SECOND ORDER SCIENCE: LOGIC, STRATEGIES, METHODS

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Second-order Science: Logic, Strategies, Methods

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Context • Philosophy of science is the branch of philosophy that deals with methods, foundations, and implications of science. It is a theory of how to create scientific knowledge. Presently there is widespread agreement on how to do science, namely conjectures, ideally in the form of a mathematical model, and refutations, testing the model using empirical evidence.

Problem • Many social scientists are using a conception of science created for the physical sciences. Expanding philosophy of science so that it more successfully encompasses social systems would create new avenues of inquiry. Two dimensions could be added to philosophy of science: the amount of attention paid to the observer and the amount of impact of a theory on the system described.

Method • My approach is to illuminate underlying assumptions. I claim that there are at least three epistemologies and that they can be combined to form a more robust conception of knowledge and of how to do research. There are at least four models and four basic elements (i.e., ideas, groups, events, variables) being used by (social) scientists.

Results • The article identifies the logical propositions underlying second-order science. It suggests strategies for developing second-order science. And it describes several methods that can be used to practice second-order science, including how past theories have not only described but also changed the phenomenon being studied.

Implications • The task for members of the scientific community, particularly social scientists, is to practice second-order science and to further develop its theories and methods. A practical implication is to accept methods for acting as well as theories as a contribution to science, since methods explicitly define the role of an observer/participant.

Constructivist content • The paper is an extension of the work of Heinz von Foerster and other second-order cyberneticians.

Key words • Philosophy of science, epistemology, models, descriptions, cybernetics.

Introduction

1. We have come a long way since the 1600s in England when Robert Boyle organized a luncheon group called the “Invisible College.” The group eventually became the Royal Society for the Advancement of Natural Knowledge, now called the Royal Society (de Beer 1950). The founding of the Royal Society is one sign of the transition from theological knowledge to natural or scientific knowledge. Since then, natural knowledge (i.e., science) has contributed enormously to our physical quality of life.

2. We are now in a transition to a new kind of knowledge. It could be called reflexive knowledge or a greater self-awareness as a result of cognitive science and an awareness of our impact on our social and biological environment. In this paper I start with a

review of the conceptual foundations of second-order science and relate it to three epistemologies which sometimes vie for influence. Next, I point to the ways in which science is changing. In particular, I emphasize that over time science has been using four different models as explanatory vehicles to describe social processes. And I note four basic elements used by different disciplines. Subsequently I present the main motivation for introducing second-order science based on the argument that social systems, which are composed of thinking participants (including scientists), are different from physical systems, which consist of inanimate objects. In order for philosophy of science to serve as a guide for creating knowledge of social systems, two dimensions should be added, i.e., the amount of attention paid to the observer and the effect of a theory, once adopted, on the system observed. These dimensions can be added in accord with the correspondence principle, a rule for describing one way that science grows. I conclude with a description of the logic, strategies, and methods of second-order science.

Conceptual foundations of second-order science

3. The idea of second-order science grew out of the idea of second-order cybernetics. The basic idea of second-order cybernetics is that science should be expanded by adding the observer to what is observed (Foerster 1974). This intention may seem to contradict a key assumption about science, namely that the purpose of science is to create objective descriptions. The observer can be excluded because, if an experiment is conducted properly, any observer will see the same things. However, if we include the observer in what is observed, we can shift our thinking from viewing science as creating descriptions of systems to viewing science as an active part of social systems. We would then think about the co-evolution of theories and societies.

4. Figure 1 illustrates several subjects of research in the history of cybernetics in the past 50 years. Karl Popper (1972) spoke about Worlds 1, 2, and 3. World 1 refers to the "mind independent world," World 2 to mental events, and World 3 to the descriptions that are found in books and libraries. Assume for a moment that the triangle depicts three epistemologies. According to the triangle there are three ways of thinking about knowledge. The mostly widely used one is on the left side. That is, scientists are supposed to create descriptions of the world and then test them with experiments and observations. Ideally the descriptions are accurate and statistically valid. A theory should be a "picture" of the mind independent world. In this realist epistemology, when we are talking about descriptions of the world, we explicitly exclude the observer. The observer is not part of what we are studying. We are only studying the mind independent world and creating a description of it.

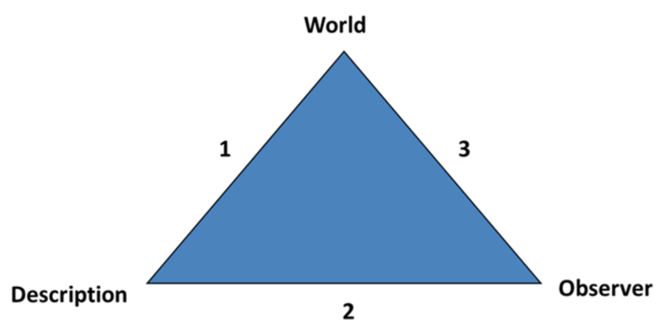

Figure 1: Popper's three worlds and three epistemologies.

5. But if one becomes interested in cognition and how the brain works, then attention shifts to the observer and how an observer creates descriptions. When the focus shifts to the observer and descriptions, there is a tendency to de-emphasize the world. After all, the world is present in the conceptions in our minds. Realists concede that although we perceive the world through our senses, our senses can be unreliable. People sometimes see mirages. And other animals live in different sensory worlds. Dogs smell and hear better than humans, and insects see infrared light. In this second epistemology, depicted by the base of the triangle, the emphasis is on how an observer creates descriptions. In this constructivist epistemology no attention is given to a mind-independent reality.

6. The third epistemology emphasizes the observer and the world. The key question is how a person should act in the world in order to achieve his or her purposes. In this pragmatist epistemology knowledge is evaluated by its practical utility. Theories are of interest only if they contribute to effective action. Knowledge tends to be embodied in methods – do A, then B, then C. Practically oriented people have little interest in theories or philosophies. They simply want to know how to act effectively in the world. Once again one corner of the triangle is deemphasized, in this case descriptions or theories.

7. Second-order science[1] is the idea that we should use all three epistemologies, since second-order science values multiple perspectives. Rather than defining science as the left side of the triangle, let us expand science to include the observer, as Heinz von Foerster (1974) suggested. We could then make greater use of what we have learned from cognitive science and from practical affairs.

8. In addition to including the observer in science, we could also acknowledge that theories (at least in the social sciences) affect what is studied. We are aware that theories affect society. Indeed, that is why we create social science theories. We hope that they will be accepted, acted upon, and the social system will perhaps operate better. But when we are acting as scientists, we tend not to think that way. We assume that our descriptions have no effect upon the phenomenon. When we seek to influence social systems, we try to formulate persuasive arguments. But when we do social science research, we assume that theories have no effect on society. We think and act in this divided way because we are trying to create objective descriptions rather than describing our perceptions.

Three conceptions of how science is changing

9. Recently, several people have described how science is changing. In an article in *Science* called "Science 2" Ben Shneiderman (2008) points out that, with the internet, scientists can share their data and their preliminary ideas. They can access other people's data and engage in conversations with colleagues far away. They can conduct experiments that can be replicated in many locations quickly. This is certainly an important trend in science. The Internet creates opportunities.

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[1] To the best of my knowledge the first use of the term "second order science" was by Karl Müller in his presentation to the annual conference of the American Society for Cybernetics in 2005, "From Second Order Cybernetics to Second Order Science."

10. Karl Müller (2011) has proposed the idea of "meta-science" or research on research. He created this point of view as a result of operating a social science data archive. He stored and made available the social science data that people sent to him. He not only collected it, he tried to make sense of it. Müller has been developing methods for combining the results of studies which used different research methods. The goal is to formulate more general knowledge that is supported by a large number of studies. And he has designed a doctoral program to teach people how to do this kind of second-order science.

11. What I am suggesting is a third conception where the intent is to take account of the observer and examine the co-evolution of theories and phenomena, particularly in the social sciences.

Four models used in science

12. To understand how science is changing, it is helpful to reflect on different types of models that are used in science. The first type of model describes *linear causal* relationships. How does variable A affect variable B, perhaps with an intervening variable C? There are many statistical methods that are available to help us establish relationships among variables, ideally cause and effect relationships. Finding these relationships is what many scientists spend their lives doing. It is certainly what many doctoral students do.

13. The second type of model describes *circular causal* relationships. Circular causality is essential in a regulatory process. For example, if you are driving a car, managing a firm, or managing a household, you are engaged in a circular causal process where you observe, make a decision, act, observe, make a decision, and so on. Circular causal processes in social systems can be modeled with causal influence diagrams and system dynamics models.

14. The third type of model is now described as *self-organization,* i.e., "any isolated, determinate, dynamic system obeying unchanging laws will develop organisms adapted to their environments" (Ashby 1962). The concept of self-organization has been important in the history of science because it explains emergence, e.g., new species or new institutions. It is the model that was used by Adam Smith when he described a society as composed of firms competing with each other and nations that compete with each other. This was also the model used by Charles Darwin when he said that organisms and species compete within an environment. A self-organizing system is a system with elements that interact within that system (ibid). Depending on the interaction rules, the elements of the system go toward a particular equilibrium. In the case of social systems the interaction rules can be changed by changing laws, regulations, or incentive systems. For example, if society does not want businesses polluting the environment, the legislature can pass a law against it, with the result that there is less pollution. As a second example, an incentive system for sales personnel is intended to increase sales efforts. By changing the interaction rules the system goes toward a different equilibrial state.

15. The fourth type of model is *reflexivity*. There are various conceptions of reflexivity (Lefebvre 1977, 1982; Soros 1987, 2013; Beinhocker 2013) but all of them have three characteristics. The first characteristic is that there is a circular process. The second characteristic is that an observer is included. The third characteristic is that a reflexive

system operates on two levels. Each person or organization in a social system both observes and participates. John Boyd (1976) calls this an "Observe, Orient, Decide, Act" (OODA) loop. Second-order science uses the model of reflexivity but it goes beyond saying that the elements of social systems both observe and act. Second-order science claims that scientists also observe and act. They do not stand outside the system observed.

Examples from three fields

16. How would social science change if the perspective of second-order science were adopted? Let us consider three fields – management, sociology and economics.

Management

17. In the field of management, including the observer is not new. The phenomenon of management is a recursive process of observing, deciding, and acting. However, for most U.S. management scholars research involves finding linear relationships among variables, ideally at a high level of statistical significance, thus a long way from the reflexivity of second-order science. Nevertheless, within the field of management, there are many methods, for example, how to improve a manufacturing process, how to create a business plan, and how to conduct a strategic planning exercise. There is a large literature on how to act using management methods (Ackoff 1981; Beer 1985; Checkland 1999; Deming 1986). Some of the most influential management literature has been created by consultants. Often their contributions take the form of methods. Consultants do not limit themselves to the point of view of a particular academic discipline. Practicing managers may find the academic management literature to be of little help, since genuine management problems are multi-disciplinary and do not fit within a single discipline.

18. For several years, I taught philosophy of science to doctoral students in the School of Business at The George Washington University. Those familiar with the literature in philosophy of science know that most of the examples are from physics. In class there were many discussions about how physical systems are different from social systems. Does it matter that social systems are composed of thinking participants who sometimes change their behavior? Can the same methods be used for the physical and the social sciences? The class was usually divided, with students in finance saying that the same methods could be used and students in organizational behavior saying that changes were needed. In his doctrine of the unity of method Popper (1957) claims that the method of conjectures and refutations works in the social sciences as well as in the physical sciences. That is, formulate a hypothesis and then attempt to refute it. However, the elements physicists deal with are inanimate objects. The elements social scientists deal with are thinking participants (see Figure 2). If one feels it is important to take that difference into account, a second question arises: Should we disregard philosophy of science? Faculty members in organizational behavior and public administration often maintain that philosophy of science does not work for social systems (Umpleby 2002). Some people consider science as a particular style of rhetoric (McCloskey 1985; Myers 1990). They argue that science is a way of persuading other scientists. Some philosophers emphasized that science is a search for reliable knowledge about the world (Comte 1856; Schlick 1925; Popper 1989). I claim that philosophy of science can and should be expanded so that it can encompass behavior in social systems. If we do that,

then we can ask: Should knowledge be organized as theories or as methods (Umpleby 2002)? The practice of management requires a large amount of procedural knowledge: If you want a particular result, do this. Baking a cake or writing a business plan or conducting a planning activity are similar in that one follows a well-defined procedure. Management and other professions, such as law and medicine, emphasize procedural knowledge because practitioners both observe and participate. So if second-order science is accepted, management scholars may spend less time trying to find reliable linear causal relationships and more time developing and improving methods to guide actions in organizations.

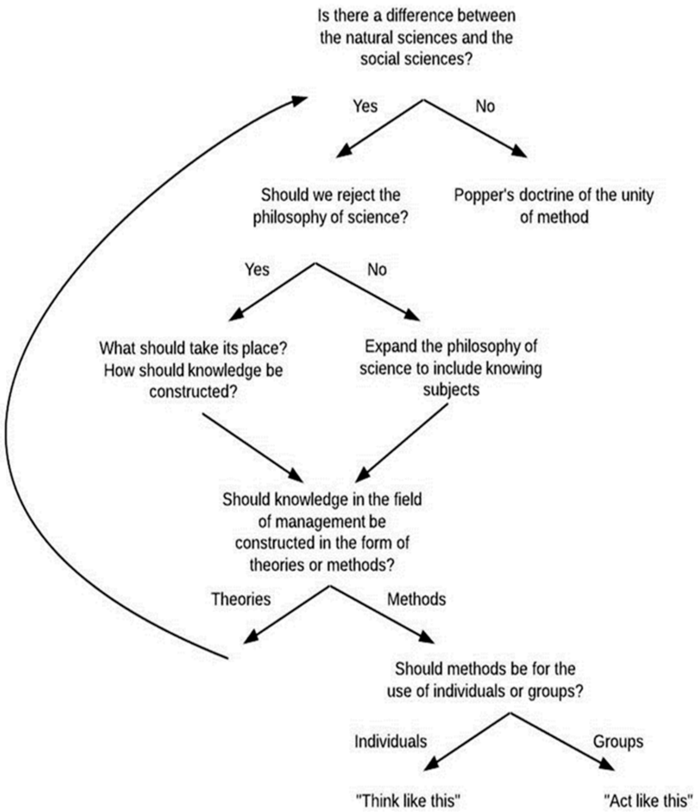

Figure 2: Questions to guide the construction of knowledge of management.

Sociology

19. The sociology of knowledge is an idea that goes back to the 1800s. People usually adopt the views of their reference group whether defined by profession, religion or nationality. Hence, there is an interaction between one's circumstances and one's opinions. What one thinks about society is influenced by one's position in society (Mannheim 1960). When I encountered the idea of the sociology of knowledge as an undergraduate, I thought it should be not just part of sociology but part of the foundation of science. Thomas Kuhn's 1962 book, *The Structure of Scientific Revolutions*, helped to introduce the sociology of knowledge to the scientific community as a whole. Second-order science is another way of calling attention to both the context and the purpose of scientific activity. Science, like other forms of knowledge, is not separate from society. It plays a role in creating society.

20. In the field of sociology knowledge is not just the product of an investigation but also part of what is investigated. The roles that people hold shape their opinions.

Sociology is probably the field whose perspective is closest to second-order science. Sociology along with literary criticism is a form of critical theory which regards ideologies as the principal obstacle to human liberation. A particular conception of science, like a particular conception of religion, shapes both world view and behavior. An overly limited conception of science (i.e., one that excludes the observer and the effects of theories on society) limits investigation and constrains how science can contribute to the improvement of society.

Economics

21. Economics is the social science that has been most successful in imitating physical science. Quantification is easier in economics due to prices and other measurable variables. Contemporary economics is defined primarily by its method, mathematical modeling, rather than its subject matter, economic activity. The predominant model in economics is equilibrium theory (Walras 1954; Debreu 1959), which is an example of self-organization. In the early days of physics, people dealt with planets, billiard balls, and pendulums – systems with a small number of elements. Later, physicists developed an interest in gases and thermodynamics. In a gas there are a very large number of particles. Using the earlier method of describing a few particles was unworkable. So, physicists chose to look at gross parameters, such as pressure, volume and temperature. For an economy the gas model seemed to be a good choice as well: The particles would be people and institutions, and the gross parameters would be imports, exports, GDP per capita, savings, etc. The model is a self-organizing system, described earlier. If an economic system is disturbed, for example by legislation or a new technology, the actors within the system act according to their rational self-interest and come to a new equilibrium. In order for the model to work, people need to behave in a similar manner or the differences in behavior need to cancel. This conception of society is based on a number of assumptions. Economists have assumed that people seek to maximize their personal profit, that they are rational, that everyone has the same information and that they all have complete information. In recent years Behavioral Economics has been challenging these assumptions. Several Nobel prize winners such as Herbert Simon (1957), Daniel Kahneman (1973) and Joseph Stiglitz (Greenwald & Stiglitz 1990) have successfully argued against one or more of these assumptions.

22. One way that economics is different from physics lies in how knowledge progresses. In physics new ideas build on older ideas and some ideas, like the ether, are discarded. In economics there tend to be swings between left and right political positions. In his book *Capitalism 4.0* Anatole Kaletsky (2011) notes that there was a laissez faire approach to macroeconomics following the stock market crash in 1929. Then, in 1936, John Maynard Keynes published his general theory, which justified government deficit spending during an economic downturn in order to provide demand and stimulate economic growth. Later there was a return to free market economics led by Friedrick Hayek and Milton Friedman theoretically and Margaret Thatcher and Ronald Reagan politically. *Capitalism 4.0* marks a return to the belief that some regulation is necessary. There is no theory in economics that resolves these two points of view. Rather, the two points of view guide the actions of political groups and the resolution occurs in the political process. There are swings between left and right. Society never returns exactly to earlier theories or to earlier legal regimes, because the economy and institutions are always changing. There is not a linear progression of steady improvement in explanations. Just as there are left and right swings in politics,

there are swings between pro-government and pro-market points of view in economics. Economic theories become part of governmental processes which act to regulate growth and distribution within society.

23. Surprisingly, the history of economic thought is no longer taught in many U.S. universities.[2] There is a belief among economists that earlier theories were inferior (i.e., qualitative rather than quantitative) and that there are so many new results, there is not room in the curriculum for earlier ideas. But if earlier ideas are eliminated, students do not develop a sense of how the field has evolved. One solution would be to have a second-order theory, a theory that explains the swings between pro-market and pro-government positions. Such a theory would describe a control system or a regulatory process. First-order economic theories (i.e., our current economic theories) would be used in the regulatory process.

Expanding philosophy of science

24. In addition to the assumptions challenged by Behavioral Economics, there are deeper assumptions about science and how we construct scientific theories (Umpleby 2011). These assumptions include the belief that the observer should not be included in what is observed and the belief that theories do not affect what is observed. These assumptions would change if second-order science is accepted.

25. If we were to decide that it is time for second-order science, for example second-order economics, how do we make the transition? Scientists need methods. They need tools to work with. A carpenter has a saw and a hammer and nails. Scientists have laboratory experiments, statistical methods, computer simulations, microscopes and telescopes. How would scientists practice second-order science? As Kaletsky suggested, in economics there is an influence cycle. One can model cycles in economics, like credit cycles, with positive and negative feedback loops. In the influence cycle (cf. Figure 3), if the party in power wants to emphasize markets, then the government could deregulate business activity. Or the party in power may choose not to enforce the rules that are on the books. In a democracy the people have a chance to influence the amount government regulation.

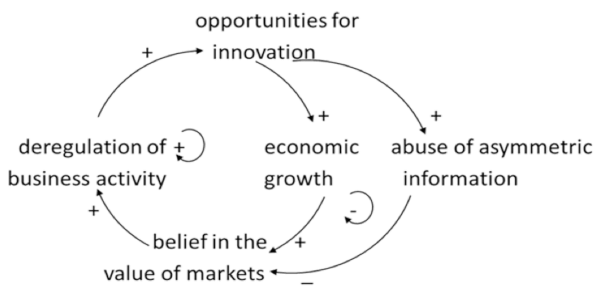

Figure 3: The influence cycle causes swings between pro-market and pro-government positions.

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[2] "Economics students need to be taught more than neoclassical theory," by Zach Ward-Perkins and Joe Earle in The Guardian, 28 October 2013. Available at: http://www.theguardian.com/commentisfree/2013/oct/28/economics-students-neoclassical-theory

26. Figure 4 shows what George Soros (1987) calls a "shoelace model." It depicts the interaction between ideas and society (Umpleby 1989). On the left side are listed Adam Smith, Karl Marx, John Maynard Keynes, and Milton Friedman. In each case, when the ideas are accepted and acted upon, society changes – the growth of industry, the rise of labor unions, and larger government. New ideas lead to new social structures, and new social problems lead to new ideas. There is a co-evolution of theories and social systems.

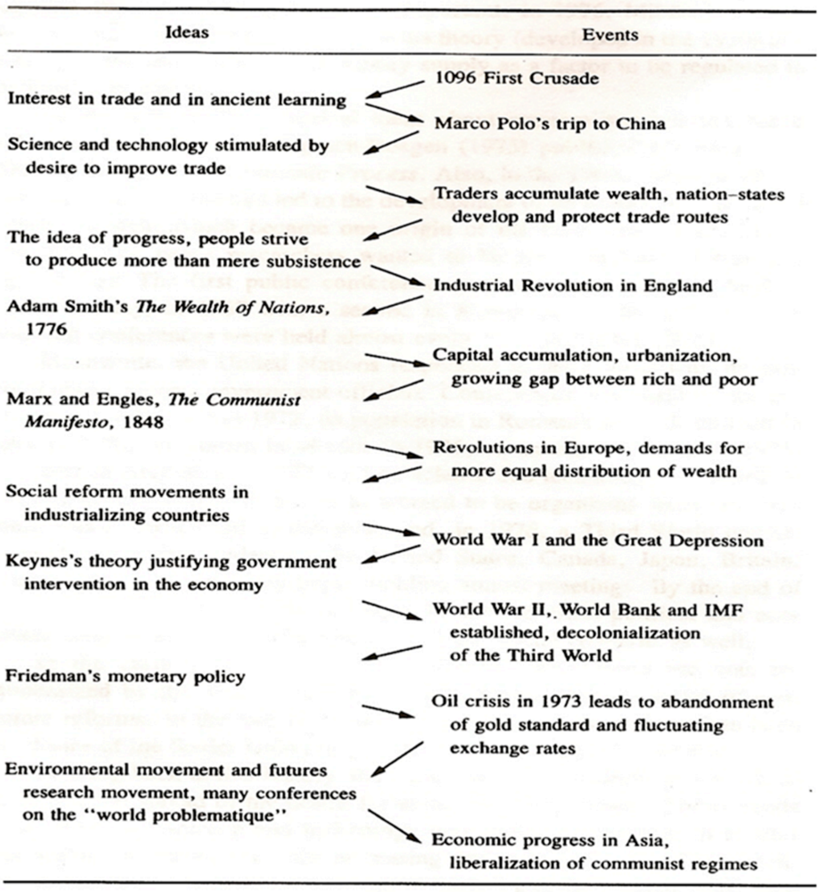

Figure 4: Interaction between ideas and society.

Four basic elements for describing systems

27. Another way of thinking about second-order science is to look at the basic elements of systems. If one studies systems in several fields, eventually one realizes that the various disciplines describe systems differently. That is, the basic elements are different. The most popular elements, the most admired basic elements of a system are *variables*, like in economics or in physics – entities that can be measured and quantified. But not all fields can easily find measurable variables. In psychology or anthropology, the *ideas* in people's minds are important. In sociology and political science, *groups* and coalitions are important. Historians and legal scholars emphasize *events* such as inventions or new legislation or court decisions. We can arrange these basic elements in a circle – ideas, groups, events, variables, cf. Figure 5 (Umpleby 1997; Medvedeva & Umpleby 2004). We then have a theory of social change. This depiction is a special case of Müller's (1998) epigenetic research program (Figure 6). An epigenetic view of life and society places science within the system observed, not outside. The genotype can be a pattern, a theory, a blueprint or a gene. The phenotype is an organism, an organization or a species. Müller proposed a general theory of

evolution that encompasses both biological and social systems. An organism with new features either survives or it does not. If so, then there is a new pattern, usually a small change from the old pattern. In the case of social systems, one can identify ideas, groups, events, and variables. When social scientists study social systems, they analyze what is happening (variables) and propose a new course of action (ideas). If the idea is adopted (groups), a new product may be invented or a bill may be passed in the legislature (event). Then the consequences are studied and a new idea is proposed. This is a multidisciplinary approach to understanding change in social systems. It provides a richer, more comprehensive description of a social system than any single discipline because it uses the modes of thinking in several disciplines.

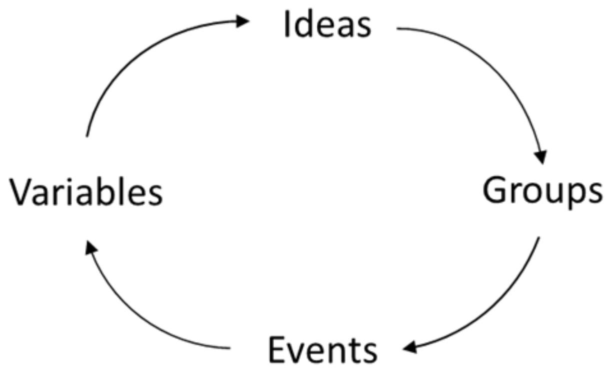

Figure 5: Social change can be described using ideas, groups, events, and variables.

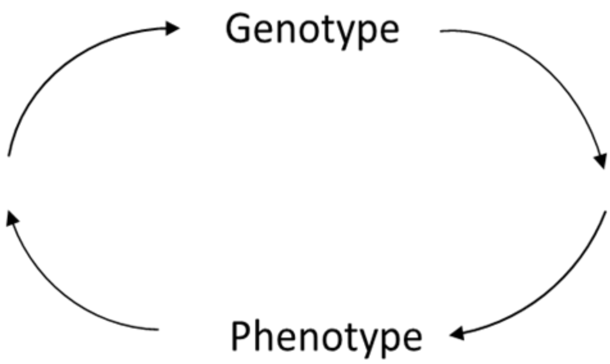

Figure 6: Müller's epigenetic theory provides a general theory of evolution.

Why adopt second-order science?

28. Second-order science requires thinking outside one's primary discipline. By adopting second-order science we would cease thinking that we can study social systems the same way that we study physical systems. If we thought about things differently, we would no doubt invent new theories and methods. We would have a larger conception of science, and we would be able to explain and influence processes we would not be able to explain otherwise.

29. Are there any reasons for not adopting the idea of second-order science? Most obviously scientists would have to alter the claim of objectivity, if they say that the observer is important. And that might reduce the authority of science in the minds of some people. But second-order science would increase self-awareness and require responsibility. There are also some logical difficulties, such as self-reference. Self-

reference can lead to paradox and logical inconsistency. This issue was addressed by von Foerster:

> "[…]'self-reference' in scientific discourse was always thought to be illegitimate, for it was generally believed that The Scientific Method rests on 'objective' statements that are supposedly observer-independent, as if it were impossible to cope scientifically with self-reference, self-description, and self-explanation – that is, closed logical systems that include the referee in the reference, the observer in the description, and the axioms in the explanation.
>
> "This belief is unfounded, as has been shown by John von Neumann [1951, 1966] Gotthard Gunther [1967], Lars Löfgren [1962, 1968], and many others who addressed themselves to the question as to the degree of complexity a descriptive system must have in order to function like the objects described, and who answered this question successfully." (Foerster 1971: 239)

30. In fact, we cope with self-reference quite regularly. We deal with self-reference each time we buy something from someone whom we know is trying to sell it to us. A sales person does not provide an objective description but rather a description intended to persuade you to buy. Also, we try to eliminate conflicts of interest. We know there are problems, so we try to minimize them. In the US the Fifth Amendment to the Constitution prohibits self-incrimination. If self-incrimination is legally prohibited, torture is ineffective, because the state cannot use that testimony as evidence against the accused person. And we let juries decide whom to believe. In practical affairs, we have learned to cope with self-reference. We think of ourselves as actors in a multi-person game where everybody else is thinking about what is happening and is pursuing their own goals.

31. Also, we lose nothing by adding a new dimension to science. The science we practiced before, can still be practiced. Niels Bohr (1920) formulated the Correspondence Principle when he was developing the quantum theory. The idea is that science progresses when we add a new dimension to an existing theory, something that was not considered before or was thought to have no effect, cf. Figure 7 (Krajewski 1977). In second-order science there are two dimensions – the amount of attention paid to the observer and the effect of a theory, once adopted, on the system observed. These dimensions are added to philosophy of science, not just to a theory within a particular field. The Correspondence Principle says that any new theory should reduce to the old theory to which it corresponds for those cases in which the old theory is known to hold. That means that all the data that supported the old theory also support the new theory, but we can now explain things we could not explain before. We do not lose anything by expanding science in accord with the Correspondence Principle.

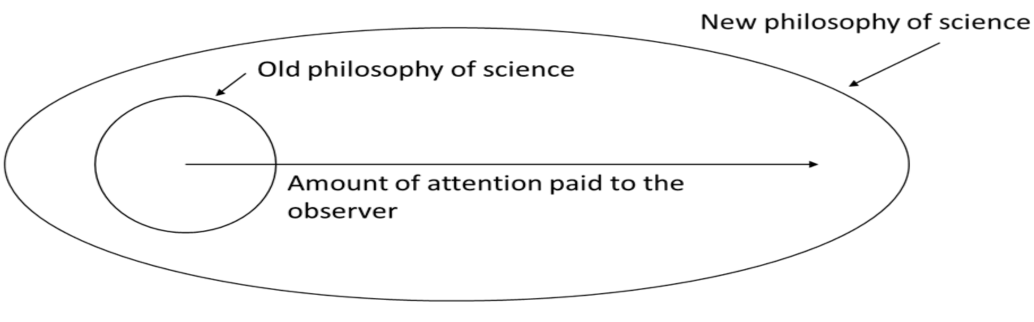

Figure 7: An example of the Correspondence Principle

Logic strategies and methods

32. Second-order science has some basic logical propositions, some strategies to promote its growth and acceptance, and methods that can be used in its practice. Second-order science makes several assumptions which serve as starting points for logical arguments. The starting points are:

1. Include the observer in what is observed.
2. Accept that theories in social systems can sometimes change the phenomenon observed.
3. Organize knowledge as methods, in addition to theories, since methods describe the actions of observers/ participants.
4. Add the dimension of time to resolve problems involving self-reference.

33. For strategies,

1. Study the biology of cognition and incorporate what is learned in our understanding of knowledge and epistemology. In cybernetics, when people studied cognition, they brought together scientists from several fields and tried to develop a new understanding of knowledge (Pias 2003). People in more specialized disciplines have tended to focus on advancing their discipline rather than reconsidering theories of knowledge. A change in epistemology can affect science as a whole.
2. Study high performing research teams and commit to using the results of that research. Universities sometimes do not act on the research that they produce. We know how to create high-performing research teams. A key requirement is that a team be composed of people from more than one discipline (Umpleby, Anbari & Müller 2007).
3. Include in literature reviews not only a description of the earlier work on the subject, but also a description of the consequences of acting on the results of earlier studies. Doing this would help to correct for the absence of instruction in the history of economic thought. An early indication of the impact of a theory can be obtained by counting citations. A second stage of impact is the use of research by professional people (e.g., engineers, therapists, legislators and managers). Long term impact can be assessed by historians of ideas. Examining the consequences of previous ideas, and how their evaluations have changed in time, would likely be helpful to researchers in all fields.
4. Focus more attention on participatory methods. Paying attention to the observer for a single observation suggests paying attention to multiple observers in the case of social systems. Numerous methods to increase participation have been developed in recent decades including process improvement methods in management (Deming 1986), service learning in education (Umpleby & Rakicevik 2008), and group facilitation methods in planning and community development (Cooperrider 2005).

34. Here are some *methods* for doing second-order science:

1. Model cycles or swings in preferred theories. Use causal influence diagrams to study positive and negative feedback processes. See Figure 3.
2. View first-order theories as elements of social control processes (Umpleby 2011).
3. Chart the interaction between ideas and society. See Figure 4.
4. Create multi-disciplinary descriptions using ideas, groups, events and variables. See Figure 5.
5. Create more general theories based on cross-cultural studies (Acemoglu & Robinson 2012).
6. Develop and use group facilitation methods, which have proven to be very effective both at improving the performance of organizations and in education. (Umpleby & Oyler 2007)

Conclusion

35. Human beings change social systems by passing laws and creating theories. As technology improves, human beings are even changing the natural environment, e.g., species extinction and climate change. We are learning to think about ourselves as participants in the systems we study. But to do that we need to change our conception of science. Robert Boyle's invisible college in the 1600s, which later became the Royal Society, was one sign of a transition from theological knowledge to scientific knowledge. Currently the development of cybernetics, including the various theories of reflexivity, combined with climate change, may be signs of a transition from an earlier descriptive conception of science to a more participatory conception of science.

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