Preface

"Those that know do. Those that understand teach."
"The whole is more than the sum of its parts."

Aristotle

"True wisdom comes to each of us when we realize how little we understand about life, ourselves, and the world around us."

Socrates

"Our species needs, and deserves, a citizenry with minds wide awake and a basic understanding of how the world works."

Carl Sagan

Understanding

This book is about *understanding*. When can a person say that they understand something? Is understanding different from what we normally call "knowledge?" Do we actually understand a phenomenon when we can make predictions about its behavior? Perhaps an example of the latter question will serve as a key to the concept of understanding.

Consider the law of gravity. We all know what gravity is; who hasn't experienced its insistence on one being pulled toward the Earth, sometimes painfully? Yet it is the case that we actually still do not really understand gravity in the sense of what causes this force to act upon mass. Sir Isaac Newton formulated the laws of motion and particularly the mechanics of planetary motions from Johannes Kepler's planetary "laws." Kepler, in turn, had derived his laws from discovering the patterns contained in Tycho Brahe's astronomical observations of the planets' motions. Newton invented a descriptive language, the calculus, and advanced the universal laws of gravitation as a formula[1] that would predict with reasonable accuracy (even today) how bodies behave when acted upon by its force (one of four fundamental forces of nature[2]). NASA engineers can predict with tremendous accuracy just how much time and with what force a small rocket engine should fire to maintain a trajectory of a space probe millions of miles from Earth so that it neatly passes by a moon of Saturn to get pictures and data.

Albert Einstein "improved" our ability to predict such behavior, indeed for all objects of all masses and all distances in the universe, with his theory of General Relativity. Rather than describe this behavior as resulting from a mysterious force, Einstein converted the language of gravitation to geometry, explaining how the behavior of objects, such as planets orbiting the Sun, is a consequence of the distortions in space (and for really fast objects, time).

Both theories provide adequate predictions for celestial mechanics. We can say we humans understand the behavior from the outside. That is, we can, given the initial conditions of any two bodies of known masses at time 0, predict with great accuracy and very impressive precision what will happen in the future. But, and this is a crucial "but," we don't know why gravity works the way it does. For example, just saying that space is curved in the region of a massive object doesn't begin to say why. Physics is still actively seeking that kind of understanding. Our knowledge includes the formulas needed to predict planetary and satellite motions, which we routinely use, but it does not include the internal workings of nature sufficient to explain why those formulas work.

And this condition, what we must call "partial understanding," is often more true of much of our knowledge than we might like to acknowledge. Systems science is ultimately about gaining more complete understanding. Notice we said "more complete" rather than merely "complete." Understanding comes in degrees. As far as anyone knows, there is no such thing as absolute (complete) understanding or knowledge (see our discussion of knowledge in Chap. 7). Rather there are approaches to understanding more about phenomena by gaining knowledge of their inner mechanics. All of the sciences work at this.

In this regard systems science can be considered the universal science. All sciences seek to gain and organize knowledge systematically. They all use methodologies that, while geared to the specific domain of interest (say physics or psychology), nevertheless are variations on concepts you will find in this volume. They all seek to establish organizations of knowledge (invariably hierarchical in nature) that expose patterns of relations, for example, Dmitri Mendeleev's Periodic Table for chemistry (and its many improvements since then) or Carolus Linnaeus' classification hierarchy for species that helped lead to the Theory of Evolution proposed by Charles Darwin. As you will see in this text, organization, structure, and many other aspects of knowledge form the kernel of systems science.

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[1] $F = G(m_1 m_2/r^2)$. F is the force due to gravitational attraction. m_1 and m_2 are the masses of the two bodies (it takes two!) and r is the distance between the centers of the two bodies.

[2] The other three being electromagnetic, weak, and strong forces. The first of these describes how elementary particles behave due to attraction and repulsion. The latter two apply to interactions between components of atomic nuclei.

What systems science does, above and beyond the efforts of any of the domain-oriented sciences, is to make the whole enterprise of gaining better understanding explicit. All scientists (in the broadest interpretation of that word) are systems scientists to one degree or another, even when they don't know that.

Mental Models of the World: Cognitive Understanding

Whenever you think about what may happen during an upcoming day in your life you are accessing what we call a *mental model* of your world. As will be described in several sections of this book, our brains construct these models based on our experiences as we grow up and age. Most of our knowledge is tucked away in what cognitive scientists call implicit form. This could be "procedural" knowledge, such as how to ride a bicycle or drive a car, or it could be more general knowledge that isn't automatically accessible to conscious thinking; you need to expend some mental effort to do so. Your ability to live in a society with a culture and to go about daily life all depends on your having built up a large repertoire of mental models about how things work. When you enter a restaurant, for example, you know basically what to do without even thinking about it. You know how to wait to be seated, how to examine a menu and decide your order, how to give your order to a server, etc. You have done this so often that it is like second nature. The places and people and menus may change, but you know the general script for how to behave and accomplish your goal (getting fed!). Perhaps as much as 80–90 % of your daily interactions with things and people are the result of processing these mental models subconsciously!

Models are manipulatable representations of things (especially people), relations of things, and how they behave in the world. Mental models are those we build up in our neural network systems in, especially, our neocortex. Our understanding of the world depends on us being able to learn what to expect from the things and people we interact with into the possible future.

We will have much more to say about mental models in Chaps. 7–9 (Part III). What we intend for this book to accomplish is to help you organize your mental models, to make connections between aspects of the world you may not have explicitly recognized. We believe that systems science is capable of helping people make more sense of their mental models—to help them better understand the world.

Formal Models of the World: The Extension of Cognitive Understanding

One of the great achievements of the human mind has been to develop abstract, external representations of the world. This started with the evolution of language (maybe 150–200 thousand years ago) as a way to communicate complex mental models. It later gave rise to the development of *signs* and *symbols* marked on a medium, the beginning of written language and mathematics. Humans have, since then, developed extremely sophisticated ways to use those signs and symbols to construct models of the world externally to their own minds. Mathematics is such a way to compactly express a "formal" model of, for example, the attributes of things (measurements with numbers), relations of things (algebraic and geometric), and behaviors (dynamics).

Formal models have extended the human ability to much better understand the world and communicate that understanding to others. Today we have computer-based models of incredibly complex phenomena (e.g., the climate and weather) that allow us to make more detailed predictions about the future than could be done with mental models alone. Part III also will cover aspects of formal modeling, and Chap. 13 will explain how modern models are built and used in the sciences and engineering.

Unfortunately the very power to build formal models has contributed to what we feel is a negative side effect, which is a major motivation for this book. We describe the tendency for the disciplines to become more isolated from one another below. In part, this tendency is enhanced by the very nature of formal modeling in the sense that each discipline has developed its own specialized language of signs, symbols, syntax, and semantics. In essence, as the models get better at helping experts understand their small piece of the world, they start to hide the connections between those pieces. Our sincere hope is that a more explicit education in systems science will help correct this situation. The left hand absolutely needs to know what the right hand is doing, and vice versa.

Why an Education in Systems Science?

A quick word of explanation for those who would equate the terms "systems science" strictly with computers and communications systems; while those are examples of human-built systems (see Chap. 14), systems science is not just about technology. Indeed the latter is just a tiny part of systems science (and engineering). In today's jargon, the word "system" has come to be dominantly associated with computational technology. This is another consequence of our education system's propensity to work against integrative understanding in preference for specialization.

Both authors have taught courses that are either explicitly about systems science or stealthfully bring systems science into the curriculum. In every case, the students' general responses invariably show surprise to learn that the world can be understood as a system of systems and that they had never been exposed to this perspective in their education previously. Moreover, they express deep gratitude for being shown how the world can be interpreted in a more holistic fashion and one that they can readily grasp. Why do they react this way?

The modern American and many other countries educational systems, in our opinion, have devolved into promoting and serving silo-based thinking. By that we mean domain-specific subjects and majors are the norm. Increasingly this tendency also squeezes out the traditional liberal studies courses that were considered essential for students to develop broad knowledge and develop critical thinking skills outside the context of just one domain. Until recently, systems science, in the form we present in this book, has not been a discipline per se. Parts and pieces of systems science have been pursued for their own sakes, but the integrated whole subject did not have an integrated whole body of knowledge that could be explored and improved in its own way. The needs of the marketplace have dominated the methods and approaches of education in such a way that an educated person, today, is expected to find a job in industry or government, in which the skills they acquired in school can be put to immediate productive use. And up until very recently, the perception of society has been that those skills were domain-specific.

But something interesting has been developing in the worlds of commerce, government, and, indeed, all fields. People are beginning to recognize that the kinds of problems we seek to solve no longer involve single domains of knowledge and skills. Rather every field is experiencing the need to involve other fields and do integrative (what has been called cross-disciplinary) work. This has led to a new problem for scientist, engineers, business people, and others. Essentially, what is the common language we can all speak that will allow us to integrate our different domains? And they are finding, increasingly, that a systems approach provides that common language. It is a kind of Rosetta stone for systemic work.

As we watch the world developing a much stronger need for systems science and systems development, we anticipate the need for more explicit education in systems science in the near future. Students who grasp systemness (that term is introduced in Chap. 1 and more thoroughly defined in Chap. 3) are better able to understand complex systems and how the various disciplinary languages can be ameliorated in a common view of those systems. We assert that a basic education in systems science will better prepare any student for any major in which they are expected to tackle and solve complex problems. Even if it is just a two-course sequence based on this book, they will emerge with a much greater understanding of what it means to understand and how to gain that understanding in whatever field they decide to specialize.

Why a Textbook on Systems Science?

It seems strange to say that there have not been any introductory textbooks in systems science[3] if this subject is "meta" to all other sciences. But that seems to be the situation. There are general books that are about systems science or systems thinking, but they do not attempt to systematically outline the subtopics and then provide an integrated perspective of the whole subject. They are excellent for motivating

[3] To be fair there have been many books that introduce the ideas of systems theory, even with titles purporting to be introductions to systems science. Many of these will be found in the bibliography. However, our assessment of the books that we have surveyed of this kind is that they are not really comprehensive attempts to lay out all of the modern topics in systems science in the form of a textbook suitable for pedagogical uses. This assessment can arguably be contested. But of all the books on the subject we assert this is the most balanced and integrative volume of its kind.

students in the idea of systems thinking but do not expose the body of systems subjects with pedagogy in mind.

We think the subject of systems science will begin to take a front seat in education because the grasp of systemness is a powerful mental framework for thinking about literally everything in the world.

There is a truism held by almost all students that no textbook is ever written well. Trade books and story books, on the other hand, are written so the average reader can understand what the author is saying. The worst textbooks are in technical and science fields where the writing is dry and, well, technical. They are hard to read.

So why write a textbook about systems science that students are going to find hard to understand? Well, our answer is that we have not written a textbook that is hard to understand because we are telling a story—a very big story.

This is an introductory textbook in a subject that is universal to many other subjects in which the reader might decide to major. We claim the reader will be able to understand, but that doesn't mean they will not have to put some effort into it. The book covers a broad array of subjects with many examples from various disciplines. We recognize that not all students will have had courses in some of these subjects. But we also don't think coursework in these subjects is actually prerequisite to grasping the main ideas in this book. In all cases where we have used explicit examples, say from biology, we also have provided reference links to articles in Wikipedia[4] that we think do a good job of explaining details. We encourage readers to use these links and get a passing familiarity with the subjects or, at least, get good definitions of terms that might be foreign to the reader.

Why Is This Textbook the First of Its Kind?

As you are about to find out, systems science is a huge subject. That is because the concepts covered here are actually found in all of the other sciences (so-called natural and social) in one form or another. Systems science is a universal science. It is therefore surprising (at least it was to us when we started researching for the kind of textbook we had in mind for our teaching) that no general, introductory textbook seemed to exist.

The idea of a "general systems theory" and several related ideas were first put forth in a formal way in the late 1940s and through the next decade. For example, general systems theory was developed by Ludwig von Bertalanffy (September 19,

[4] Wikipedia, if you don't already know, is a FREE online, crowd-sourced encyclopedia containing pages on just about everything that anyone knows (or believes they do). But, there is no such thing as free, as many of these chapters will show. Wikipedia is supported by a foundation, the Wikimedia Foundation (http://en.wikipedia.org/wiki/Wikipedia:Wikimedia_Foundation) that accepts charitable contributions to keep Wikipedia going. We use Wikipedia links extensively throughout the book where we think the information is good and could provide readers with additional links to a vast warehouse of information. Please consider a donation to the Foundation if you find yourself taking advantage of this rich resource.

1901–June 12, 1972) during the 1950s and published in English in the 1968.[5] von Bertalanffy was a biologist, and many think of him as the father of systems biology. What he sought were the principles of organization and dynamics, the spatiotemporal patterns that were common across all kinds of systems. He felt these could be captured in universal laws that would apply to all systems and could be codified in mathematics.

But the emphasis on mathematics (or at least the appearance of the emphasis) kept the concepts from gaining broad acceptance, let alone understanding. Many researchers already possessing the mathematical skills, of course, jumped onto the various aspects of systems science and have done tremendous work in those areas. But the overall subject has remained invisible to the average educated person.

Several other fields of research coming out of efforts made during WWII, such as cybernetics, information theory, operations research, computation, etc., were also mathematical in their origins and so remained inaccessible but to a few mathematicians who could grapple with the equations. And those who studied these fields, even while extolling the notion that they were all deeply related in the nature of "systems," found it easier to isolate themselves into their respective subdomains, driving deeper into those domains and creating an invisible boundary between them. As a consequence, the idea of general systems got more and more difficult to envision from a higher perspective. And the underlying interrelations gave way to increasingly real language barriers. Ironically, what started out as a truly integrative idea ended up in the same kinds of disciplinary silos into which all the other academic subjects had fallen.

And the general public, even those with higher education degrees, partly because of the continuing emphasis on more sophisticated mathematics and partly because the systems scientist themselves encouraged increasing insulation, grew ever more ignorant of the concept of general systems theory even while using the word "system" in increasing frequency. Everyone knows (or "feels" they know) what you mean by a "computer system." They know what you mean by the "educational system." But all they really know is that somehow the parts of those "systems" are related and the whole "system" is supposed to perform a function. Beyond that, the deeper principles remain in shadows, not even hinted at by the cyberneticists, the communications theorists, and the evolutionary and systems biologists.

The areas that actually had much better success in recognizing systemness and the importance of general systems theory has been business management and military science. Much of the seminal thoughts had come from efforts by mathematicians to discover principles of control and command, both organizational and mechanical. Communications, especially encrypted during WWII, gave rise to information theory. Thermodynamics was an old science in physics, but there were new surprises there as well. But after WWII, in the west, business management theorists started applying concepts from cybernetics and information theory in a framework of systemic organization and process management. Other organization theorists developed languages to describe models of organizations

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[5] See: von Bertalanffy (1968) and http://en.wikipedia.org/wiki/Ludwig_von_Bertalanffy.

and, eventually, computer simulations of those models that demonstrated systems dynamics of system behaviors.

With all of this foment and active research into systems-related subjects, the question remains. Why are there no general textbooks that introduce the broad range of sub-subjects in an integrated way and make the concepts accessible to, say, lower division baccalaureate students? To be fair, there are a number of books with titles like *Introduction to Systems Science*[6] and *An Introduction to General Systems Thinking*.[7] And these books do attempt to explore systems science and systems thinking, but, truthfully, they are not very comprehensive. This is because their authors harken back to a time when there was very little knowledge about some subjects that would, more recently, change many perspectives on what general systems theory might encompass. Most of the authors who have written introductory books have taken a more philosophical approach to describing systems science. They sought generalizations but were less concerned with fundamentally tying the pieces together. They were not writing textbooks but summaries of every insight they had gained up till the time of writing.

And insightful they were. We hope many of those insights have been captured in these pages.

But an introductory textbook to any subject has to explore the breadth of it and dip into some depths when it is appropriate to show how the whole fabric is stitched together. In this book we have attempted to do three basic things. The first is to outline what we think are the fundamental principles of systems science and show how they apply across a wide array of systems examples. Second, we are attempting to demonstrate some depth in the sub-subjects so that you get a better understanding of them and what kinds of work go on when digging deeper within each. The third objective is to show how all of these different sub-subjects relate to one another, *strongly*.

Unlike most other subjects where subfields tend to become more specialized and distant from one another, we claim that systems science has strong interrelations between the sub-subjects at all levels of study. You cannot really isolate, for example, internal dynamics from network theory. Dynamics work themselves out in networks of relations. Someone studying overt dynamics (external behavior) might be able to ignore some details of the network organization of the parts of the system, but ultimately, in order to fully understand that system, they will need to show how the dynamical properties and behaviors are partly a consequence of the network structure.

The same can be said for complexity theory and, for example, emergence and evolution. All of these principle-based sub-subjects have to be understood in light of all the others. We attempt to show this in Chap. 1.

So the answer to the question is that this may be a unique confluence in time of several "systemic" factors that allow an approach such as we have taken. First the existence today of accessible high-speed computers makes a kind of experimental systems science feasible, but more than that, the way in which computers work and

[6] See Warfield (2006).

[7] See Weinberg (2001).

are organized wholes has provided an intellectual scaffold for grappling with systems principles. Second, many new areas not well understood by earlier thinkers have developed in the last two to three decades. One in particular, the exponential growth in understanding of the brains of animals and man has forced many systems thinkers to reconsider ideas about complexity. Along those lines, new understandings of emergent phenomena and evolution have added another dimension to systems thinking that was not well understood even into the current century. The capabilities to sequence and catalog the genomes of many species, especially us, and the ability to map those genes and their developmental control programs have changed the way we understand information and knowledge.

Third, there is a social problem that systems science might be able to help with. The modern specialist education was seen in the mid- and late twentieth century as the route to a more effective and efficient economy. Liberal studies took a back seat to silo-based and professional degrees. This worked in the early part of the so-called Information Economy, but as the kinds of endeavors humans have been undertaking keep getting more and more complex, with components needed from multiple disciplines, the need for a higher-level viewpoint and an ability to grapple with complex patterns has emerged as a new capability needed by society. Generalists are hard to come by because most people think, and rightly so as far as it goes, that you can't know everything and you can't be a specialist in everything. As everyone knows you can be a jack of all trades but will not be a master of any.

Except that, general systems science and systems thinking apply everywhere. And a deep knowledge of systems science may yet prove to be the twenty-first century equivalent to liberal studies in that it promotes generalist understandings along with real critical thinking and integrative thinking. The world needs many more systems scientists to help integrate the work of specialists. Systems scientists have a basic vocabulary and semantics that can readily fit into any discipline, and they are thus positioned to grasp what the specialists are talking about. They can provide translation services when two different disciplines have to work together.

The need for broad systems thinking and the tools of systems science are needed more than ever today owing to some of the planet-wide systemic problems that are facing humanity. Our hope in writing this book, and telling the story, is that introducing more students to the concepts and the way of thinking will induce them to pursue whatever majors they choose from the perspective of systems.

About the Math

We mean for this book to be accessible to a very broad audience. The reason is straightforward. We feel that knowledge of systems science is something that every thinking person could benefit from. And we recognize, even while there is a current panic in our society that students aren't learning enough math (or math well enough), not every person will be comfortable believing that they will never understand something if they don't understand the math. Our feeling is that the fundamentals and principles of systems science are completely understandable without necessary recourse to mathematics. And so we have minimized the use of mathematics in the book in the hopes that non-math-oriented readers will not be intimidated into feeling they cannot understand the principles.

We do assume that readers will have had at least a course in algebra since algebraic expressions can often convey the kinds of relations we present. Even when this much math is included in the text, it is possible for readers to extract the relational information from the verbiage, but just with a little more effort on their part. We are not advocating that it is OK for people to avoid mathematics. Rather we are trying to show that these ideas can be expressed in English but could generally be expressed more compactly mathematically. Perhaps some people who were math-phobic at the start of this book will start to see the benefit of using math to express these ideas by the time they reach the end.

But, if the reader is a math-phile, we have included special boxes (*Quant Boxes*) that illustrate the kinds of problems encountered in various sub-subject domains and the kind of math that is used to solve those problems. Or they give examples of how special topics are defined mathematically. Many of the reference works in the chapter bibliographies could take the reader much deeper into the mathematical side of the subjects.

About a Central Theme: The Brain as a Complex Adaptive System

Starting in Chap. 3 we have constructed a set of boxes (*Think Boxes*) that carry a theme throughout all of the chapters thereafter. That theme is about the human brain as a complex adaptive system. The purpose of these focused boxes is to show that the brain is best understood as a complex system that demonstrates all of the principles discussed throughout the book. Thus in each chapter we introduce aspects of the brain that can be understood from the perspective of the principle discussed in that chapter. An obvious example is the fact that the brain is composed of high-level organized networks of neurons (Chap. 4) and the principle of network representation is nowhere better seen than in the way the brain encodes and stores memories of concepts.

Our hope is that these Think Boxes will not only be interesting for what they may reveal regarding how the brain works, but they will help students pause to consider something we find remarkable (and mind boggling; no pun intended). The brain is a system that is capable of understanding itself. It is a complex system capable of modeling its own complexity (see Chap. 13 and Principles 9 and 10). It is our belief that an understanding of the brain as a system will help students think about some of the most important and difficult existential questions that regularly invade intellectual life: What am I? How does my mind work? What is my place in the universe?

About the Pedagogy

Textbooks generally have questions and problems at the end of every chapter to exercise the student's learning of the material covered in that chapter. But those are not textbooks about systems science! This book does not take that route.

Systems science, as we argued above, is integrative in a way that almost no other subject is. Even though we have broken this subject into chapters that each focus on an aspect of systems science, as you will soon experience, these sub-subjects cannot really be taken in effective isolation such that little pieces of one can be memorized without reference to the rest. In every chapter you will find forward and backward references to other chapter contents as we try to establish how all of the aspects interrelate. The book reflects the holism that systems science is about.

Instead, throughout the book we have positioned *Question Boxes* near subjects that we want to get readers actively engaged in thinking about. Often those questions ask the reader to consider what the current subject means in relation to subjects that have been covered previously. And the questions are open ended. That is, there is no necessary single right answer. Rather the questions act as probes to elicit critical thinking on the part of the student.

We envision this book being used in a course that is conducted more along the lines of a seminar, that is, a general discussion around the current topic, but with the freedom to explore its relations with other topics. To that end, the Question Boxes can be used to spur discussions in class. The teacher can act more as a facilitator than an instructor. We have conducted several such classes at both undergraduate and graduate levels in this manner and have routinely found that student learning is much greater when the student is actively engaged in thinking and expressing their thoughts than when they are motivated by the need to pass a test.

Teachers can always construct various means of assessments, of course, to see if learning is taking place.

About the Use of the Book

In truth it is hard to suggest how the book "should" be used because there are not many courses devoted to the way in which this book integrates sub-subjects within systems science. In other words, there is no "norm" to point to and to which to map the contents of the book.

For Students

There are probably many different ways to approach this book based on your background, previous coursework, and interests. Our main objective is to promote critical and holistic thinking about the world.

Given the way we have organized the book, in chapters like typical textbooks, might imply you should read straight through from Chap. 1 to the end. But that linear approach would not be as productive as actually tracking the forward and backward references when given in the text (e.g., when you see a parenthetical "see: Chap. 4, Sect. 4.2.3"). The subject of systems science is so integrated that it really is not possible to think of one sub-subject without reference to many or all of the others.

Nevertheless, the subjects do build as the book progresses. So even though you could start reading a later chapter covering a topic you might be attracted to, the reading would eventually point you back to something in an earlier chapter (or several).

About the Think Boxes

The name we chose for these focus boxes has a double meaning. They are meant to get you thinking, of course. But they are also *about thinking*. That is, they reflect on how your brain actually does what it does. In some cases the Think Box will come toward the end of the chapter where they will attempt to show how the subject of the chapter applies to the study of brains. In these cases they can act as a review of the subjects in the chapter. In other cases they can act as previews of what is to come. Think about it!

About the Quant Boxes

As indicated above we intend this book to be read by a very diverse audience. Some chapters, such as Chaps. 7 and 8, have mathematics throughout the text, but it is relatively low level and is needed to explain the content. Elsewhere we rely on qualitative descriptions and reserve the math for the Quant Boxes. And those are only meant to be illustrative of the kind of math that is routinely used in the sub-subject. Occasionally we ask a question that would require some exercise of that particular math as a challenge to your thinking (and understanding). We assert that at this stage of your learning in systems science you do not need to get caught up in mathematical details in order to understand the subjects. If you stick with systems science, you will take courses in each of these subjects where the math will be made more explicit and you will have to exercise your skills in solving problems relevant to the domain.

About the Question Boxes

More important than the Quant Boxes, in our view, are the Question Boxes that pose open-ended questions that we hope will push you to think holistically, integratively, and critically. There are no right or wrong answers to most of these questions. They are not meant to show up in an exam, but rather to drive the tone of a discussion.

For Teachers

Both authors have taught courses that drew on materials found here. And we have discussed how such a book "could" be used in courses. For an undergraduate program, we've envisioned the book being used in a two-semester sequence at a sophomore level. The first third of the book (Parts I and II) and Chaps. 7 and 8 could be covered in one semester as the foundations needed. Chapter 9, Cybernetics, and the rest of the book could be covered in the second semester. Chapters 9–11 use the principles and fundamental ideas developed in the first chapters and are fairly heavy in terms of intellectual load. The final part is all about methodologies, somewhat similar to many technical subjects, but they are more like surveys of the subjects rather than instructive in details. Chapters 7 and 8 should probably be reviewed at the start of the second semester. Or some of the material might be moved into the second semester to lighten the load in the first semester. But these are just suggestions.

It is possible that upper-division courses (junior and senior) might be able to cover the entire book (or large sections of it), especially in programs that have bits and pieces of systems science already in their other offerings. For example, a junior in a biology program will already have a lot of background knowledge that will allow them to move through the book more quickly.

We also suggest that the book would make a good basis for a graduate course in any of the sciences (social and natural) as a way to broaden the students' perspective to see how their chosen field can be seen as systemic as well as related to other fields. The potential for encouraging interdisciplinary studies can be enhanced.

At this stage of the maturation of the subject and with no feedback from practitioners who have taught courses like this, we prefer to let others develop their courses (and pedagogy) in ways that seem good to them. We would appreciate hearing of their experiences.

Tacoma, WA, USA

George E. Mobus
Michael C. Kalton

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