Reductionist Science and the Rise of Capitalism: Implications for a New Educational Program of Agricultural Science

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The thesis of this essay is that there is a way of doing science that is characteristic of scientific inquiry under capitalism because its methods provide the kind of "irresponsible knowledge" that a profit-at-whatever-cost social system like capitalism requires. As my title implies, I will argue that as capitalism evolved to become an ever more dominant shaper of societies, a parallel scientific paradigm developed that conformed to the needs of capitalism in the same way that the rise Protestantism provided a set of religious beliefs and values that conformed to capitalist values better than did those of the Catholic Church. Then I will outline an alternative program of agricultural science that avoids the distortions and lacunae that are typical of current agricultural science under capitalism, and exemplifies a fundamentally different way of doing education and research.

Capitalism as used here refers not to a mere system of production and marketing, but to a whole social system whose major institutions have a distinctive character that is shaped by rules that facilitate the concentration of wealth and ultimate power in a minority investor class. Under capitalism institutions of government become power brokers to serve the interests of the wealthy minority; at the same time they function as theater to maintain the illusion of serving the majority. Market institutions, according to whose economist priesthood naturally serve the best interests of the consumer public, in fact operate largely under monopoly control of a handful of huge corporations in each market sector. These industrial giants extend market control through a sophisticated industry devoted to the manufacture and manipulation of consumer demand. The same capitalist class owns the mainstream media and exerts further control by funding its operation exclusively by advertizing. Under these conditions of effective media control of the collective consciousness, freedom of the press offers only the illusion of democratic power over information.

In such a society, it would be surprising if the institutions of the production of knowledge remained somehow autonomous. In fact, behind the illusion of academic freedom, it is well known that big business has infiltrated academia and bent the pursuit of knowledge into the service of its interests. But capitalist influence does not stop there; the very way that science is done serves those same interests, which brings us to the subject of this essay.

Thomas Kuhn's *The Structure of Scientific Revolutions* transformed the history of science when it was published in the 1960s because it demolished the belief of many scientists that the acquisition of knowledge is a stable, cumulative process of stone upon stone. Kuhn demonstrated a history of successional paradigms, each new one conquering and replacing, or at least subordinating the previous one as anomalies accumulated that cannot be explained under the existing paradigm. A reigning paradigm is a kind of overarching meta-theory or worldview that defines the status of knowledge and determines research design and its methods. Because it is historical, Kuhn's conceptual framework is a useful one for the purpose of this analysis of the evolution of what constitutes legitimate scientific activity.

There was a time when the holistic nature of the world was taken for granted. In the European Middle Ages for example, church theology dictated how all things fit together in the universe. Even as late as the 19th century great scientists like Darwin, Liebig, and Marx assumed that their quest for understanding the way the world works required the mastery of numerous disciplines. Starting in the Enlightenment however, scientific inquiry developed its methods partly in reaction to the faith-based knowledge paradigm of the church, and sought knowledge in ways that could be "proven" by replicable experiment. Predictability became the standard of scientific validity. But prediction required a focus on very few variables, a reductive method that, for experimental purposes, excludes the rest of the universe. A new Kuhnian paradigm of acquiring knowledge was taking shape.

This approach contrasted sharply with not only the previous religious paradigm which viewed the universe as a coherent whole, but also with common observation of the connectedness of reality. Perhaps for these reasons, and because fields of inquiry only gradually became well-defined, well into the 19^{th} century normal habits of study of the better scientists were what today we call multi-disciplinary. For example, students of society and its power laws understood that power is both economic and political, and naturally called themselves political economists. However, as it began to take shape the scientific paradigm that started in the Enlightenment characteristically broke the pursuit of knowledge apart into distinct disciplines, just as it narrowed the method of inquiry into a focus on increasingly smaller pieces of reality.

Like the religious revolt against an authoritarian church, the way scientific inquiry developed from the 18^{th} century onward was affected by economic forces as well. Private capital holders and entrepreneurs were gradually throwing off the strictures of church and state and were taking increasing control over investment and production decisions. In the expanding economic system of free enterprise, capitalists eagerly exploited the new predictive knowledge of science because it allowed them to develop powerful and profitable technologies. Because these technologies relied on a mode of inquiry that the reductive method limited to the interaction of few variables, little was known about the possible consequences of their application over time. But that did not matter because in the capitalist economy, where competitive success depends to the maximization of short-term profit, long-term consequences are not a serious concern.

Hence the reductive method of scientific research fit hand-in-glove with the goals of business under capitalism, and gradually became the dominant paradigm of science. That is, in keeping with the Kuhnian concept of paradigm, the reductive method hardened into a reductionist ideology according to which only knowledge acquired by the reductive method had the status of scientific knowledge.

As mentioned earlier, the holistic paradigm did not die an easy death. Because research that was acceptable in the reductionist paradigm was incapable of accounting for the interconnected, systemic nature of the universe, Kuhnian anomalies accumulated: technologies built exclusively on the products of reductionist science succeeded as predicted in the short run, but with more distance in time and space destructive consequences appeared and multiplied, exhibiting nonlinear behavior over time that the reductive method was not designed to capture or explain. Thus the vaunted predictive power of purely reductionist science increasingly stood revealed as a short run affair, almost inevitably altered through time as the impacts of a single technological intervention ripple through the interconnected universe. A striking example is the unrestrained application of fertilizers born of the Haber–Bosch technology for the synthetic fixation of atmospheric nitrogen. Once celebrated for its narrowly conceived ability to vastly improve agricultural productivity, it is now revealed to have a constellation of negative ripple effects on agricultural systems: soil compaction, deadly destruction of soil food webs, adverse effects on plant health, diminished nutritional qualities of food, and massive pollution of waterways. Today it seems incredible that generations of agricultural scientists have promoted the practice, but the dominant reductionist paradigm conferred legitimacy on such narrowly researched technologies.

The accumulation of destructive technologies stimulated the growth of a school of holistic science that created modern tools of multivariate analysis to model the feedback structures that generate these all too common nonlinear phenomena. It was becoming clear that if the planet and the human species is to survive the ever more powerful but ultimately ever more destructive technologies born of reductionism, a new Kuhnian scientific revolution must occur.

What might a new paradigm look like? It is more than ever apparent that if applied science is to have positive results that are sustainable, it must acknowledge as primary the importance of a research focus on how things change over time. This will require methodological tools that discover and model the dynamics of the ‘system of interest’ that governs the nonlinear behaviors that a problem under investigation often exhibits when tracked over sufficient time horizons. It is now widely accepted that such complex systems are not susceptible to accurate prediction. But the objective of science in the new paradigm is not to claim predictive power, but to use the tools of systems analysis to gain insights and discover probabilities in the form of probable outcomes over time of specific policies of intervention, and thereby reduce the chance of counterintuitive results.

In the new paradigm, reductive research will play an important but subordinate role by contributing knowledge of specific causal relations in the systemic modeling of research problems. In applied science, modeling of the system of interest in regard to a particular problem would thereby reveal the important relationships and thereby set the agenda of reductive research. In short, a macroscopic primary focus would regain dominance over the microscopic in the way we acquire knowledge, in keeping with the systemic nature of the universe.

How the emerging holistic way of doing science looks on the ground is already evident in those areas of inquiry where adoption is strongest. A systems approach to science has long been the hallmark of engineering with its focus on control theory (positive feedbacks and homeostatic mechanisms), from which historically it has often spread to other fields. In medicine where intervention often has life or death consequences, and especially in public health where the consequences involve whole human populations, the best health practitioners assume a systems approach to understanding health problems that ignores the disciplinary boundaries that reflect the goals of the reductionist paradigm. Similarly, many scientists in field of ecology view the study of the dynamics of whole ecosystems as necessary to the understanding of the behavior of specific organisms. Even in the business world, managers of complex corporation-wide processes have seen the need for modeling the system dynamics of problems whose system of interest includes design, production, marketing and management.

How does scientific training have to change to conform to the new paradigm? To show the contrast with present training programs, a look at agricultural science, a field where reductionist research and training are still the norm might be instructive.

An Academic Program for Agricultural Science

What I will attempt here is *not* a complete curriculum but an outline that contains enough suggestions to demonstrate the general character and aims of academic training under the new paradigm and how different it would be from the current program of study in most US agricultural schools.

In conventional programs shaped in the reductionist paradigm, there is immediate pressure to plunge into the details of subject areas and to treat them separately on the whole. In the holistic paradigm the focus is not on detail complexity but dynamic, operational complexity of the subject matter, which of necessity is a concern with wholes and how they work. Moreover, agricultural science becomes a historical science, a science of systems of interdependency and how they behave over time. Most importantly it becomes a program of a*gricultural science as sustainable agroecosystem design and management,* based on these assumptions:

a. Design for sustainability requires a systems perspective:
    i. A farm, like a pond, or a coastal estuary, or a forest, is an ecosystem.
    ii. Ecosystems support many different kinds of life which, to sustain themselves must interact in a manner that tends to produce the greatest good for all.
    iii. Design for sustainability thus shifts the primary frame of reference of scientific training from a short term snapshot approach to what will succeed in the long term, and from individual practices to the health of the agroecosystem as a whole.
    iv. Sustained agroecosystem health depends on adaptive management of evolving relations of a diversity of wild and domestic species.

Hence a holistic educational program for agricultural scientists, farmers or farm service providers needs to start with a study of the universal properties of systems and with the study of systems ecology. Thus I propose two core courses, running concurrently because they are complementary.

Core course I, *Introduction to Systems Science*, organized to achieve these goals:

1. Intellectual and historical awareness of the habits of short-term, reductionist thinking that have permeated not only academic culture, but also the general culture of our society, a prerequisite to their unlearning and replacement.
2. Understanding of the universal properties of complex systems.
3. An introduction to thinking dynamically/historically and modeling those dynamics:
    a. big picture thinking
    b. dynamic/historical thinking
    c. circular causality vs. unidirectional: the feedback perspective
    d. System as cause thinking: causal structures generate patterns of behavior
    e. Operational thinking – modeling how systems work
    f. Modeling
        i. Focus on context-oriented problem solving – modeling the 'system of interest'
        ii. Visual tools including mapping and causal loop diagrams
        iii. Combination of qualitative and quantitative properties

Core course II, *Systems Ecology* covers:

1. Levels of organization: organisms, populations, communities and their emergent properties.
2. Concepts of Ecosystem Dynamics: ecological load, carrying capacity, food webs, positive and negative feedbacks and their role in dynamic equilibrium.
3. Laws of Energy and Materials
    a. Thermodynamic laws and other power laws of nature as they apply to all species including humans.
    b. Liebig's Law
    c. Concepts of Emergy and Transformity
4. Ecosystem processes: cycles and flows
    a. Energetics
    b. Mineral and water cycles
5. Evolution: succession, coevolution, adaptation
    a. Oscillation – growth cycles of overshoot and collapse at different scales

6. Managed ecosystems, agroecosystems
    a. Notions of "efficiency": energetic-, labor-, the Jevons effect

The core courses in general systems theory and natural ecosystemics lay the foundation for courses in:

1. Agroecology: agroecosystem components, community dynamics, interdependencies and services in sustainable design:
    a. Soil, plant and animal biology
    b. Design and Management Strategies for health at the system level
        i. Building soil and net primary productivity
        ii. Input self-sufficiency: endogenous ecological inputs and services
        iii. Thresholds: sources and sinks
        iv. Species interactions: mutually adaptive solutions, predator/prey relationships
        v. Landscape layout and interactions at different scales – rotations, habitats, conservation agriculture, aquatic system services
        vi. Resilience: storage, redundancy and other strategies
    c. The Social Context of Agriculture
        i. Energy, Real Wealth Economy and the Market Economy

2. System Dynamics Modeling Methods – a theory and lab course
    a. Elementary nonlinear behaviors and associated feedback structures
    b. Problem articulation: behavior over time, boundary definition, endogenous perspective, key variable selection, delays
    c. Stock and Flow model building, simulation and testing

3. Historical Perspective
    a. History and Sociology of Science
    b. History of Agricultural Science.
    c. History of Agriculture
    d. Historical Models of Sustainable Agroecosystems,

4. Reductive Research Methods applied to determine specific causal relations that agroecosystem modeling bring to light and reveal as important to the understanding of agroecosystem dynamics.

5. Related Courses: the Physics, Chemistry, Biology and Political Economy of Agriculture.

A short, suggestive list of references.

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