quite often the openings to these tunnels and spaces are blocked by slightly swollen or edematous gum tissue. Therefore, in order to enter the spaces or tunnels, the cleaning instrument must be sufficiently resistant to bending perpendicular to its longitudinal axis to enable it to depress or displace the gum tissue blocking the entrance or exit to the tunnels or spaces. Furthermore, the posterior interproximal tunnels are often quite tortuous, i.e., the path of the passageway is circuitous.
>
> Therefore, the instrument must be sufficiently bendable to follow this tortuous tunnel as it contacts the hard surfaces of the teeth and firm healthy gingival tissues. It must also have sufficient strength to dislodge food debris and loosely adherent calcular material from the walls of the tunnel or space. It must also intimately conform to the walls of the sides of the tunnels and spaces and must have sufficient abrasiveness to remove the dental plaque without injuring the tooth or gum tissues. Additionally, it must be able to fit into the usually narrow space between the anterior teeth.[8]

Who would have thought that designing a simple toothpick would require such a detailing of the work a pick would have to do? And this description does not even cover concerns about ease of manufacture, the availability of material, the cost of production, and other such matters that an engineer needs to consider before settling on a particular design solution.

Yet, however detailed, nothing in this design statement determines any particular solution. Even a more extended statement is not going to determine a conclusion. We are not working with a mathematical problem here where the premises determine the conclusion as in, to use the simplest of examples, 2 + 2 determines the conclusion, 4. Any solution will be constrained by quantitative considerations, of course. Not any object can serve as a toothpick. A dandelion stalk is straight, but too flimsy to do any picking; a titanium shaft dusted with industrial diamonds will certainly do a lot of picking, but endanger our gums and enamel. Presumably we could quantify the range of stiffness permitted, a range that would exclude the dandelion shoot as not stiff enough and the titanium shaft as too stiff. An engineer has to take such matters into consideration, but one feature of such a design statement as that for a toothpick is how much conceptual space it leaves open for solutions. Even the simplest of objects, that is, can have many different variations, and that means that no design statement determines its solution.

The intellectual core of engineering, and the source of the joy of success, is the working through of various possibilities and settling on a particular design that both solves the original problem and, where possible, pushes the envelope of design (and is, perhaps, aesthetically pleasing as well).

So we end up with flat toothpicks and round ones, with toothpicks pointed at one end to toothpicks pointed at both, and even a toothpick that fits on the end of one's tongue as in Figure 1.2.[9]

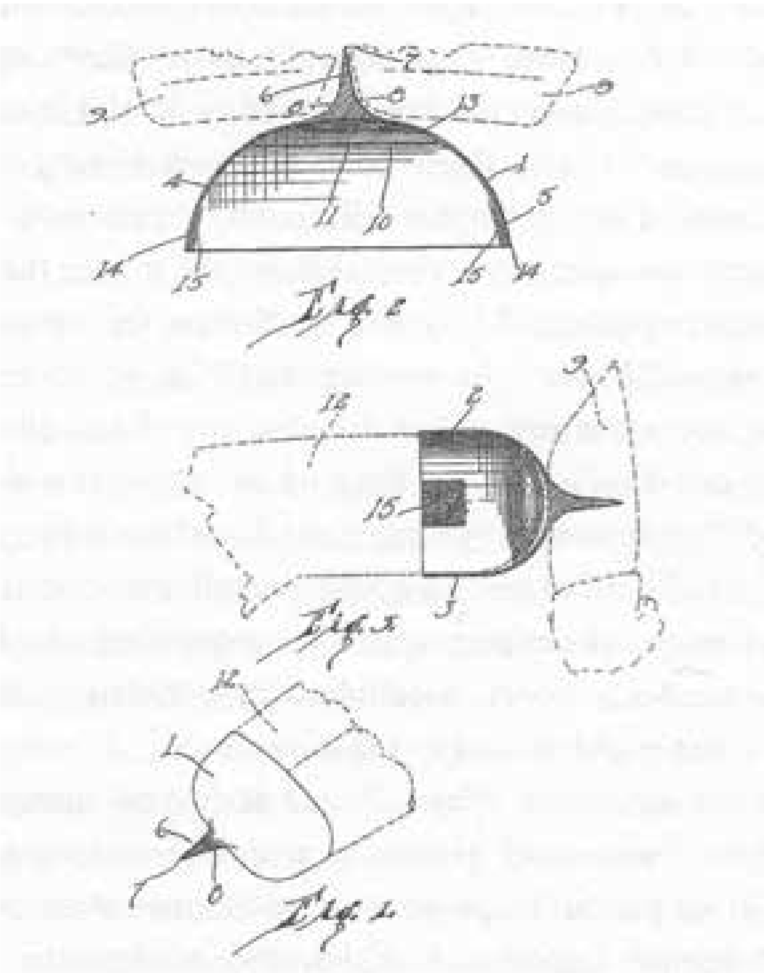

FIGURE 1.2 ***Toothpick for the tongue.***

Who would have thought? Human ingenuity knows few bounds.

Design problems are subject to extension and modification, that is, as various possible solutions are considered, their strengths and weaknesses assessed, and new possible features are considered and incorporated into the original design problem. Our inability to reach certain "interdental spaces and the interproximal tunnels" easily was presumably a consideration for the odd tongue toothpick. Its inability to reach the front of our teeth readily, and a serious concern about accidentally swallowing it as we probe and pick and push, would certainly be considerations in deciding whether to use it in place of more familiar solutions to the design problem.

Conceptual space for creative solutions

What is most important for our concerns here is that though the design problem constrains potential solutions, it leaves open enormous space for creativity. Engineers are in no different position than, say, poets in this regard. A poet is constrained by prior choices, both the poet's and those of others. We can no longer say, "It's a slam dunk!," without invoking for many George Tenet's mistaken response to the question whether Iraq had nuclear weapons. The phrase resonates differently now than it did before Tenet uttered it in that context. That new resonance is as much a constraint on a poet's choice of words as are, for instance, the meter chosen, the rhymes and rhythms of various words used, and the subject matter, and the point, of the poem. These are not quantitative constraints, of course—though the meter may be—but they constrain the creative genius of a poet just as much as, and no more than, a design statement and quantitative considerations constrain an engineer's choice of a design solution.

In both cases conceptual space exists for creative solutions, and engineers who think themselves immune from considerations of value because they are in a realm of crystalline quantitative clarity misdescribe the intellectual core of their discipline. It is as though they are taking the quantitative constraints of a design problem not as constraints on the problem, but as the only matter of concern to engineers. But the intellectual core of engineering—the intellectually exciting part of the discipline—is the solution to a design problem, and those solutions are not determined wholly by quantitative considerations. Engineering design solutions do not bear the same relation to an engineering design problem that mathematical conclusions bear to their premises. A creative mathematician may find an elegant way of deducing the proper conclusion from the premises, but however creative a mathematician may be, the chain of inference is deductive, and the statement of the problem leaves no conceptual space for a different conclusion: 2 + 2 equals 4 no matter how one arrives at that conclusion from those premises.

The relation between an engineering design problem and a solution is mediated, however, not by deductive inferences, but by a creative mind capable of imagining different ways of solving the problem and equally capable of choosing between those different solutions, weighing the advantages and disadvantages of each possible solution, and making a wise choice. As Petroski, among others, has said, a design problem does not determine its solution.[10] Fastening on a particular design solution is a two-stage process, that is. In the first stage, we brainstorm alternative solutions to the problem, and in the second stage, we choose one of the alternatives, preferably culling out those features which are not essential to the design's resolving the problem.

As the toothpick examples illustrate, a design choice reflects value considerations.

The Japanese toothpick design ranks the healthy disposal of a toothpick above the convenience of having two pointed ends with which to work. The toothpick that fits on the end of a tongue values the capacity to reach into odd corners inside the teeth higher than, say, the oddity of having such an appendage on one's tongue, the difficulty of trying to keep it there, and the risk of swallowing it by accident.

Different choices not only play off different values against one another, but also produce different effects when realized in an artifact. Someone trying to use a toothpick with only one useful end may need more toothpicks than someone with two ends to use. That will mean more toothpicks manufactured with more trees cut down, more waste disposed of, more toothpicks packaged and carried to market, more toothpicks purchased—all effects of a simple design choice: one useful end or two?

So not all design choices are equal, obviously. Each reflects a particular configuration of values with a particular set of effects, the effects ranging from those produced by obtaining the material from which the artifact is to be manufactured, to those produced in the manufacture, to those produced in moving the artifact to market and storing it until it is sold, to those produced in disposing of or recycling or remanufacturing the artifact once its useful life is completed. Not all artifacts are susceptible to all these effects, obviously.

We do not remanufacture toothpicks, for instance. But laying out the possible range of effects allows us to see that in picking any one design solution, we are picking out not only one array of values over another, and one set of effects over another, but one set of harms over another.

As we can see from the tongue-mounted toothpick, some design solutions are more likely to cause or risk harm than others, and in some cases the harm can be more than a trivial annoyance. We should rank a tongue-mounted toothpick fairly far down the list of viable solutions. After all, swallowing a pointed implement large enough to fit on the end of your tongue and sharp enough to pick your teeth is not a trivial matter. It would be a matter of even more concern if the engineer failed to craft the details of the tongue-mounted toothpick so that it would fit tightly on a tongue and not slip off easily, and that problem is not simple either since there are, no doubt, differently sized tongues, longer and shorter, thicker and thinner, requiring smaller and larger toothpicks of varying widths. There may also be differently shaped tongues, some unable to hold onto, as it were, the variant pictured in the patent application. So choosing the tongue-mounted toothpick as a design solution is to choose a design with many possible unnecessary harms. We are lucky other design solutions are possible.

Ethics in engineering

As soon as possible harm enters, ethics enters. Engineers are in a position to do great harm—by designing a bridge that will soon fail, an X-ray machine that will overradiate patients, a car or truck with a high risk of exploding if hit. Everyone is subject to the minimal ethical principle: do no unnecessary harm! Engineers are not immune from that principle. Indeed, they have a special obligation to take care not to cause unnecessary harm because they are in a position, by virtue of being engineers, to cause—and mitigate—a great deal of harm.