



SUSTAINABILITY AS AN INTERFACE PROBLEM

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Sustainability represents one of the most challenging interface problems in science today. The design of a sustainable interface between the natural environment and the built or designed environment is as essential to our collective well-being as any intellectual pursuit of the age. Along with such guiding principles of modern societies as human rights, sustainability is an epochal question that must be addressed by the citizens of a planet with a population that already exceeds six billion and is projected to approach ten billion. My objective is to establish a context for the problem and then to consider some fundamental design flaws in the knowledge enterprises that we call universities. These design flaws obstruct progress toward the integration of knowledge with action. But first I should begin by confessing that much of what I am going to say will mark me as a heretic. I have only avoided being burned at the stake because I have been fortunate enough to serve as president of an institution whose faculty and students for the most part seem eager to transcend existing orthodoxies. Apparently I am not the only heretic hiding out in Arizona.

In order to address sustainability as an interface problem that science must negotiate, we must first consider our own preconceptions about science and its role in society. The polymath Herbert A. Simon developed a useful construct in his 1969 book *The Sciences of the Artificial* that allows us to conceptualize a central problem in sustainability. Simon analyzes the distinction between the natural world and the artificial world, referring by the term "artificial" to objects and phenomena—artifacts—that are man-made as opposed to natural. He terms knowledge of such products and processes "artificial science" or the "sciences of design." The most obvious "designers" of artifacts are engineers, but Simon's usage of the term is broad. Everyone is a designer, according to Simon, who "devises courses of action aimed at changing existing situations into preferred ones." The natural sciences are concerned with how things are, as he puts it, and the artificial sciences with how things ought to be. Artificial science—or design

science—determines that which we build—tools, farms, cities—but also our organizational and social structures. Artificial science even refers to our use of symbols—the “artifacts” of written and spoken language. In this sense the intellectual processes associated with producing artifacts are fundamentally no different than the conceptualization of microeconomic theories or public policy. All professional activity is design and design should be taught equally in schools of engineering and law and medicine and architecture and business. He laments the fact that even professional schools focus on analysis rather than design, and I would argue that little has changed during the intervening decades. Simon also develops the notion of understanding nature in order to design from nature. He invested immense effort in developing these concepts in order to help us understand the implications of the interface between the natural and the artificial.

In terms of the interface between science and design, interface problems become apparent at three levels. In our basic attempt to understand nature we encounter interface problems within the natural sciences and even more serious interface problems become evident within the artificial sciences. Simon discusses these in terms of “constraints” in the inner environment and “parameters” in the outer environment, and elaborates on possible “optimization methods,” but except in the most general terms these considerations lie outside the scope of the present assessment. For our purposes it is sufficient to understand that the third level of the interface problem occurs in the relationship between the natural sciences and design sciences. While the flaws inherent in both the natural and artificial sciences impede functional relationships between the two broad domains, it is precisely from within this interface that the core of sustainability must develop. We cannot yet conceptualize the sustainable interface between the natural and built environment to a sufficiently robust degree. While many in the academy are involved in this effort, we have not yet even reached consensus regarding optimal outcomes nor determined whether we could design a sustainable interface at scale.

In the natural sciences our attempt to understand how the Earth works and to determine to what scale we must adjust our focus requires us to ask appropriate questions. The problem of scale is an important dimension to scientific examination and technological endeavor that has not been sufficiently examined. I believe we do not understand either the implications of scale or how to shape questions at an appropriate scale in order to understand nature. Should we be framing questions at nanoscale or world scale or universal scale or all of the above? We remain profoundly ignorant and do not know what questions to ask or whether we are on the right path. We have traditionally believed that knowledge is best when it is driven by curiosity. We tend to ask isolated questions about nature motivated by no purpose higher than curiosity. We are driven to understand how things work and are content with simple explanations that are incommensurate with the complexity and magnitude of a problem such as sustainability. How do we know what insights are important and how do we formulate

our questions about nature to discover those insights? I have addressed these concerns in a number of articles because I believe knowing what questions to ask is key to any proper understanding of nature.

Science with purpose: Overcoming “Stone Age logic”

The domination of nature has been one of the most conspicuous objectives of Western science since the Enlightenment. But what if our objective were sustainability rather than exploitation? To what extent would scientific research change if we were more concerned with conserving and enhancing as opposed to consuming? Despite the inevitable valorization of basic research and the unquestioned assumption that the purpose of science is to generate more and more disembodied knowledge, I would argue that both our questions and methodologies would be different if the purpose of scientific understanding were different. In our scientific culture, scientists generally remain oblivious of the context within which they conduct research and assume that their work will somehow at some point be applied and put to use. Scientific knowledge is generated without asking what purpose that knowledge will serve. It is not that scientists are indifferent to purpose but rather that they simply assume that others will determine its purpose. We have only to consider the state of our world today to see the outcomes of this lack of foresight. Fortunately, there is growing sentiment to demand science with purpose—science predicated on outcomes that are defined in advance and science utilizing methods calibrated to gain the information necessary to reach a conclusion. There is an emerging literature on purposeful science, and I particularly recommend the work of the philosopher Philip Kitcher, and especially his book *Science, Truth, and Democracy*.

Efforts to change scientific culture will not advance as long as we tolerate the unimaginable language barriers that have formed between disciplines. Each discipline seemingly lacks the impetus to develop a formal language to make itself comprehensible to other disciplines. We lack the capacity to link the social sciences and the natural sciences in any meaningful way and on a scale necessary to attack issues like sustainability. We have not developed the means for chemists to talk to political scientists, and for political scientists to talk to earth scientists, and for earth scientists to talk to engineers. While we have made significant advances in establishing crossdisciplinary linkages in other areas such as medicine and public health, we have yet to integrate anything as broad-based and scientifically complex as sustainability. For over twenty-five years I have encouraged scientists to work together across multiple fields, but science has its own social constructs and these are very difficult to break down. The lack of communication is exacerbated by misunderstanding and mutual lack of respect among scientists from different disciplines. I have sat in meetings listening to geochemists and ecologists verbally abuse one another for their alleged ignorance and stupidity. The prospects for connectedness and collective understanding sometimes appear dismal.

The artificial sciences have interface problems of their own as well. Design science, according to Simon, is still overwhelmingly focused on short-term goals—very simplistic models governed by what I call “Stone Age logic”: we find it, we burn it, we bury it. We continue to extract dark substances from the remains of prehistoric plants and animals dug up from holes in the ground, and we deliver these treasures to primitive machines for combustion to maintain the energy system on which we base our entire civilization. We invest immense scientific and technological effort to find it more efficiently, burn it cleaner, and bury it somewhere we will never have to see it again, at least not in a time horizon that will concern any of us. Find it, burn it, bury it—our dependence on fossil fuels is worthy of cavemen.

As we gain knowledge, we have never taken the opportunity to step back and rethink outcomes from a design science perspective. As we gain insight, we might ask what do we now know that we need? From a design perspective and with the objective of optimal outcomes in mind, what is it about our buildings, cities, factories, and farms that is clearly inadequate? Can we not finally see that the path we are on is not sustainable? Can we overcome our simplistic Stone Age logic long enough to change? This is the major interface problem in the design sciences.

The collapse of the interface

The most critical level of the interface problem obstructs the relationship between the natural sciences and the design sciences. The challenge is thus to find a juncture between what we know and can predict about nature and what we have built and how we operate it. An effective interface between the natural sciences and design sciences will be required if we are to guide ourselves to sustainability. The scientific community does not yet fully understand the implications of this interface problem. For example, nearly every outcome from Hurricane Katrina in the summer of 2005 had been predicted either by hydrologists or engineers or social scientists. Yet we lacked the capacity to translate that knowledge in a manner that was useful either prior to the hurricane or in its aftermath. Our failure to protect against and respond to this relatively mild hurricane should be an embarrassment to the nation. Nor did our knowledge make any difference in the outcome for Hurricane Mitch in Central America in 1998. The amount of rain associated with Mitch and its delivery on mountain slopes coincided perfectly with the U.S. Geological Survey models and ten thousand people died. USGS modeled the terrain precisely because the devastation was inevitable but among decision-makers there would be no utilization of the prediction. In both cases everything that happened was predicted but had no bearing on the outcome.

While we possess the knowledge we apparently lack the capacity to plan. Take metropolitan Phoenix as a design problem. The terrain and climate would suggest that the region is inhospitable for human settlement but the present population of 4.1 million

is projected to increase to 8 million. In a semi-arid climate the availability of water presents an obvious challenge but until recently no one considered the nighttime heat index. This indicator has increased by ten degrees during the last twenty years, increasing one half a degree per year. With the current trajectory the nighttime temperature in central Phoenix is projected to remain above one hundred degrees every night for three entire months of the year. On a larger scale, consider the imperative for design in China. I will not even address global climate change, a disaster of incalculable magnitude. Scientists can say all they want—the sky is falling, the ice shelf will flow off, the sea level will rise and Miami and Washington will be submerged—but it will make little difference until we can resolve the interface problem.

Any discussion of the relationship between scientific knowledge and its implementation must be construed across multiple interrelated dimensions. We cannot assume that scientists necessarily know what is needed and need only communicate their knowledge to decision makers. That simplistic model encourages the assumption that all we need to achieve optimal societal outcomes is more information. Nevertheless, with each month that passes the gap between what scientists know about nature and what decision makers need to know grows ever wider. What then is it that makes it so difficult to move fundamental understanding of nature into the design realm so we can actually design based on what we know about nature? What is it that makes it so difficult to move from what “is” to what “ought” to be? I term our present predicament the “collapse of the interface”: we know more and more and our knowledge means less and less. The collapse may in part be attributed to the fact that we are working at the wrong scale and that we do not even know what scale is appropriate or what scale might actually lead to an understanding of the complexity that confronts us. We may even have the wrong focus and we may be looking at the wrong things. The collapse of the interface is further exacerbated by a corresponding collapse of meaningful language. Perhaps we need new languages to understand science and to translate science into design because whatever languages we now possess are not effective, particularly in the discussion of sustainability. New languages might allow scientists to influence decision-makers.

The integration of science and design

What is required to overcome the collapse of the interface is an approach that integrates science and design, and I have a number of recommendations regarding what we need to do to create an integrated approach. First, we must consider the notion that scientific research conducted with application and social context in mind—outcome-driven science or science with purpose—should be granted equal accord with fundamental research. We could go one step further and say that the tension between them is inherently false because fundamental research itself can be outcome driven. In other words, fundamental research motivated by curiosity can be guided by the objective of solving real-world problems. If our goal is to create a more effective interface between

what we understand about nature and what we need to accomplish in terms of design, I would argue that understanding with a purpose is essential. Second, we must establish a comprehensive intellectual framework that allows us to integrate natural science with design science at all levels. Rather than pick and choose between the two we must consider science and design together at the same time and not in isolation.

Third, in order to overcome the collapse of the interface we need new tools, and by this I mean that we must develop new conceptual and organizational mechanisms to integrate science and design. At ASU, for example, we are working on an initiative we call real-time technology assessment (RTTA). The objective is to enhance the complex reciprocal linkages between science and society by integrating science and policy research from the outset. The project fosters interaction between natural scientists, engineers, and social scientists working together to conceptualize the implications of new knowledge as discoveries occur. RTTA encourages an awareness of the context within which research is conducted, one that despite conventional misconceptions is neither free nor autonomous but rather highly governed and buffered by cultural, political, economic, social, as well as natural constraints—constraints that dictate choices in ways that most scientists never consider. Researchers associated with the Consortium for Science, Policy, and Outcomes and the Center for Nanotechnology in Society at ASU (CNS-ASU) are using RTTA to understand the social implications of nanoscale science and engineering (NSE). How do you determine those social implications? What are the social implications of being able to predict climate or El Niño or mudslides?

Fourth, in order to overcome the collapse of the interface we need new institutional designs. For the past twenty years I have served as the lead architect in the design of a new class of large-scale multidisciplinary and transdisciplinary institutions and organizations at the forefront of education and research. Institutional design is challenging because of the sociocultural barriers I have described, but new designs offer new ways of shaping and examining problems and advancing the questions we have been discussing through cooperation between large numbers of groups, programs, and initiatives. As the architect in the establishment of the Earth Institute at Columbia University, for example, I served as its first director, a role now played by the economist Jeffrey Sachs. One of the entities of the Earth Institute is the International Research Institute for Climate and Society (IRI), established to advance research on climate risk management. The product of many years of elaborate planning, including the establishment of collaborative relationships with partners such as NOAA and intensive fundraising exceeding \$100 million, IRI brought researchers together to predict rainfall and heat variance between 20° N latitude and 20° S latitude three seasons in advance in areas as small as 5,000 square kilometers. Yet while information from scientists doing El Niño modeling may have been transmitted to Peruvian industrial fisheries concerned with the maintenance of anchovette stocks off the west coast of South America, it was not communicated to artisanal fisherman, demonstrating once again that science-

derived information must be managed carefully and deliberately to have any hope of achieving critical outcomes.

Advancing sustainability: Global Institute of Sustainability (GIOS)

With the establishment of the Global Institute of Sustainability (GIOS), ASU has positioned itself in the vanguard of interdisciplinary research on environmental, economic, and social sustainability, especially as it relates to human-dominated environmental systems across the globe. The institute brings together scientists and engineers with government policymakers and industry leaders to share knowledge and develop solutions to pressing real-world problems. Our sustainability initiative also provides a framework to connect the university to institutions similarly interested in collaborating on applications relevant to the global community. GIOS thus has developed productive partnerships with a number of premier institutions around the world, including Stanford, Harvard, MIT, the University of Washington, Tec de Monterrey, and Cambridge. GIOS is integral to the institutional framework we are designing to address the escalating complexity and competitiveness that confronts us, both in terms of the state of the planet and as a nation charting its course.

To prepare students capable of integrating a broad range of disciplines in a rapidly changing global knowledge economy, we have conceptualized and launched the School of Sustainability (SOS), the first of its kind anywhere in the world. With both undergraduate and graduate degree programs, the school is educating a new generation of leaders through collaborative, transdisciplinary, and problem-oriented training that addresses the environmental, economic, and social challenges of the twenty-first century. Teaching and research in the school seeks adaptive solutions to such issues as rapid urbanization, water quality and scarcity, habitat transformations and the loss of biodiversity, and the development of sustainable energy, materials, and technologies. With the formation of the school we express the conviction that the only way to overcome the interface problem is to focus on it comprehensively. Every student at the school is grounded in both the physical and design sciences, and every student and faculty member is focused on the challenges I have been considering in this presentation.

The Decision Center for a Desert City (DCDC), funded by the National Science Foundation, is one of the key initiatives in GIOS. An effort to understand water allocation in Arizona and the Southwest is one of its key objectives. During the past hundred years, a series of decisions have determined the allocation of water, 99 percent of which were based on politics. There is an urgent need to understand the implications of the fact that the last hundred years have been the wettest of the last several thousand, yet policy has been enacted with little input from natural scientists. Water allocation has thus been based on a political model. This is sheer idiocy and provides evidence that idiocracies make idiotic decisions. In an effort to upgrade our thinking, the Decision

Center brings together natural scientists, social scientists, and engineers with politicians and decision-makers representing every constituency in Arizona that has any stake in water allocation. We have developed a facility called the Decision Theater, which is an interactive setting for the presentation of immersive, three-dimensional visualizations of complex multivariate relationships based on environmental data, permitting simultaneous engagement in political and physical model simulation. We have taken fifty-eight physical science models and reduced them to simulations that would be meaningful to all constituencies. The Decision Theater brings real science to real decision-makers, and we hope that through input from natural scientists the urgency of the situation will become comprehensible to a broad audience, thus preventing outcomes like those we had in the wake of hurricanes Mitch and Katrina.

Design aspirations for a New American University

Fundamental change at scale will require society to rethink its institutions. At Arizona State University we have resolved to lead change through a large-scale experiment in rapid institutional redesign. ASU is at once the nation's youngest and largest major research institution and because of its youth is still fluid in its positioning. We take nothing for granted and at every step we question our identity and purpose. We have challenged some of the unspoken tenets of American higher education by choosing to be egalitarian instead of elitist and committed to societal advancement rather than removed in analytical isolation. By focusing on finding solutions to real-world problems we have focused on the interface problem that we have been considering. To attain our objectives for the transformation of the American research university we articulated a set of "design aspirations" for the institution. We have taken the "genetic code" of the academy and are commingling that ancient tradition with our differentiated model. We call our experiment the New American University. New faculty recruits invariably arrive with unquestioned assumptions shaped by their socialization in the traditional academy. While we do not pretend that we will ultimately overturn all previously held convictions, we do hope to build "genetic variation" within the institution as a function of our eight design aspirations.

There are many ways to parse the concept of the New American University, but in brief our objective is to reconceptualize and transform a large public university *and* to establish a new paradigm for public higher education through the creation of a prototype solution-focused institution that combines the highest level of academic excellence, inclusiveness to as broad a demographic as possible, and maximum societal impact. Reduced to their essential terms, these design aspirations enjoin the academic community to (1) embrace the cultural, socioeconomic, and physical setting of the institution; (2) become a force for societal transformation; (3) pursue a culture of academic enterprise and knowledge entrepreneurship; (4) conduct use-inspired research; (5) focus on the individual in a milieu of intellectual and cultural diversity; (6) transcend disciplinary limitations in pursuit of intellectual fusion; (7) socially embed the

university, thereby advancing social enterprise development through direct engagement; and (8) advance global engagement. The restructuring of ASU is taking place in the context of the design aspirations of the New American University.

While our design aspirations might appear to be mere rhetoric, to us they represent codes that we think will spark some variation in the scholarly output and lead to institutional differentiation. All of our decision regarding hiring, funding, and investment in infrastructure are made with the expectation of differentiation. To look at one example, let us consider intellectual fusion. In an effort to advance the fusion of academic disciplines we have conceptualized and launched fourteen new interdisciplinary schools, including the School of Global Studies, the School of Human Evolution and Social Change, the School of Materials, and the School of Earth and Space Exploration. Organizational predecessors such as departments of biology and geology and anthropology have been subsumed in the reconceptualized schools, and while the disciplines still thrive we have reduced the constraints of the arbitrary social constructs imposed by discipline-based departments.

We have established major interdisciplinary research initiatives such as the Biodesign Institute. In a perfect exemplar of intellectual fusion, the institute accelerates the pace of discovery through the convergence of formerly distinct fields including biology, chemistry, physics, medicine, agriculture, environmental science, electronics, materials, and computing. Unlike conventional institutions, we encourage the reorganization of academic units to facilitate research in order to tackle important societal problems. Those who prefer to be resident in a traditional department, by contrast, are free to exercise that option. While we advance both modalities simultaneously, the transcendence of disciplinary silo mentality is especially relevant to the advancement of useful knowledge for sustainable development.

Other design aspirations include what we term “leveraging place,” meaning a focus on the region in which our institution is situated. While many universities abandon their geographic locales, we think we know or have the capacity to know more than anyone about Arizona. Who better to bring sustainability to this region than us? Knowledge and outcomes related to sustainability must be framed in terms of specific geographies. With its semi-arid climate, fragile topography, and rapid urbanization, few settings could be more challenging than metropolitan Phoenix. Another design aspiration is “societal transformation,” with which we register our intent to engage society constructively. If our objective is to transform society we must actually assume partial responsibility for society. We cannot just talk about sustainability, but we must actually practice sustainability. The aspiration of societal transformation demands that we not be isolated from the rest of the community. I would argue that science underperforms in its potential impact on the built environment in part because we have not developed an adequate interface between science and society. This is relevant to our aspiration of

social embeddedness, which calls for direct engagement with the community instead of analytical isolation.

The design aspiration of “academic enterprise” suggests that even large public institutions like ASU can be agile, competitive, adaptable, and responsive to the changing needs both of our constituencies and global society alike. I have sought to instill into our institutional culture a sense of enterprise. The speed with which we now make and implement decisions and establish collaborative relationships with other academic institutions and with business and industry is characteristic of private enterprise. “Enterprise” is a concept sometimes wholly lacking in discussions about higher education. Enterprise and the entrepreneurial academic culture that such an orientation instills encourage creativity and innovation with intellectual capital. In this context I refer to ASU as a “comprehensive knowledge enterprise committed to teaching, discovery, creativity, and innovation” because this formulation encapsulates my recommendations for the transformation of universities and systems of higher education.

We produce knowledge but what is that for? How will it be used? We think the design aspiration of “use-inspired research” contributes answers to those questions. In the area of sustainability what matters more than trying to improve the human condition and quality of life and our collective survival through using our knowledge appropriately? This is what we call the appropriate application of knowledge, and it brings up the question of what is the appropriate *allocation* of knowledge? The case of Hurricane Mitch demonstrates that the appropriate allocation of knowledge is not limited to its publication in the *Geophysical Journal*. But I would contend that taken together the design aspirations that guide our academic enterprise at ASU advance the potential for knowledge to find appropriate allocation.

At Arizona State University we have made an institutional commitment to sustainability. What we are trying to do in this one isolated corner of our nation is resolve some of the interface problems we have been discussing because I believe they are major impediments to the realization of sustainability. Earlier this month I delivered the annual Sackler Lecture at the National Academy of Sciences. Arthur Sackler was another polymath whose mastery of disciplines spanned the natural sciences and humanities and arts. In my lecture I quoted him: “It is clear that bridges must be built to unite peoples in mutual respect and reciprocal esteem in a shared striving for great common goals.” Let us assume that the goal is sustainability. Where is the mutual respect and esteem between scientists working within the natural system and our engineers, designers, developers, and decision makers? Such “bridges of understanding” must indeed be built—bridges between the natural science and the sciences of design, as well as bridges between disciplines, between institutions, and between nations. And sustainability would certainly be one of the “great common goals” that Dr. Sackler specified.