Ecological Economics

A Workbook for Problem-Based Learning

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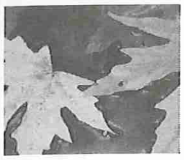
To Andrea, Pat, and Marcia
And to the next generation, especially Liam, Louis, Jon, Anna, Will, and Isabel



Contents

Note to Instructors: The Guide on the Side

We wrote this workbook with three overarching objectives in mind. First, to help students learn ecological economics. One metric of success in learning is the degree to which knowledge is retained, recalled, and applied. As educators, we often delude ourselves into thinking that a word spoken in the classroom is a word learned. But there is much evidence to the contrary. The average retention rate among students ranges from 5 and 10% for lectures and reading to upwards of 75 and 90% through practice and teaching. The following learning pyramid matches our lifetime experiences with learning, recalling, and applying new knowledge.[1]

	Average Retention Rate
Lecture	5%
Reading	10%
Audio-Visual	20%
Demonstration	30%
Discussion Group	50%
Practice by Doing	75%
Teaching Others / Immediate Use	90%

A goal of increasing retention should be supported by a variety of learning media. Having your students read this workbook alone will not achieve that objective (they'd be lucky to retain just 10% of what we wrote). Teaching it through lectures won't either (although you'll retain a lot, your students will retain very little). This workbook is meant for a problem-based learning environment, in which you will not be a traditional instructor, but a "guide on the side." Our aim is the lower third of the learning pyramid—to help you engage your students in a process of self-discovery through problem-solving and to develop a knowledge base and life skills to solve the world's most daunting social and environmental problems.

A second objective is to encourage a learning environment of self-discovery. Success in "teaching" is less the result of the talent of the orator or the intellect of the student than it is the medium of communication itself. As the saying goes, "The medium is the message." Neil Postman and Charles Weingartner in *Teaching as a Subversive Activity*[2] challenge the typical learning environment where students are expected to guess and supply "The Right

[1] National Training Laboratories, Bethel, Maine, www.ntl.org.

[2] Neil Postman and Charles Weingartner, *Teaching as a Subversive Activity*, Dell Publishing Co., New York, NY, 1969.

Answer," and since the content of most classes isn't retained beyond the last quiz, they argue that "just about the *only* learning that occurs in classrooms is that which is communicated by the structure of the classroom itself." The message in this traditional educational medium includes:

> Passive acceptance is a more desirable response to ideas than active criticism.
>
> Discovering knowledge is beyond the power of students and is, in any case, none of their business.
>
> Recall is the highest form of intellectual achievement, and the collection of unrelated "facts" is the goal of education.
>
> The voice of authority is to be trusted and valued more than independent judgment.
>
> One's own ideas and those of one's classmates are inconsequential.
>
> Feelings are irrelevant in education.
>
> There is always a single, unambiguous Right Answer to a question.
>
> English is not History and History is not Science and Science is not Art and Art is not Music, and Art and Music are minor subjects and English, History, and Science major subjects, and a subject is something you "take" and, when you have taken it, you have "had" it, and if you have "had" it, you are immune and need not take it again. (The Vaccination Theory of Education?) (pp. 20–21)

We believe students *should* be active learners, discussing, debating, and discovering knowledge. Today's daunting social and environmental problems require armies of independent-minded, collaborative, and passionate problem-solvers, not more Jeopardy champions. Decisions are urgent, uncertainty is high, and values matter. The Vaccination Theory of Education has created a world of isolated specialists behind high disciplinary walls. Most problems don't fit neatly in the confines of our disciplinary boxes, so solutions necessarily require many disciplines and collaboration among academic, government, citizen, and industry groups alike.

And finally, we have an objective of engaging armies of ecological economic problem-solvers worldwide to start solving problems . . . NOW. Why wait until they have their diplomas in hand? Why only read cases of other people solving problems? Or work through hypothetical problems with idealized right answers? To learn by doing requires doing. To become a problem-solver requires trying your hand at solving some problems. This can be a slow and frustrating learning process, but in the end can inspire a passion for lifelong learning, incubate the next generation of thinkers and doers, and contribute toward solving a few problems along the way. In our experience, the rewards outweigh the risks!

With these goals of learning ecological economics by working on problems, we wrote this workbook to accompany our textbook *Ecological Economics*. While our textbook in ecological economics helps to establish a working vocabulary, conceptual frameworks, and a pre-analytic vision for the problem-solving process, the workbook faces the added challenge of creating a generic process for a multitude of problems. No two problems are alike, and there is no magic recipe to problem-solving . . . at least we haven't found one. As such, the instructors in a problem-based course (and the authors of a problem-based workbook) don't have the answers. The instructor becomes the "guide on the side," not the "sage on the stage." And this workbook is a guide for the guides as much as it is for the students.

We follow a fairly generic problem-solving process that includes four steps:

- build the problem base
- analysis
- synthesis
- communication

In each step we provide examples, exercises, and ultimately project steps, all cast through the lens of ecological economics. All are meant to be adaptable and malleable to the needs of the problem-solver. If they help in the process, great! If a particular step or exercise is not useful, skip it! If a different sequence makes more sense, change it! Problem-solving rarely follows a linear process. Reevaluation of goals and objectives should be encouraged. Dead ends are commonplace. And solutions are rarely the proverbial "low-hanging fruit." If they were, perhaps there wouldn't be so many interesting problems in the world to tackle.

There is no fool-proof recipe for success in problem-based classes. In problem-based learning the instincts of the instructor and energy of the class are perhaps the closest things to magic ingredients. However, we've learned what does and doesn't work for us by trial and error. In fact, this workbook is more the result of convincing ourselves what doesn't work than what does. With some of these hard won lessons in mind, we envision a number of ways the workbook can be used to aide in problem-based learning.

***Supplement to the Textbook* Ecological Economics.** A class with the primary goal of introducing the content, frameworks, debates, policy prescriptions, and pre-analytic vision of ecological economics presented in the textbook *Ecological Economics* by Daly and Farley can use the workbook and problem-based cases for supplementary examples of ecological economics in application. Even if students are not working on directed research projects of their own, the case studies are intended to provide sufficient background for them to complete the exercises found in each chapter.

Workbook for the Ecological Economic Problem-Solver. Much of the material presented in the textbook can be reinforced and truly learned by application in an individually or group designed term project. Projects can be initiated with sponsors (see Project Step 2 in Chapter 2) before the term begins, or developed by students in the beginning weeks of a semester. An intermediary approach is to build on ongoing faculty research, in which case the department or university may be the student's client. Each student or group can then develop his or her own project within the parameters set by the larger research agenda. A term project puts much of the onus of learning ecological economics on the student and can become a major vehicle for student evaluation. We've found the most success working with small student groups with some constraints on projects to choose from. In many chapters, the exercises can be assigned as individual assignments, providing content for group brainstorms on project steps.

At the undergraduate level, it is unrealistic to expect to cover all the material from the textbook and workbook in one semester. The more emphasis you put on covering the textbook material, the less demanding the projects should be, and vice versa.

Textbook for a Problem-Based, Topical Class. In this scenario, ecological economics becomes the vehicle for a more specific focus on a specific problem. Classes with a primary focus on watershed management, sustainable forestry, regional economics, community development, and dozens of others can be taught as problem-based courses with the aide of the workbook. Many of the workbook cases were the result of topical semester-long courses or intensive workshops or travel-study experiences. Here the textbook *Ecological Economics* becomes a supplement to the workbook. To aide in making these connections, throughout the workbook we've provided page and section references to content in the textbook. In our experience, this approach works better for students who have already taken ecological economics as a prerequisite. The workbook in this case is essentially the textbook for an upper-level course in ecological economics.

As we have pointed out, any of these approaches to using the workbook is quite different from traditional lecture courses in a university. Students are accustomed to taking courses where the professor has all the answers, and they are merely expected to learn and regurgitate what the professor already knows. In a problem-solving course, by definition, the professor does not know the answers—if s/he did, the problem would already be solved. If you think about it, the traditional approach is a curious way to prepare students for real life—how many jobs are they likely to hold in the future where their boss knows all the answers to the work they are assigned?

Nonetheless, students are quite comfortable with this approach and can be resistant to change. To be honest, the traditional approach is probably easier for faculty as well. We therefore offer some additional suggestions on getting started, gaining momentum, and avoiding serious stumbling blocks.

First, we strongly recommend that you make it clear to students in the course description and on the first day of class that your approach will be different. You must make sure students have appropriate expectations for the course. Make it clear that trying to solve complex problems can be frustrating. The appropriate methodologies to use may not be obvious. Desired information may not be available, and when it is, alternative sources may offer conflicting facts. Most important, they will be able to turn to you for suggestions, but not for answers. More than most courses, they will have to show initiative and rely on their own resources. Students must understand that your role is to help guide them and provide feedback, not to spoon feed them.

We have found that there are usually predictable stages in the problem-solving process. The first stage is one of excitement, when students identify the problem they will work on and start to understand its basic features. A common problem at this stage is that students will strive to take on too much, more than can be accomplished in a single semester. You should try to keep them focused on a bite-size chunk of the project. As students delve more deeply, they begin to learn how complex the problem really is. At this stage, excitement may give way to anxiety and frustration, as students struggle to figure out what elements of the problem are most important and what methodologies are required to address it. Remind your students that frustration is normal—if they are not experiencing these problems, the problem they chose was probably too simple. Students may need help at this point in paring down the problem to something they can finish in the remainder of the semester. Another danger is when students try to continue with the research and analysis stage too far into the semester. Synthesis and communication are critical to effective problem solving and require quite a bit of time. Call a halt to background research while there is still plenty of time to prepare a solid final product. Unless research results are effectively communicated, they are unlikely to contribute to problem solving.

Finally, while between us we have quite a bit of experience conducting problem-based courses, we are still on the steep part of the learning curve ourselves. Whatever path you choose or invent, we'd appreciate learning if and how this workbook has been helpful in problem-based courses, workshops, or other experiences. We've been collecting problem-based cases and plan to assemble them on the World Wide Web for access to future classes and inspiration to ecological economic problem solvers everywhere. You can find the beginnings of our Web site at http://www.uvm.edu/~jdericks/eewkbk. Please visit us there, and use the site to send us your experiences, ideas, and feedback.

Acknowledgments

We are grateful to the growing community of ecological economists around the world for intellectual contributions, to the governmental and nongovernmental organizations with whom we have worked on the problem-based projects described in this book for turning ideas into reality, and to the many students and other participants in these projects who have taught us so much about effective teaching. Bob Costanza deserves special thanks for freely sharing his ideas—many of which have inevitably crept into this book without due acknowledgment—and vision. We are immensely grateful to Jack Santa-Barbara for his generous funding, encouragement, and promotion of this book, and to our editor at Island Press, Todd Baldwin, who played an invaluable role in transforming a jumble of ideas and experiences into a published book.

Introduction

■ What Does an Ecological Economist Do?

Both ecology and economics share the root *oikos*, the Greek word for household. Literally, economics is the management of the household, and ecology the study of the same. One way to think about the job of the ecological economist is to think about how you might manage your own household. Managing a household requires that you set budgets and priorities in such a way as to make the household livable, comfortable, clean, healthy, and in good repair for the indefinite future—the necessary conditions for a high quality of life. You must take care of your home by fighting the forces of **entropy**: fixing or replacing leaky plumbing, worn-out wiring, rotting floorboards, and weathered roofs. You must also make sure you have enough food, water, energy, and furniture, appliances, clothes, and the like. These are the flows of resources into your home, and you must be careful to use them wisely. Resource flows are inevitably transformed into waste outflows, so you ensure that sewage, garbage, fireplace ashes, and the like are adequately disposed of. Finally, as a practical matter, few households remain happy for long if benefits of your well-managed home are not shared equally or if there is not a fair distribution of labor among household members.

Entropy is the natural process that leads everything to break down, fall apart, and become less useful over time. See Chapter 2, pp. 29–35, and Chapter 4, pp. 64–70, in the textbook.

With little effort, we can extend the notion of household management to larger human communities. For example, just as households need roofs and plumbing, communities have infrastructure needs—roads, water systems, electrical lines, and the like. They also require a healthy economy that transforms the raw materials provided by nature into the necessities of a high quality of life. Just as in the smaller household, these resource flows inevitably become waste, which must be dealt with. Economists tackle these larger allocation problems by helping to identify problems, set priorities, and make choices at various societal levels. In a sense, the role of the economist is to help us manage our households, to keep them in order.

But, increasingly, the human household (the economy) is becoming so large that it is disrupting an even larger household—the supporting household of nature, the ecology and ecosystems of the planet we all inhabit, humans, plants, animals, all of life, together. It's no longer sufficient to act just as manager of the human economy. The economist must now take into account (literally) the impacts of human activities on the planet's living systems and at the same time recognize the contributions that healthy living systems make to human well-being.

Economics is generally defined as the study of limited, or scarce, resources among alternative, competing ends. See Chapter 1, pp. 3–5, in the textbook on the question "What is economics?"

This larger task requires detailed study of nature's household as well as careful ethical reflection. Study reveals that nature's household supplies us with all the resources required for our economy to function and absorbs all of the waste our economy produces. In the human household, the manager combats the forces of entropy, repairing what nature and human activity wear out. But in nature's household, human activity only speeds up the forces of entropy. A finite flow of solar energy maintains nature's household in a state of repair (low entropy). If humans speed up the entropy process too much, the finite solar flow becomes inadequate, and the household falls into

Box I.1 Oikonomia or Chrematistics?

The definition we provide of economics may be quite different from the popular understanding of the word. Most people, when they think of the work economists do, think of banking, stock markets, and the accumulation of monetary wealth rather than the production and allocation of the real goods and services required to run a household—be it a household containing a nuclear family, or one containing the entire human population. In fact, the ancient Greeks clearly distinguished between two activities and two types of value we in the modern world lump together as economics. *Oikonomia* referred to the production and management of the physical commodities we actually use in our lives, objects that have what economists refer to as "use value." The desirable end in *oikonomia* is to acquire those things that contribute to the well-being of household members. There is a finite limit to how much of anything we can actually use, so use value is bounded and finite. In contrast, the manipulation of property and wealth to maximize short-term monetary exchange value was referred to as *chrematistics*. The accumulation of money becomes an end in itself in chrematistics.

In fact, chrematistics is more closely related to the redistribution of real wealth than with its actual production. For example, during the 1990s in the United States, stock prices were rising at 15–20% per year, while the rate of increase in the production of real goods and services was in the range of 3–4% per year. When someone purchased an existing stock, he or she provided no new capital for production and in fact contributed nothing to the production process. The physical output of the company represented by the stock might have been increasing at 5% per year while the owner of the stock saw a 20% return on investment through speculation on future earnings. Without actually producing anything himself, the owner of the stock was able to purchase a greater share of the output of others—those who actually did produce something. Such returns would certainly provide an incentive for the owner of a forest—a stock of capital that exhibited a natural but slow increase in real physical output—to cut it down and invest the profits in the rapidly growing stock market. But such speculative bubbles cannot continue forever, and when they finally burst, they often cause substantial unemployment of productive resources, thus diminishing real output. Those who foresaw the bursting bubble sold stocks short, and made a profit from the decrease in real output!

disrepair. Reflection leads us to recognize that we are one species among millions and one generation among many. Few people believe it is ethical to destroy or degrade what belongs to everyone for our own private gain. In a full world, the economist must integrate both ecology and ethics—become an ecological economist—to help manage nature's household.

That's a tall order. Can we realistically claim that ecological economists manage nature's household, the global ecosystem that contains and sustains us all? The truth is that we do not know enough about the global ecosystem to manage it. In fact, because ecosystems are characterized by complexity and unpredictable evolutionary change, we can never know enough. At best, ecological economists strive to *manage human impacts on nature's household*. In ancient Greece an economist (or *oikonomos* in Greek) was generally the caretaker of someone else's house, and the word is thus frequently translated into English as "steward." We might say that the ecological economist strives to manage the human households of family, community, and society while serving as a steward or caretaker of nature's household based on the knowledge we obtain from the study of ecosystems.

In an empty world, the economy is small relative to the containing environment. In a full world, the economy is relatively large, and the opportunity cost of continued growth is significant. See Chapter 2, pp. 16–18, in the textbook.

But what does it mean to be a steward of nature's household? The steward's role is not that of creator—the steward is a creature subject to the same laws of nature as all other species. Yet it would be silly to pretend that humans had no special power and consequent responsibility compared to other species. After all, we do not blame deer for overgrazing nor expect them to read this book! Rather than allocating resources toward maintaining nature's household, a steward must make sure that resource allocation does not lead to the destruction of the household and the multiple services it provides.

In the case of the Earth household, nature has provided us with a livable, comfortable, clean, and healthy environment. But in today's crowded, high-consumption world, we are at risk of allocating too many natural resources toward the human household, and not enough toward the maintenance of nature's household. The failure of traditional economists to recognize that we are pushing the limits of what nature can provide has resulted in a multitude of serious problems at the interface of human systems and the global ecosystem that sustains us.

These problems are first and foremost **complex,** part of interconnected social and ecological systems where one "twitch" affects the next, and the next, and the next, potentially feeding back on the original twitch. In complex systems, the whole is greater than the sum of the parts, processes are highly nonlinear, and surprises are to be expected. Consider the problem of global climate change. Extensive study of the paleoclimate record suggests that we should not expect climate change to be smooth, gradual, and predictable. Past climate change has in general been characterized by surprises in the form of sudden, unexpected shifts between alternative patterns of atmosphere and ocean circulation, leading to rapid changes in regional and global climates.[1]

These problems have very **high stakes.** If we make the wrong decisions with respect to global warming (or ozone depletion, or the production of persistent organic compounds, or deforestation, wetland loss, overfishing, etc.) we could cause untold suffering to future generations of humans. We could trigger a catastrophic extinction episode that would destabilize global ecosystems and dramatically degrade their ability to sustain human civilization.

These problems are **urgent.** Fortunately, the changes occurring in the ozone layer were recognized while there was still time to act: although initial reports of an ozone hole over Antarctica were rejected as implausible, the seriousness of the problem (even with imperfect information) eventually forced countries to react quickly to the threat. Unfortunately, the time may be short to respond to other environmental problems such as climate change, species extinction, toxic waste emissions, and ecosystem loss before their effects are irreversible and we are locked into an undesired path.

[1] Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, 2001.

Box I-2 COMPLEXITY

Complex means a lot more than complicated. Complex systems are characterized by positive and negative feedback loops, highly nonlinear change, emergent phenomena, surprise, and chaotic behavior. What does this mean? *Positive feedback loops* increase the impact of an action. For example, global warming may thaw the arctic tundra, releasing methane, which is a powerful greenhouse gas. This will lead to more global warming, more thawing of the tundra, and more methane emissions: a positive feedback loop. Alternatively, increased atmospheric carbon dioxide (CO_2) contributes to global warming, but a warmer average climate with high CO_2 may accelerate plant growth, increasing the rate of CO_2 sequestration in a *negative feedback loop.* Feedback loops lead to *nonlinear change:* we should not expect a linear increase in atmospheric CO_2 concentrations resulting from greater anthropogenic CO_2 emissions, nor a linear increase in temperature owing to greater CO_2 concentrations, nor linear change in the ecological and economics impacts of climate change.

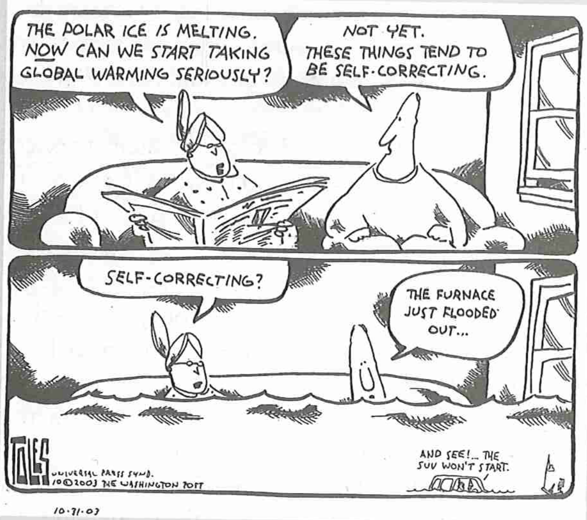


Figure I.1 Negative-feedback loops.

Emergent phenomena are global behaviors that cannot be understood on the basis of the rules of the underlying interactions. For example, consciousness emerges from the interaction of neurons but cannot be understood solely on the basis of the rules guiding the behavior of neurons. Many ecosystem functions are emergent phenomena, and human impacts on these ecosystems may therefore cause unpredictable *surprises.* A related source of surprise is the fact that complex systems may hover around attractors, a more or less equilibrium state to which a system returns even after large shocks. However, a sufficiently large shock may send a system toward another attractor, which may be a dramatically different but similarly stable state. Finally, *chaotic behaviors* are those in which even infinitesimal variations in initial conditions lead to entirely different outcomes. Thus, an immeasurably small difference in initial conditions may lead a system to fall into one attractor basin rather than another as the result of human impacts. In contrast, it's pretty easy to predict what will happen if we fail to repair a heater or air conditioner in our household.

> The basic point in such systems is that the whole is greater than the sum of the parts. When dramatic change will occur cannot be predicted, nor can the state into which a system will change. Evolution is a complex behavior, and ecological and economic systems coevolve. In such systems, cause and effect is neither deterministic nor linear. A reductionist, analytical approach of breaking a problem down into ever-smaller pieces alone will not help us to understand it. We must instead take a *systems approach,* described in more detail throughout the workbook.

So how should the human household respond to the coming era of climate change and other threats to nature's larger household? We have traditionally relied on objective scientists to gather the facts, perform their objective analysis, and tell us what to do. For ecological economic problems, however, the solution is not so simple, for at least two reasons.

Coevolution describes a process of adaptation to changing circumstances between and within economic, social, and environmental systems. See Chapter 1, pp. 7–10, in the textbook.

First, *facts are uncertain* and cannot be confirmed. Natural systems are infinitely complex and are not amenable to traditional experimentation or repeatable scientific observation. Many environmental problems have a sample size of one: a single unique ecosystem or, at the most extreme, a single planetary system. This is certainly the case with our global climate. We can make observations or perform experiments on a smaller scale, but complexity means that observation at one scale does not necessarily translate to understanding on a larger (or smaller) scale. Nor is it possible to make numerous observations of the same system over time. Global climate change is not a misnomer. The interconnected nature of the global ecosystem and global economy means that systems are in a constant state of change. In a continually **coevolving system**, observations at different times are based on different conditions. Even with baseline data (which can be hard to come by), we can't be sure it is relevant to current conditions.

Further, even if experimentation were possible, tinkering with human systems or unique ecosystems presents serious ethical problems, precluding us from obtaining sufficient observations for statistical analysis or from using scientific "controls." Even if ethical experimentation were possible, **uncertainty** and **ignorance** in complex systems are often irreducible—they are properties of the system itself and not simply manifestations of incomplete knowledge or characterized by **risk**. We're able to reconstruct recent climate change through temperature and precipitation records and to look back thousands of years by analyzing oxygen isotope ratios (an estimate of temperature) and greenhouse gas concentrations in air bubbles trapped in ice cores. However, we'll never know with certainty what our future holds. This is our very first global experiment in releasing stored carbon over a few centuries that took millions of years to be deposited in fossil fuels.

Risk occurs when we know the outcomes and can assign probabilities to their occurrence. *Uncertainty* occurs when we know the outcomes but cannot assign meaningful probabilities to them. *Ignorance,* or absolute uncertainty, occurs when we do not even know the range of possible outcomes.

Second, objective facts alone are an insufficient basis for decisions under complexity. *Values matter*. What is our ethical responsibility to future generations and other species? How do we weigh uncertainty, especially when it affects future generations? How do we decide between different alternatives that have different sets of winners and losers? Should we reduce carbon emissions now at the expense of economic growth because it might save lives and increase the well-being of people not yet born? There are no objective answers to such questions.

Sustainable scale, just distribution, and *efficient allocation* are the three main goals of ecological economics. See Chapter 1 in the textbook for an overview.

The task of the ecological economist is to solve problems in the face of complexity—without the ability to experiment and test, in systems where uncertainty and ignorance are the norm, when there are no "right" answers, and the stakes are high and decisions urgent—and to shape the world into one that is environmentally sustainable, socially just, and economically efficient. Like the household manager, the ecological economist does not have all the requisite expertise but knows where to find it and how to apply it. Teaching these skills is the particular challenge of this workbook.

WHY ECOLOGICAL ECONOMICS NOW?

The world of today is different than the world of the last century, when conventional economic theories were developed. Since then, human economic activity has grown to an unprecedented global scale, with unprecedented global impacts. Humans now have the capacity to irreversibly alter the very systems that sustain us but still lack the capacity to understand those systems. This is why stakes are high, decisions are urgent, and values matter. This is why society must change the very means by which we understand the world around us—science.

In the traditional view of scientific inquiry, science is seen as a value-free puzzle-solving exercise based on careful observations and repeatable experiments. Scientists seek to understand nature through observation and measurement. As observations accumulate, the scientist develops a hypothesis that explains what has been observed and uses the hypothesis to make predictions about what might occur. These hypotheses are then tested by experiments or further observations. If the hypothesis is shown to be wrong (falsified), then the scientist develops another hypothesis that explains the discrepancies between observations and the previous hypothesis. When a hypothesis is found that consistently explains predictions, it becomes a theory, at least until new observations falsify the theory, and the process continues. This circular, trial-and-error approach constantly tests the degree to which theories presented explain reality. This approach has served us so well for so long that it has come to be accepted as "normal" science.

However, as we described above, complex natural systems dominated by human activities pose significant challenges to such science. Where scientists once believed they could study physical phenomena in isolation from human influence, they now must recognize the role of humans both in changing the physical environment and in determining what they study and how they study it. Moreover, science must recognize the role it has to play in societal decision making about complex problems. In response, a new approach to science has emerged, **post-normal science**,[2] which suggests four important modifications to traditional science.

First, post-normal science challenges us to extend our notion of *who speaks with authority in the decision-making process*, including representatives who are not scientists or credentialed experts. This approach emphasizes diverse

[2] Silvio Funtowicz and Jerome Ravetz, "The Emergence of Post-Normal Science," pp. 85–123 in R. von Schomberg, ed., *Science, Politics and Morality: Scientific Uncertainty and Decision Making*, Dordrecht: Kluwer, 1993.

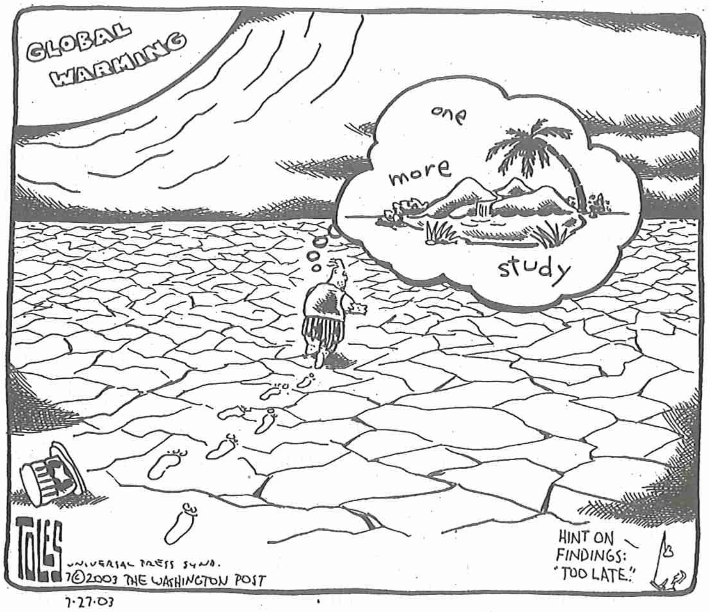


Figure I.2
Delaying a decision while we acquire more information is itself a decision.

values and expertise of stakeholders who may have intimate contact with a specific system, and observations and gut instincts not limited by disciplinary blinders. Scientific expertise can tell us how an air-conditioning system works, and a professional repair person may be needed to fix it, but they are not the ones who should decide the temperature at which the thermostat is set.

Second, post-normal science challenges us to ask the question, *what kind of information is acceptable for the decision-making process?* Acceptable information should reflect the expertise of the decision makers as well as the uncertainty of scientific "facts." Folk wisdom, local knowledge, anecdotal evidence, investigative journalism, and small-scale surveys can have a place alongside expert opinion, scientific evidence, and **peer-reviewed** reports.

Peer review is a formal process by which experts within the author's discipline judges the quality of their work. *Extended peer review* includes both credentialed and stakeholder expertise.

Third, post-normal science forces us to ask the question, *how much information is required to make a decision?* Too often, on a sensitive issue, policy makers play it politically safe by asking scientists for more data before making a decision. The study of climate change won't ameliorate its course. In a post-normal world, we see that we cannot wait for more studies. There are considerable costs to acquiring additional information, the most important of which is the possibility of irreversible changes that could occur while we are acquiring it (see Figure I.2).

Forced to make decisions in the face of uncertainty and ignorance, we should rely on the **precautionary principle**. That is, we should avoid decisions that risk catastrophic and or irreversible outcomes, even when we perceive the risk of such outcomes to be low. Rather than trying to maximize probable net benefits, for example, it may instead be better to minimize maximum regrets.

Fourth, post-normal science rethinks *how to assess the quality of a decision*. The quality of research in complex ecological-economic systems simply

Stakeholders are those who affect or are affected by the problem.

As a transdiscipline, ecological economics draws on knowledge *across* disciplines.

cannot be judged solely on the basis of "hard" scientific criteria such as replicability, analytical rigor, and peer review. Instead, its quality must be determined by an open debate among those interested in the outcome. Verdicts from such a group carry "moral force and hence political influence."[3]

Thus, a post-normal lens to problem solving emphasizes the central role of stakeholders in decision making, knowledge generation, and **extended peer review**. The role of stakeholders, together with the complexity of problems in the realm of the ecological economist's purview, further demands a **transdisciplinary** orientation to problem solving. As taught in many universities, traditional disciplines expose students to a set of tools they are expected to apply to any problem. If the disciplinary toolset is inappropriate for a particular problem, the researcher is expected to choose a different problem.

Outside academia, however, we do not typically have the luxury of choosing a different problem if our toolset is insufficient for the problem at hand. In the real world, most problems are so complex that no single discipline is equipped to resolve them. Ecological economists must transcend artificial disciplinary and institutional boundaries. As steward of the household, it's not what you know, but who you know. Thus, decision makers drawn from a broader pool are more likely to think "outside the box" to come up with innovative solutions. Even if the policies advocated by the traditional expert-based and extended-peer-community approaches were the same, the implementation would likely be easier in the latter case simply because stakeholders were an integral part of the process.

Thus, ecological economics takes an alternative approach in which there is no one specific set of methodologies. Instead, ecological economics defines a broad area of interest in which problems abound. The researcher selects a problem of interest, and this problem then determines the tools and disciplinary insights needed to resolve it. The necessary tools, methodologies, and insights for resolving the problem can be drawn from any discipline. The prefix *multi* means "many," *inter* means "between," and *trans* means "across." By incorporating *knowledge across disciplines*, very often the combination of tools and ideas lead to new tools and ideas, and transdisciplinary knowledge and understanding is born. The ecological economist strives to integrate transdisciplinary insights with human values—including but going beyond traditional notions of economic value—into a decision-making framework for solving problems in the real world.

THE PROBLEM WITH LEARNING, AND PROBLEM-BASED LEARNING

Transdisciplinary problem solving poses an interesting learning challenge. No one is likely to become proficient in all disciplines or incorporate all stakeholder perspectives. Yet we're making the case that solving such problems requires knowledge across disciplines and broad participation from stakeholders. This requires no less than a new way of learning.

[3] Silvio Funtowicz and Jerome Ravetz, "Post-Normal Science: Environmental Policy Under Conditions of Complexity," NUSAP.net, http://www.nusap.net/sections.php?op=viewarticle&artid=13. Accessed Nov. 10, 2004.

Traditionally, primary, secondary, and higher education has been a mold of specialized, disciplinary, sequential learning isolated from the messy world of uncertainty and dynamic change. Yet the challenges facing this century's graduating classes are inherently multidimensional, cross disciplinary, and interdependent. As an integral part of the sustaining and containing global ecosystem, the economic system cannot be understood in isolation from the whole—we can't erect neat disciplinary boundaries around this inherently complex field of study. Nor is it feasible to teach students how all the elements of the system work—a lifetime of education would not be enough. The most one can hope to learn is a process for problem solving. But this is hard to figure out in the abstract. We cannot conceive of an effective way to teach transdisciplinary problem solving that doesn't focus on real problems.

Furthermore, traditional lecture-based courses are simply not very efficient ways to learn. What do you recall from a class in which the instructor lectured and your performance was evaluated on how well you could memorize and regurgitate each lecture? Does an accountant learn accounting in a classroom, or by doing it? Does a lawyer learn law in a classroom, or by doing it? A doctor? An engineer? A policy maker? In fact, although each of us holds a Ph.D. in economics, none of the authors of this book actually learned economics in our undergraduate or graduate classes. We were "exposed" to economics in class, but we truly learned and retained knowledge of economics when we first had to teach or apply economics. Ecological economists must learn through practice every bit as much as a musician or athlete. Why wait to learn until you get out of school?

The more progressive medical, engineering, and business programs have long recognized the power of **learning by doing** and have pioneered **case-based learning**. Ecological economics builds on the case-based tradition of education with some new twists. The term we prefer is **problem-based learning**. In many courses, professors design problems to study or work on in a case-based format—a time-consuming process with little to no benefit to those most affected by a problem. In ecological economics, however, one finds enough real-life problems demanding immediate attention that there is little need to spend time devising artificial ones. Even as students, you can play an important role in solving real problems. In your first attempts at problem solving, you may make mistakes. You may fail. But learning from failure can be as important as learning from success.

Throughout the workbook, we provide examples of student projects that have helped toward solving real-world problems. These should inspire you, helping your creative juices to flow, but you'll get the most out of a problem-based learning approach to ecological economics by working on your own problem. And that is exactly what the rest of the workbook is designed to help you do.

Problem Solving and Systems Thinking

This workbook is designed to help guide research, stimulate ideas, and provide examples of transdisciplinary learning and decision making. Table I.1 outlines the problem-solving steps, focal questions, and project milestones

The problem-solving process:
1. Build the Problem Base
2. Analysis
3. Synthesis
4. Communication

along this journey, organizing them into four primary tasks: building the problem base, analyzing the problem, synthesizing the findings, and communicating the results. Building the **problem base** includes choosing, defining, and structuring an ecological economic problem. **Analysis** involves breaking down the problem into manageable components. **Synthesis** is the reintegration of the parts in a way that helps us better understand the whole. **Communication** is the translation of results into a form relevant to stakeholders, who are broadly defined as the **extended peer community**.

The workbook is similarly organized into four parts, although problem solving is rarely a linear, sequential process. If you follow these steps and find the process to be as easy as 1-2-3, then either you're a truly gifted problem solver or you've only scratched the surface of your problem of study. Problem solving isn't easy. If it were, there wouldn't be so many problems to solve! In the course of solving most projects, you will visit and revisit, over and over, the steps in the process, sometimes finding more dead-ends than open alleys. Most projects will be messy and at times frustrating. But if you stick with them, you'll ultimately find the experience rewarding, both personally and socially.

It is essential to maintain a **systems perspective** throughout the problem-solving process. As we've said, complex systems are, well, complex. Understanding their intricate and evolving balance and how they contribute to the properties of an underlying system of study brings us one step closer to knowing how, where, and when to intervene in a system. For instance, in holistic medicine, a healer doesn't simply treat the symptoms of the disease but searches for a cure by evaluating the entire person—lifestyle, habits, diet, and so on. In ecological economics, simple technological fixes to problems (the equivalent of surgery in modern medicine) are rare. More often than not, if an effective technical solution to a problem exists, then the real question is, Why has that solution not been implemented? Often, closer inspection reveals that the technical fixes, like surgery, are often not real solutions in the first place. Heart surgery on an overweight smoker does not solve the underlying problem, nor do hydrogen powered "hyper-cars" in a world where the number of cars and the miles driven per year exhibit exponential growth.

Solving a problem is nothing more than making the appropriate intervention in the appropriate place at the appropriate time. Donella Meadows, lead author of ***Limits to Growth***, a well-known report to the Club of Rome's Project on the Predicament of Mankind,[4] was one of the great systems thinkers of our age. Her life's work on systems modeling and education led to deep insight into **leverage points**—those places in a system where a small shift in one thing can lead to large changes in everything else. The vast majority of private and public policy attempts to leverage a system with what Meadows categorizes as the "numbers"—taxes, subsidies, and standards—yet this is typically the least effective place to intervene in a system and change its course.[5] Each year's local, state, or federal budget debate becomes the dominant place

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[4] Donella H. Meadows and Dennis L. Meadows, Jørgen Randers, and William W. Behrens III, *The Limits to Growth*, New York: Universe Books, 1972.

[5] Donella Meadows, "Places to Intervene in a System," *Whole Earth*, winter, 1997. Available at http://www.wholeearthmag.com/ArticleBin/109.html.

Table I.1

Overview of the Problem-Solving Process

Problem-Solving Step	Focal Questions	Project Milestone
	The Problem Base	
Choosing a problem	What is an ecological economic problem? What are the desirable ends? Who is working on the problem?	Project team and general project description
Defining the problem	What are the available means? What are the characteristics and state of knowledge of the scarce resources? Who receives the benefits and who receives the burdens?	Contacting and contracting with a sponsor
Structuring the problem	What is the context of the problem? How did the problem become a problem? What are the decision alternatives needed to achieve the desirable ends?	Background research and preliminary literature review
	Analysis	
Breaking down the problem	What are the objectives of the problem solver? What are the marginal benefits and costs of the objectives? What is the optimal scale as it relates to your problem?	Problem statement
Evaluating the objectives	What knowledge and skills are needed to evaluate the objectives? Where and how can such knowledge and skills be found among stakeholder expertise? Where and how can such knowledge and skills be found among disciplinary expertise?	Problem restatement, goals, and methodology
	Synthesis	
Bringing it all together	How do the objectives influence one another? What are the key positive and negative feedback loops in the system? What ends get priority, and to what extent should resources be reallocated to achieve them?	Synthesizing results and preparing an abstract
Synthesis frameworks	Examples: multi-criteria decision aids, dynamic systems modeling, integrated accounting, life-cycle assessment, integrated assessment	Choosing a synthesis framework
	Communication and Next Steps	
Communication	What are your communication goals and who is the audience? How should you organize effective communication skills and techniques? How should the communication be evaluated and improved?	Final communication and extended peer reviews
Changing the world	How can your work help to change the world? How can your project inform policy and management reform? How can you increase the odds your work is carried on?	Plant a seed, hand off to sponsor

Box I-3 The Post-Normal, Systems Thinker in the Brazilian Forest

The call for a post-normal science has been answered to a large extent by the tradition of systems thinking. Similar to traditional science, systems thinkers break problems down into their component parts. However, more like post-normal science, a systems approach focuses on the interactions of these parts in an effort to achieve a greater understanding of how the whole functions. The systems thinker asks:

Does a change in a system component lead to a change in other components?

Do those changes feed back into additional changes in the first component?

Do those feedbacks reinforce the first change (positive feedback), or dampen it (negative feedback)?

For example, when dairy farmers in Brazil's Atlantic Forest cut down trees, the moisture-laden water blowing in from the ocean no longer condenses on the now cleared forest, reducing the amount of water in the system. The canopy no longer forms an insulating layer that retains humidity and reduces temperature extremes. Flammable grasses grow where the forest once stood. The grasses burn, damaging and eventually destroying the remaining forests. Tree seeds cannot germinate on the dry soils in the dry air. Eventually, the forest may disappear altogether through a self-reinforcing, *positive feedback loop*. By focusing on the nature of feedback loops and understanding the other properties of complex systems, system thinkers take a holistic approach, complementing more reductionistic analysis.

The *preanalytic vision* in ecological economics starts with an image of the economy with the containing and sustaining ecosystem. See Chapter 2 in the textbook.

to seek change in the system. But this is only playing with the numbers in a system that is plumbed the wrong way, or with antiquated rules, or long forgotten goals, or a failed mindset worshipped by unquestioning parishioners. Fixing the plumbing—the material stocks and flows, the positive and negative feedbacks, the information exchanged between system components—has higher leverage than playing with the numbers. Changing the rules (the incentives, punishments, and constraints) has higher leverage still. Changing the goals of the system still higher. And what Meadows finds to be the most effective place to intervene in a system is its mindset or paradigm—its **preanalytic vision**—from which the goals, rules, and feedback structure arises.

A systems perspective, or systems thinking, is implicit throughout the textbook. When you begin to apply ecological economics to solving problems, systems thinking should predominate. Without actively, consciously, and conscientiously taking a systems perspective, you run the risk of adopting a "solution" that causes other, even bigger problems. Throughout the workbook, we emphasize the importance and uses of systems thinking to minimize this risk.

It's also essential to contact a **sponsor**—an individual or organization already working to solve a problem in which you are interested—early in the process. It's very rare that a problem is solved during the course of a semester, or even an academic year. There are times, however, when critical decisions must be made quickly, and a semester may be all the time available to gather, analyze, synthesize, and communicate the necessary information. Whether you are contributing to a project that will continue long after you move on, or you are racing to complete your project before an imminent deadline, a sponsor brings continuity and accountability to your work.

A sponsor might be a local institution from the not-for-profit sector, a government department, a local teacher or school, a for-profit business concerned with social or environmental issues, or your professor. Sponsors can save you time defining your problem, provide essential background materials, point out where your project will be most useful, show you how to deliver your results in an appropriate format, and offer the continuity and structure that ensures your research is put to use.

By following a problem-solving process, maintaining a systems perspective, and working with a sponsor, your work can make a contribution, however small, toward solving a problem that concerns you personally. But research is only useful if you communicate your results to someone who can act on them. It's been said, "We are drowning in information, yet starving for wisdom." In analysis, academia has perhaps earned a grade of B+. There is little doubt that the ivory tower has generated volumes and volumes of information through analysis of the parts. In synthesis, we're closer to a D. The sciences have just scratched the surface of synthesis, but the social sciences and humanities are woefully behind. In communication, we deserve an F.

The biggest hurdle to effectively communicating research to the general public is "objective distance." Many academics excel at generating information that is presented only to their peers or sits on library shelves in obscure journals, theses, and dissertations. Books are published and sold to these same libraries to be sourced and cited by other academics. Knowledge advances, but wisdom is evaded. Research at times informs policy, but too often researchers keep their objective distance, declining to advocate or implement solutions.

The three keys to success in problem solving: communication, communication, and communication.

We take a different tact. A critical leverage point in problem solving is this objective distance, which can be shortened via effective and timely communication. Jane Lubchenco in her presidential address to the American Association for the Advancement of Science (a highly respected professional society for science) stressed the importance of communication from the scientific enterprise in the "century of the environment" in what she calls a "new social contract for science":

> The new and unmet needs of society include more comprehensive information, understanding, and technologies for society to move toward a more sustainable biosphere—one which is ecologically sound, economically feasible, and socially just. New fundamental research, faster and more effective transmission of new and existing knowledge to policy- and decision-makers, and better communication of this knowledge to the public will all be required to meet this challenge.[6]

This is the challenge put forth to the ecological economist: to plot the course toward "a more sustainable biosphere" through transdisciplinary problem definition, analysis, synthesis, and communication. Let's get on with it!

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[6] Jane Lubchenco, "Entering the Century of the Environment: A New Social Contract for Science," *Science* 279: 491–497 (1998).