### 1.2.1 Our definition of engineering design

*Engineering design is a thoughtful process for generating designs for devices, systems, or processes that attain given objectives while adhering to specified constraints.*

The following formal definition of engineering design is the most useful one for our purposes:

- **Engineering design** is a systematic, intelligent process in which designers generate, evaluate and specify designs for devices, systems or processes whose form(s) and function(s) achieve clients' objectives and users' needs while satisfying a specified set of constraints.

It is important to recognize that when we are designing devices, systems and processes we are designing artifacts: artificial, human-made objects, the "things" or devices that are being designed. They are most often physical objects like airplanes, wheelchairs, ladders, cell phones and carburetors. But "paper" products such as drawings, plans, computer software, articles, and books are also artifacts in this sense, as are the "soft" electronic files that become "real" when displayed on a computer screen. In this text we will use device or system rather interchangeably as the objects of our design.

With further recourse to our dictionary, we note (and then comment on) the following definitions:

- **form** *n*: the shape and structure of something as distinguished from its material

  So what we mean by *form* is pretty straightforward, and its meaning in the engineering context is consistent with its more common use.

- **function** *n*: the action for which a person or thing is specially fitted or used or for which a thing exists; one of a group of related actions contributing to a larger action

  Simply put, *functions* are those things the designed device or system is supposed to do. As we describe in Sections 2.3 and 4.1, *engineering functions* involve the transfer or flow of energy, information and materials. Note, too, that we view energy transfer quite broadly: It includes supporting and transmitting forces, the flow of current, the flow of charge, and so on.

- **means** *n*: an agency, instrument, or method used to attain an end

  Although not explicitly recognized in our definition of engineering design, *means* is nonetheless important as in this context it refers to a way of making a function happen.

- **objective** *n*: something toward which effort is directed; an aim or end of action

  An *objective* in our context is consistent with its common usage.

- **constraint** *n*: the state of being checked, restricted, or compelled to avoid or perform some action

  This definition, too, is what we would expect from standard use. It is worth stressing that *constraints* are extremely important in engineering design because they impose absolute limits which, if violated, mean that a proposed design is simply not acceptable.

Anticipating another point we will stress again (in Chapter 3), note that objectives for a design are entirely separate from the constraints placed on a design. Objectives may be completely achieved, may be achieved in some measure, or may not be achieved at all. Constraints, on the other hand, are binary: They are satisfied or they are not satisfied; they are black or white, and there are no intermediate states. Thus, if we were designing a corn degrainer for Nicaraguan farmers to be cheaply built of indigenous (local) materials, an objective might be that it should be as cheap as possible, while a constraint might be that it could not cost more than $20.00 (US). Making the degrainer of indigenous materials could either be an objective, if it is a *desired* feature, or a constraint, if it's absolutely required.

Our definition of engineering design states that designs emerge from a *systematic, intelligent process*. This is not to deny that design is a creative process. However, at the same time, there are techniques and tools we can use to support our creativity, to help us think more clearly, and to make better decisions along the way. These tools and techniques, which form much of the subject of this book, are not formulas or algorithms. Rather, they are ways of asking questions, and presenting and reviewing the answers to those questions as the design process unfolds. We will also present some tools and techniques for managing a design project. Thus, while demonstrating ways of thinking about a design as it unfolds in our heads, we will also talk about ways to deploy the resources needed to complete a design project on time and within budget.

### 1.2.2 The assumptions behind our definition of engineering design

*Design is a thoughtful process that can be understood.*

There are some implicit assumptions behind our definition of engineering design and the terms in which it is expressed. It is useful to make them explicit.

First, design is a *thoughtful* process that can be *understood*. Without meaning to spoil the magic of creativity or the importance of innovation in design, people do *think* while designing. So it is important to have tools to support that thinking, to support design decision making and design project management. (One piece of supporting evidence for this obvious hypothesis is that computer programs have been written to emulate design processes. We couldn't write such programs if we couldn't articulate and describe what goes on in our heads when we design things.)

The idea that there are *formal methods* to use when generating design alternatives is strongly related to our inclination to think about design. This might seem pretty obvious because there's not much point in considering new ways of looking at design problems or talking about them — unless we can exploit them to do design more effectively.

*Form cannot be deduced from function.*

*Form* and *function* are two related yet independent entities. This is important. We often think of the design process as beginning when we sit down to draw or sketch something, which suggests that form is a typical starting point. However, we should keep in mind that function is an altogether different aspect of a design that may not have an obvious relationship to shape or form. In particular, while we can often infer the purpose of an object or device from its form or structure, we can't do the reverse, that is, we cannot automatically deduce what form a device must have *from the function alone*. For example, we can look at a pair of connected boards and deduce that the devices that connect them (e.g., nails, nuts and bolts, rivets, screws, etc.) are fastening devices whose function is to attach the individual members of each pair. However, if we were to start with a statement of purpose that we wish to attach one board to another, there is no obvious link or inference that we can use to create a form or shape for a fastening device. That is, knowing that we want to achieve the *function* of attaching two boards does not lead us to (or even suggest) any of the *forms* of welds, screws, rivets, or glues.

The relationship of form and function is important in understanding the creative aspects of design. If we can systematically articulate all of the functions that a device is expected to perform, then we can be creative in developing forms within which these functions can be realized. In this sense, the use of organized, thoughtful processes *adds* to the creative side of design.

There are benchmarks available to assess how we expect a design to perform and to implicitly measure the progress made toward a successful design. These benchmarks derive from a questioning process (see Chapter 2) that begins with the designer:

- translating the client's desires into *objectives* for the device or system being designed;
- establishing a set of *metrics* that can be used to ascertain or measure the extent to which a proposed design will meet the client's objectives;
- establishing the *functions* that a successful design will perform; and
- establishing the *requirements* that express in engineering terms both the design's attributes and its behavior, that is, the design's functions.

Let us formally define the two new terms we have just introduced, that is, metrics and requirements. Our definitions, while presented in standard dictionary format, represent a blend of actual dictionary definitions with our understanding of the "best practices" of engineering design as it is currently done in industry. Thus:

- **metric** *n*: a standard of measurement; in the context of engineering design, a scale on which the achievement of a design's objectives can be measured and assessed

  *Metrics* provide scales or rulers on which we can measure the degree to which objectives are achieved. To offer a truly simple example, let us suppose an objective of being able to jump 10 meters. A metric for a jump would award 1 point for each meter jumped, so that a jump of 2 meters earns 2 points, while a jump of 8 meters earns 8 points, and so on. As we discuss at length in Chapter 3, not all objectives are so easily quantified, and not all measurements are so easily made. Thus, there are interesting issues that must be addressed when we talk about metrics in depth.

- **requirement(s)** *n*: thing(s) wanted or needed; thing(s) essential to the existence or occurrence of something else; in the context of engineering design, engineering statements of the functions that must be exhibited and the attributes that must be displayed by a design

  The design requirements, which are often called *design specifications*, are stated in a number of ways, depending on the nature of the requirements the designer chooses to articulate. As we explain in Chapter 5, design requirements may specify: *values* for particular design attributes; the *procedures* used to calculate attributes or behavior of the design; or *performance levels* of the functional behavior that must be attained by the design. We shall explore the nature of design requirements (or specifications) extensively in Chapter 4.

*Fabrication specifications enable implementation independent of the designer's involvement.*

The endpoint of a successful design is a set of plans for making the designed device. This set of plans, often called *fabrication specifications*, may include drawings, assembly instructions, and lists of parts and materials, as well as a host of text, graphs, and tables that explain: what the artifact is; why it is what it is; and how it can be realized or brought to life. This will be the case whether the artifact is a physical object, a process description, or some soft representation.

Further, fabrication specifications must be clear, unambiguous, complete, and transparent. This is because fabrication specifications must, *by themselves*, enable someone other than the designer (or others involved in the design process) to make what the designer intended so that it performs as the designer intended. This is a facet of modern engineering practice that represents a departure from a (long-ago) time when designers were often craftsmen who made what they designed. These designer-fabricators could allow themselves latitude or shorthand in their design plans because as fabricators they knew exactly what they intended as designers. Nowadays engineers rarely make what they design. Sometimes designs are "thrown over the wall" to a manufacturing department or to a fabricator who acts entirely on "what's in the specs." But increasingly manufacturing issues are addressed during the design process, which means that manufacturing engineers and even suppliers become part of the design team, which also means there are further needs for designers to be good communicators!

It often happens that the manufacture or use of a device highlights deficiencies that were not anticipated in the original design. Designs often produce *unanticipated consequences* that may become *ex post facto* evaluation criteria. For example, the automobile does provide the intended personal transportation. On the other hand, some regard the automobile as a failure because of its contribution to air pollution and traffic congestion. In addition, changing societal expectations have dictated serious redesign of many of the automobile's attributes and behaviors.

Finally, our definition of engineering design and the related assumptions we have identified clearly rely heavily on the fact that communication is central to the design process. Some set of languages or representations is inherently and unavoidably involved in every part of the design process. From the original communication of a design problem through the specification of requirements and of fabrication specifications, the device or system being designed must be described and "talked about" in many, many ways. Thus, *communication is a key issue*. It is not that problem solving and evaluation are less important; they are extremely important. But problem solving and evaluation are done at levels and in styles — whether spoken or written languages, numbers, equations, rules, charts, or pictures — that are appropriate to the immediate task at hand. Successful work in design is inextricably bound up with the ability to communicate.

*Communication is a key issue in design.*