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Analysis

Varieties of experimentalism

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ABSTRACT

Across a range of disciplines and issues, experimentalism has emerged as a prominent approach for addressing environmental problems. Yet the meaning of "experiment" varies markedly across these domains. We survey the diversity of experimentation, identifying three distinct experimental logics—controlled, Darwinian, and generative. Building on Pragmatist philosophy, we argue that each of these logics has different strengths and weaknesses, but taken together they offer a valuable experimentalist approach to environmental problem-solving. However, from a transdisciplinary perspective, it is important to recognize the different values, purposes, and stances toward knowledge that they entail. Controlled experiments primarily aim to isolate causality, while Darwinian experimentation endeavors to enhance systemic innovation and generative experimentation seeks to generate new solution concepts. Appreciating these differences allows us to be more reflexive about an experimentalist agenda, illuminating the appropriate role of these logics and suggesting possibilities for fruitfully combining them. To advance this reflexive agenda, we also distinguish between epistemic and political learning and argue that experimental approaches to environmental problem-solving may benefit from being more sensitive to this distinction.

A quiet revolution is afoot in efforts to address environmental challenges and promote sustainability. Over the last decade or so, economists, policymakers and communities have expanded their use of experimentation to understand human behavior, evaluate policy, and solve environmental problems. This experimentation ranges from experiments designed to value environmental goods or understand common pool resources to climate change pilot projects and experiments in watershed governance. Some of these experiments take place in the laboratory; some in the field. Some are designed by ecological economists; others are developed by cities or regions to address local environmental challenges. Diversity characterizes this experimental revolution. It is inspired by the experimental movement in economics, by demands for evidence-based policy and by the need to find creative solutions to intractable environmental problems.

We observe six broad uses of experimentation in environmental problem-solving (not including the extensive use of experimentation in ecological and evolutionary science):

1) To adaptively manage ecosystems in the face of socio-ecological uncertainty and change (Lee, 1999; Walters and Holling, 1990);
2) To encourage socio-technical and design innovations that support transitions to sustainability (van den Bosch, 2010; Gross, 2010; Rotmans and Loorbach, 2008; Hoogma et al., 2002);
3) To conduct basic research on economic and environmental behavior and to value environmental goods (Noussair and van Soest, 2014; Osbaldiston and Schott, 2011; Hoyos, 2010; Gowdy, 2007; Gintis, 2000; Hanley et al., 1998);
4) To design and evaluate different institutional and governance arrangements for managing environmental resources (Rommel, 2014; Bulkeley and Castán Broto, 2013; Bos and Brown, 2012; Greenstone and Gayer, 2009; Ostrom, 2006);
5) To encourage social and political learning and to mobilize support for sustainability (Ceschin, 2014; Brown and Vergragt, 2008; Brown et al., 2003; Irvine and Kaplan, 2001) and
6) To harness learning processes as an institutional strategy for democratic governance (De Burca et al., 2014; Overdevest and Zeitlin, 2014; Overdevest et al., 2010).

This wide range of uses of experimentation suggests that it is an important strategy for environmental problem-solving. Yet even a quick scan of these literatures reveals that they do not necessarily mean the same thing when they use the term "experiment." Clearly, experiment and experimentation are protean concepts (Karvonen and van Heur, 2014). An interrogation of the different meanings of experiment can help to advance and delimit the potential of experimentalism as an overarching strategy.

For a number of disciplines, including economics and ecology, "experiment" typically means a randomized controlled trial. From this perspective, an experiment is a "trial" (an intervention) where conditions are controlled in order to isolate its effect. This meaning of experiment

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is drawn from the laboratory and is focused on deductive knowledge production. For other fields, such as planning and architecture, and for many practitioners and policymakers, the term "experiment" is more associated with innovation and design. From this perspective, an experiment is a novel attempt to solve a problem. These two conceptions are not necessarily antithetical—it is quite possible to use controlled experimentation to evaluate novel solutions. Yet the logics of control and solution generation are not necessarily convergent and may have different imperatives.

Why should ecological economics care about this broader range of meanings? Drawing on the problem-oriented philosophy of environmental pragmatism (Karkkainen, 2003; Norton, 2005; Overdevest et al., 2010) and a mission driven, transdisciplinary, and pluralist view of ecological economics (Norgaard, 1989, 2004; Funtowicz and Ravetz, 1994; Martinez-Alier et al., 1998; Max-Neef, 2005), we argue that ecological economics needs an array of experimental strategies to tackle environmental problems. Our position is inspired by the rising attention across a range of disciplines to the value of experimentation for addressing some of our most intractable environmental problems, such as climate change, sustainability, water governance, and energy transitions.[1]

While inspired by this agenda, our goal is to foster greater reflexivity about the varied conceptions of experiment that it entails (Popa et al., 2015). In the remainder of the text, we refer to "experimentalism" when speaking about experimentation as a distinctive strategy and to refer to Pragmatism's appreciation of the experimental method in general. "Experimentation" is used in more neutral terms to refer to experiments in their various forms.

To think of experimentalism as a generic *strategy* for environmental problem-solving requires attention to the values, purposes and knowledge criteria entailed by different conceptions of experimentation (Böschen, 2013). Such attention can foster awareness of the appropriate uses and limits of experimentation and help to identify where different conceptions of experimentation can be used together in a complementary or hybrid fashion to produce collective learning (Norgaard, 2004). And it can make it clearer where different values, purposes and attitudes toward knowledge are only weakly commensurable (Martinez-Alier et al., 1998) and where issues of scientific adequacy must be addressed in conjunction with value judgements (Farrell, 2011).

Building on the philosophy of Pragmatism, we distinguish three basic logics of experimentation: controlled, Darwinian and generative. We offer a comprehensive comparison of the three logics and conclude by outlining how the different types of experimentation can promote learning processes, both in an epistemic and political sense.

1. Pragmatism and Experimentalism

To think of experimentalism as a strategic approach to problem-solving, it is useful to situate it in a conceptual framework that views different experimental types as alternative or combinable tactics useful for different purposes. We find this conceptual framework in the philosophy of Pragmatism. A number of scholars have made the wider case for Pragmatism as a philosophical framework for adaptive, reflexive and problem-oriented environmental governance (Light and Katz, 1996; Karkkainen, 2003; Norton, 2005; Bromley, 2008; Overdevest et al., 2010; Popa et al., 2015). Our goal is not to reproduce their arguments, but rather to articulate the Pragmatist rationale for embracing multiple experimental logics for strategic problem-solving.

Experimentation is a central motif for Pragmatist philosophy, particularly in the work of Charles Peirce and John Dewey. Inspired by Darwinism, this motif represents Pragmatism's naturalism of logic and ethics and its belief, as Norton writes, that "[e]very belief must be tried, over and over, by the jury of experience" (2005, 79). Yet we find no unified conception of experimentation in Pragmatism. Peirce largely focused on experimentation as a scientific method, arguing that the experimental "method of science" allows and encourages the constant examination and revision of the status quo (Peirce, 1992, p. 109). One of the leading logicians of his time, Peirce was one of the early contributors to the development of the concept of randomization in experiments (Manzi, 2012).

Dewey sought to expand the scope of application of experimentation beyond the scientific domain. Recognizing that experimentation had led to a "gigantic forward movement in science," (Dewey, 1911, p. 554), Dewey hoped experimentalism could also become central to democracy and ethics. Building on Dewey's understanding of experimentalism, Donald Schön offered a useful and succinct definition of experiment: "In the most generic sense, to experiment is to act in order to see what action leads to. The most fundamental experimental question is, 'What if?'" (1983, 145).[2] The philosophical grounding for this experimentalism is a deep appreciation of uncertainty as an inescapable human condition (Bromley, 2008).

Experimentation is a key strategy for dealing constructively with uncertainty (Sanderson, 2009) and is closely linked to the Pragmatist emphasis on inquiry and creativity.[3] Peirce declared the simple adage "Do not block the way of inquiry" to be one of the key rules of philosophy (Peirce, 1998, p. 48). In complementing the two classical accounts of inference–induction and deduction–with his own mode of abduction, he tried to pin down this character of science as inquiry, i.e. as a creative and open-ended endeavor. Creativity, for Pragmatists, is not an endowment of a few geniuses but rather "an anthropological universal in human action" (Joas and Kilpinen, 2009, p. 323). In contrast with rational choice theory, Pragmatism views means and ends as interdependent and as shaped experimentally through action (Whitford, 2002; Bromley, 2008). Experimentalism is therefore a process of iterative adaption to new circumstances and experiences that entails a certain idea of progress and improvement but no teleological endpoint. This perspective leads to an appreciation for historicity and to a conception of growth as a continuous reconstruction of experience (Dewey, 1938; Koopman, 2010, 2011).

Peirce's concept of abduction is valuable for thinking about varieties of experimentation. Although the precise meaning of the term is still debated by Peirce scholars, it is broadly speaking a conjecture (hypothesis) generated from a body of incomplete knowledge. Unlike deduction, it is an "ampliative" inference that generates new ideas. It draws on experience and habit, but unlike induction it "pulls things together into some form of coherence that allows … further investigation" (Mullins, 2002, 199). Hintikka (1998) argues that Peirce's concept of abduction also reflected his strategic sense of how science accumulates knowledge over the long term. For Peirce, abduction economically generates hypotheses worthy of subsequent testing and evaluation (Kapitan, 1992; McKaughan, 2008). Adding abduction alongside deduction and induction, Peirce offers a wider lens for appreciating different types of experimentation.

A final Pragmatist point helps to draw together our strategic conception of experimentalism. Pragmatism understands meaning as indeterminate until "fixed" in relation to a particular situation or purpose. From this perspective, the type of experiment deployed depends on the particular purpose, which in turn often depends on what is problematic and on pre-analytic values and visions (Costanza, 2001). When

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[1] See Irvine and Kaplan (2001); Rotmans and Loorbach (2008); Callon (2009); Bai et al. (2010); Berkhout et al. (2010); Evans (2011); Hoffman (2011); Farrelly and Brown (2011); Bos and Brown (2012); Bulkeley and Castán-Broto (2012); Castán Broto and Bulkeley (2013); McGuirk et al. (2015); and Nastar (2014), among others; for more cautionary views, see Jordan and Huitema (2014) and Van der Heijden (2014).

[2] For Dewey, an experiment "operates to change the customary state of things, and thereby to present challenges to thought, seeming discrepancies, unexpected phenomena, that require explanation" (Dewey, 1911, 554).

[3] Given the problematic connotation and history of social experimentation, ethical concerns must be taken very seriously. From a Pragmatist perspective, however, an experimentalist approach cannot be ruled to be ethical or unethical in general (Weber, 2011). Experiments, however, do raise important ethical issues, but these must be judged on a case-by-case basis (Greenberg and Shroder, 2004, 8; Krohn and Weyer, 1994; Doorn, 2015).

combining Pragmatism's broad understanding of experimentalism with its idea that meaning depends on purpose and situation, the perspective of deploying different types of experiments for different purposes emerges.

In the next section, we describe three "logics" of experimentation. Our discussion identifies the values, purposes and attitudes toward knowledge underlying each of these logics and shows how they broadly parallel the distinction between deductive, inductive, and abductive inference. This discussion is meant to reinforce the methodological pluralism of experimentalism and to open a discussion about how these different logics might be combined to enhance collective learning (Norgaard, 2004).

2. Three Logics of Experimentation

In this section we describe the three different logics of experimentation that are compatible with Schön's definition of an experiment. We label them the controlled, Darwinian and generative logics of experimentation. These logics do not, of course, capture the full range of variation of experimentation, but we would argue that they capture central tendencies in an ideal-typical fashion. While we present these logics as distinctive, we note at the outset that they are often combined in practice, a point we return to following our analysis of each logic. We begin by discussing controlled experimentation, which is by far the best known logic of experimentation.

2.1. Controlled Experimentation

The first logic of experimentation is the one that comes closest to the colloquial understanding of scientific experimentation. *Controlled experimentation* emphasizes the use of experiments "to confirm the truth or rational justification of a hypothesis" (Little, 2004, p. 1181). It is characterized by its search for valid inferences about cause and effect. The main tools for this search are a tightly controlled environment and the isolation of relevant factors. Such factors are conceptualized as variables prior to the experiment, which is carefully designed to isolate the effects of certain factors and to avoid confounding them with the effects of other factors.

The basic idea of controlled experimentation is an old one in science and the concept of using "control" and "treatment" groups extends back to at least the mid-18th century. The concept of randomization was developed later to prevent experimenter bias and to minimize bias from unknown factors. These ideas then came together in the mid-20th century to create the randomized controlled trial, which randomly assigns subjects, by characteristic, to control and treatment groups (Manzi, 2012; Dehue, 2001). Controlled experimentation demands strong separation between the attitudes of the researcher and the conduct of the experiment, since the goals and expectations of the researcher can themselves become a confounding factor. Careful experimental design is therefore required to minimize experimenter bias (Kroes, 2015).

As a result of this controlled intervention, experimental data is considered to be less biased than observational data, i.e. where the available data has solely to be observed and analyzed by the researcher (Cox and Reid, 2000; Gerber and Green, 2008; Greenstone and Gayer, 2009; Manzi, 2012). The chief difference between experimental and observational data is the fact that the experimental setting can be much more controlled than the observational one.

Systematic randomization is possible in experimental situations where treatment and control groups are randomly assigned to estimate the average treatment effect. Under such conditions the findings of controlled experimentation can also claim to be valid for the whole underlying population. By identifying certain cause-effect mechanisms and controlling for other factors, the results are said to be "externally valid" and replicable in additional runs of the experiment. Randomized controlled trials (RCTs) are therefore often regarded to be the "gold standard" of controlled experimentation (Cartwright, 2007, 2011; Ettelt et al., 2015). As Cartwright notes, this claim stems from their deductive character: An RCT is designed so that if the treatment produces a particular outcome, a hypothesis can be *deduced* that is very likely to be true.[4]

Mainstream economics has identified a range of subtypes of controlled experimentation. The best known typology distinguishes controlled experiments along three dimensions (Harrison and List, 2004):

(1) Standard versus non-standard subject pools (the standard subject pool is university undergraduates);
(2) Abstract versus realistic framing (abstract framing describes a set of goods, incentives, etc. in abstract terms; realistic framing uses actual goods or incentives);
(3) Imposed rules versus rules set naturally by the context.

In this framework, a "conventional lab experiment" is one in which there is a standard subject pool, an abstract framing of the experiment, and imposed rules. A "natural field experiment" is one in which the subjects "naturally undertake these tasks and where the subjects do not know they are in an experiment" (Harrison and List, 2004, 1014). Laboratory experiments are able to better control the factors associated with interventions, but may lack the external validity of field experiments (Campbell, 1969).[5] The concepts of "natural experiments" and "quasi-experiments" are also variants of the logic of controlled experimentation.

Ecological economics and environmental science utilize a range of different kinds of experiments (Noussair and van Soest, 2014; Cook et al., 2004). Most of the experiments reported in this journal (*Ecological Economics*), for example, can be grouped into five categories: choice and valuation experiments, willingness-to-pay experiments, common pool resource experiments, simulation experiments, and auction experiments (see Table 1 for a description of each type).[6] As indicated in Fig. 1, the overwhelming majority of these experiments are choice experiments, which clearly follow a logic of controlled experimentation (Hanley et al., 1998, 415).

2.2. Darwinian Experimentation

We label the second logic *Darwinian experimentation* because its principles are often inspired by the processes of variation, differential reproduction and heredity described by Darwin.[7] This evolutionary logic regards variation over time or at the population level as a key mechanism for achieving successful outcomes. These ideas have been influential in evolutionary economics, in studies of technological innovation, and are gaining notice in the field of policy experimentation (Dosi and Nelson, 1994; Nair and Roy, 2009).

Applied to social problem-solving, Darwinian experimentation suggests that the rate of individual experimentation needs to be increased and the number of units experimenting expanded. In general it puts more faith in successful innovation arising probabilistically from a large

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[4] In fact, one could also argue that it is not the aspect of control that makes randomized control trials so powerful but the element of random sampling or the normal distribution assumption of the central limit theorem. We agree with this argument but have found that the term "control" allows the clearest framing of controlled experiments, especially when contrasting them with the other two types of experimentation.

[5] The contrast between laboratory versus field experiments is similar to the contrast in biology and chemistry between in vitro (in test tube) versus in vivo (on live animals) experiments. Laboratory and in vitro experiments achieve great control and are often very efficient. However, results are criticized for being unrepresentative and reductionist. On in vitro and in vivo experimentation, see Lipinski and Hopkins (2004).

[6] We offer these categories not as a definite and exhaustive list but to provide a rough overview of which types of experiments are especially prominent in this journal. For details see Annex 1 (online only).

[7] The variation of certain traits in a given population leads to differences in reproduction (either due to nonrandom environmental influences or sexual selection). Because these traits are inheritable, the composition and character of the population changes over time, leading to the differential reproductive success of certain groups of the population that possess the beneficial traits (Mayr, 2001, chap. 6).

Table 1
Description of main experiment types in *Ecological Economics*.

Experiment type	Main characteristics
Choice and valuation experiments	Used to determine valuation of an environmental good. Subject given choice among some set of outcomes assigned different attributes. Researcher has full knowledge of non-chosen alternatives and can vary attribute levels independently
Willingness-to-accept/-willingness-to-pay experiments	Based on different conditions, participants asked the price at which they are willing to buy or sell a particular good. Experiments used to test for a valuation disparity based on the introduction of intrinsic motives, such as moral concern.
Common pool resource experiments	Experiments to evaluate conditions of cooperation in use of common pool resource among set of participants who make interdependent decisions in a controlled setting with rules that define a payoff structure. Experiments may proceed through several rounds and may be conducted in lab or in field.
Simulation modeling experiments	Interactive game that evaluates outcomes based on player behavior or simulation models run with different scenarios against a baseline model.
Auction experiments	Market situations are simulated and buyers are allowed to buy and sell based on certain pre-established conditions. Used to evaluate different policy designs.

numbers of trials than it does in a more teleological conception of rational design. By contrast with controlled experimentation, Darwinian experimentation is more inductive than deductive, relying on trial-and-error learning. This Darwinian view embraces the power of large numbers, which is also a theme of Pragmatism (Menand, 2001). While controlled experiments make use of the law of large numbers via randomized sampling to eliminate bias and confounding influences, Darwinian experiments use it to increase the frequency of innovation. In other words, controlled experimentation requires sample sizes large enough to guarantee sufficient degrees of freedom to estimate statistical differences between treatment and control groups; the Darwinian logic requires a high degree of freedom in order to generate sufficient variation.

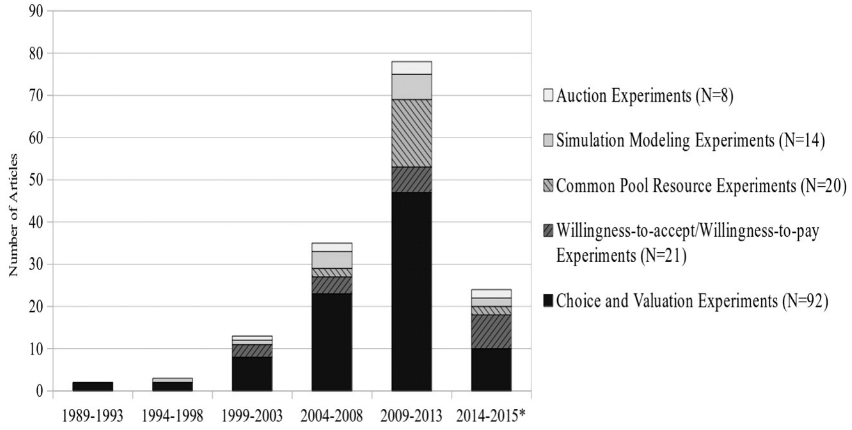
The literature on Strategic Niche Management explicitly adopts this variation-selection-retention framework for promoting sustainability experiments (Raven et al., 2008). It attempts to "… improve the functioning of the variation selection process by increasing the variety of technology options upon which the selection process operates" (Hoogma et al., 2002; loc 4821). Strategic niches can *shield*, *nurture*, and *empower* variations, protecting them from selection pressures, as Verhees et al. (2013) have illustrated for the Dutch photovoltaics sector.

One strategy for encouraging variation is to promote "parallel experimentation," which Ellerman (2004) argues can generate a portfolio of "best practices." Callon describes the proliferation of cap-and-trade experiments in these terms: "This is truly collective, distributed experimentation, deployed in time and space, more or less chaotically or organized, but always explicitly" (2009, 538). Another strategy to increase the number of trials is to rapidly run many experiments in sequence, a strategy called "rapid experimentation" (Thomke, 2003). Simulation modeling is sometimes used in this way. In a discussion of resource management, for example, Jager and Mosler argue that agent-based modeling creates the possibility of "… conduct[ing] thousands of experiments in a very short time …" (2007, 99).

Isolating causal inference, however, is not the chief aim of Darwinian experimentation. Instead, its chief value arises from the idea that successful new traits and adaptation to new environments may arise from many trials. By producing variation through many different trials and by examining which of them are successful (according to certain specified criteria) it is more likely to generate novel ideas and innovations and also quickly sift out trials that do not work. One important tension in evolutionary thought when applied to socio-cultural evolution relates to the issue of whether variation is "blind"—particularly the issue of whether variation and selection are independent processes (Campbell, 1974). The evolutionary economics literature on strategic niches suggests that directed variation (where variation and selection are not independent) plays a larger role in socio-technical evolution than it does in natural evolution (Schot and Geels, 2007). In addition, learning, which is often the source of directed variation, is not implied by Darwinian evolution, but is often assumed to be a key factor in institutional and socio-technical evolution.

Given its faith in the power of large numbers, Darwinian experimentation is unique in its toleration and even embrace of failure. For example, in a discussion of urban sustainability innovation, Ahern et al. (2014) describe the importance of "safe-to-fail" experiments. With respect to innovation in general, Thomke (2003) argues that it is important "to fail early and often."

The literatures on "democratic experimentalism" (Dorf and Sabel, 1998; Sabel and Zeitlin, 2010, 2012) and "laboratory federalism" (Oates, 1999; Polsby, 1984; Kerber and Eckardt, 2007; Saam and Kerber, 2013) both adopt strategies that resemble Darwinian experimentation. The democratic experimentalism literature begins with the idea that many different local units (which could be firms, local governments, state governments, etc.) experiment in parallel to achieve broad



Source: The literature review covered all volumes of Ecological Economics *from February 1989 till April 2015. See appendix for further details.*
** Since standardized 5-year time spans are used the last bar covers only the time span Jan 2014-Apr 2015.*

Fig. 1. Articles on experiments in *Ecological Economics*.

framework goals. These parallel experiments are then monitored and this information is pooled and peer-reviewed. Best practices are identified and then fed back to the units to inform subsequent experiments. Dedeurwaerdere (2009) describes the successful application of these ideas to forest management in Flanders. Similarly, the laboratory federalism literature suggests that one of the values of federalism is that it allows state governments to conduct parallel policy experiments. In the U.S., these ideas have been promoted as a way of encouraging local policy experimentation for climate change (Engel, 2015; Burger, 2009).

A distinctive feature of a Darwinian view of experimentation is that it shifts the focus from individual experiments to systems or ecologies of experimentation. A fascinating discussion of this systemic perspective in the area of environmental governance is Hoffmann's (2011) analysis of the proliferation of climate governance experiments. He argues that this large group of experiments can "evolve" toward either a "division of labor" (where the different experiments provide complementary bits of a global governance system) or a "Tiebout sorting" outcome where citizens or interest groups competitively align themselves with different experiments based on their interests, ideologies and levels of commitment. Another area where we see this systemic perspective applied to sustainability is in the concept of "living labs," which encourage sustainable innovation by creating platforms for experimentation (Nevens et al., 2013; Voytenko et al. (2016).

It is clear that the logics of Darwinian and controlled experimentation differ in at least two regards. First, while controlled experimentation understands experimental data as the result of carefully designed intervention, and therefore different from observational data, the Darwinian approach is experimental despite being observational. The business of Darwinian experimentation is not primarily to organize and plan controlled trials but to create the conditions where variation is possible and to collect, compare and evaluate the different results. Second, it does not require the strict randomization that is crucial for controlled experimentation. While Darwinian experimentation is not necessarily opposed to controlled experimentation, its core logic aims to increase variation rather than control.

2.3. Generative Experimentation

In addition to controlled and Darwinian experimentation, we call a third distinct logic of experimentation *generative experimentation*. It can be thought of as a process of generating and iteratively refining a solution concept (an idea, innovation, design, policy, program, etc.) based on continuous feedback and with the goal of addressing a particular problem. This type of experimentation embodies what Donald Schön called a "move-testing experiment," which takes action to achieve a purpose and evaluates whether that purpose has been achieved (Schön, 1983). It is a logic often associated with design and referred to as a "design experiment." We refer to this logic more generically as "generative" to indicate its focus on generating solutions.

Like controlled experiments, generative experiments concentrate on a single experiment at a time, but discerning causal mechanisms is not their primary goal. The aim of a generative experiment is to stimulate production and analysis of information about an intervention in order "… to help re-specify and re-calibrate it until it works" (Stoker and John, 2009, p. 358). In other words, generative experiments focus on the process of elaborating new and innovative solutions to existing problems. They often adopt a "probe and learn" strategy in which a prototype is introduced and then successively refined based on feedback (Lynn et al., 1996).

Since control is not the *raison d'etre* of generative experiments, they are more likely to be conducted as "real-world" (Gross, 2010; Gross and Krohn, 2005; Gross and Hoffmann-Riem, 2005) or "wild" experiments (Lorimer and Driessen, 2014). Gross and Hoffman-Riem, for example, describe how an ecological restoration project can be understood as a real-world experiment "taking place *in* and *with* human-nature systems…" (2010, 272; authors' emphasis). Similarly, Van den Bosch notes that sustainability transition experiments typically take place in a real-life societal context (2010, 61; see also Kroes, 2015). Relaxed control and in situ experimentation may have both positive and negative implications. A potentially positive implication is a relaxation of the boundary between experimenter and participant, opening new possibilities for collaboration and participant input into the experiment. A potentially negative implication is that participants establish indicators that rig the evaluation of the experiment to advance their own agendas.

Both Darwinian and generative experimentation typically occur in "real world" contexts, but Darwinian experimentation always refers to a population or ecology of experiments, while generative experimentation refers to the iterative refinement of a single experiment. Darwinian experimentation hopes to discover a successful trial from a population of many less successful, or even failed, trials. Hence it regards failure as a necessary condition for success and thus places great value on increasing the number of trials. Generative experimentation does not think in population or ecosystem terms. Instead, it focuses on designing and redesigning a single solution concept with the aim of making it successful. The Darwinian logic is about increasing the *chance* of success through many independent trials, while the generative logic is about *designing* a successful solution through accumulated knowledge and experience. "Rapid prototyping" combines both logics.

A key feature of generative experimentation is that experiments evolve through time as they are iteratively redesigned to adapt to new findings and changing circumstances. Bai, Roberts, and Chen, for instance, describe the evolutionary "pathways" of sustainability experiments in Asia as follows:

> A lesson gained from all the case studies on pathways is that many of the experiments did not evolve as planned. There are dynamics and events which occur during the evolution and development of projects that change design outcomes and modalities for implementation (2010, 322).

Generative experiments therefore exhibit a strong historicity. As Pohl and Hirsch Hadorn (2007) note: "Recursiveness (or iteration) implies foreseeing that project steps may be repeated several times in case of need" (2007, 22). Given this iterative adaptation through time, a generative experiment cannot be understood as a single and discrete "trial."

A good example of how generative experimentation can be used for environmental problem-solving is provided by Bos and Brown (2012), who studied a successful ten-year governance experiment on the Cooks River catchment in Australia. They describe an "emergent process of experimentation" that transitioned through several stages of development (2012, 1343). The first phase identified stormwater management options and priorities in the catchment with several municipalities. The second phase extended this process to eight municipalities. And in the third phase, a formal catchment association was created to carry the projects and collaboration forward. The experiment engaged the concrete problems of the catchment, learned as it iteratively refined its strategy, and built capacity along the way.

Pilot projects often exhibit the logic of generative experimentation. In an analysis of water governance pilot projects in the Netherlands, Vreugdenhil et al. (2010) distinguish pilot projects from laboratory (controlled) experiments on a number of dimensions, noting that the interaction of pilot projects with contextual factors is only controlled to a limited extent. *Explorative pilots*, they write, are used "to test and refine innovations in their context and gain experience" (2010, 11). This type of pilot comes closest to the generative logic.

The Strategic Niche Management literature was described above as embracing a logic of Darwinian experimentation. However, this literature and the related literature on transition management typically describe individual experiments in generative terms. Hoogma et al., for example, characterize niche experiments as "learning-by-doing" or "probe and learn" (2002, loc 4744) and Wildt-Liesveld et al. (2015) describe them as having an "emergent project design" realized through an "iterative, cyclical process" (2015, 156). A closely related literature on "bounded socio-technical experiments" describes sustainable mobility and building experiments as having the following features: "learning by doing, doing by learning, trying out new strategies and new technological solutions, and continuous course correction …" (Brown et al., 2003, 292; Brown and Vergragt, 2008). Ceschin describes socio-technical experiments as "… open to continuous adjustments and refinements" (2014, 3) and Gross and Hoffmann-Riem describe the continuous renegotiation of the design of an ecological restoration experiment (2005, 272).

"Design experiments" are a good example of generative experimentation. They trace their origins to diverse fields, from aeronautics, artificial intelligence, and education (Stoker and John, 2009) to art, architecture, and design research (Bang and Eriksen, 2014; Steffen, 2014; Schon and Wiggins, 1992). Despite nuances in meaning, these fields broadly share a common conception of a design experiment as something that "manipulates an intervention and observes it over an extended time period, usually in one location, until acceptable results emerge. The experiment progresses through a series of design-redesign cycles" (Stoker and John, 2009, p. 356). Design experiments often measure experimental outcomes, but often relax control in favor of contextual success.

Design and design experiments are important strategies for sustainability (Childers et al., 2015; Ceschin, 2014). Urban design experimentation, for example, can be seen in Blok's description of sustainable design projects in Nordhavn, a district of Copenhagen (Blok, 2013). Generative experimentation utilizes abduction in a way that parallels how it is used in design. Recall that abduction is about generating a new hypothesis for a pattern of data. This process is synthetic and draws on prior experience. Building on prior experience, designers work backwards from "function" [problem] to "form" [solution] (Kroll and Koskela, 2015; Krogh et al., 2015), following a "logic of discovery" rather than a "logic of justification." As an abductive process, a generative experiment generates a solution concept that is then evaluated against the functional demands of the problem or against the expectations and demands of stakeholders. Whether this is a pilot project, a new governance institution, or a design concept for an ecologically sustainable landscape or technology, a generative experiment answers Schön's "what if?" with a synthetic new solution concept.

While important lessons may be inferred from whether a generative experiment succeeds or fails, much of the valuable information from a generative experiment is about how the process unfolds through time. A generative experiment may "test" a solution concept, but this test is often more like a "proof of concept" or "prototyping" than hypothesis-testing. While a generative experiment may set out clear criteria at the outset for judging its success, the success of many generative experiments is evaluated in terms of whether they meet the expectations of the involved stakeholders. As Funtowicz and Ravetz (1994) note in their discussion of extended peer review, the "criteria of quality" replaces the criteria of "absolute truth."

3. Comparing and Combining the Three Logics of Experimentation

Table 2 summarizes the three logics of experimentation highlighting how controlled, Darwinian and generative experimentation differ along three dimensions. First, when it comes to the allowance of failure both controlled and Darwinian experimentation accept and encourage the failure of experiments (either through neutrality toward their hypothesis or through the appreciation of wide variation). Generative experimentation on the other hand is designed and continuously re-designed to succeed; it aims to prevent failures through its flexible and adaptive character.

Second, the three logics differ with respect to their analysis of routine processes or novel innovations. Controlled and Darwinian experiments are both useful for analyzing established routines or in evaluating new reform projects. They can help researchers and policy-makers to gain knowledge about longstanding practices (such as the long-term management of common pool resources) but also about the chances of success of new policies, institutions, or technologies (for instance, cap-and-trade designs). With their ambition to improve existing practices, generative experiments are not really intended to be used for evaluation of existing policies and programs. Their strength is in the development and creation of novel solutions for existing problems that can be simultaneously evaluated and incrementally refined.

Third, in a broad sense, the three logics of experimentation parallel the distinction between types of inference: controlled experiments are deductive, Darwinian experiments are inductive, and generative experiments are abductive.[8] Consequently, these three types of experimentation are useful for different purposes. Controlled experimentation exercises strong control in order to isolate causality so as to deductively prove or disprove hypotheses; Darwinian experimentation requires sufficient variation in order to inductively produce innovations or benchmarks; and generative experiments iteratively refine ideas or design concepts in order to abductively generate novel solutions.

Each type of experimentation confronts challenges arising from its own distinctive logic, which often mirror its strengths. The classic challenge of controlled laboratory experimentation is external validity. To achieve control, experimenters often impose artificial and unrepresentative conditions. Field experiments, natural experiments, and quasi-experiments are used to create more representative conditions (Greenstone and Gayer, 2009; Harrison and List, 2004). Darwinian experimentation buffers experiments in protective niches to encourage innovative variation, but this buffering may also make it difficult to scale-up and mainstream innovations. The strategic niche literature has addressed this challenge by focusing more attention on the critical "transitional" features of experiments (van den Bosch, 2010). Generative experiments are context-sensitive and unfold through interaction with real world settings, but their generalizability and transferability are often limited as a result (Vreugdenhil et al., 2010; Bai et al., 2010).

Finally, the three logics differ in how they make use of interventions and observations. For controlled experiments, applying a well-planned and ordered intervention is crucial; experimental data are seen as an improvement over observational data for isolating causal mechanisms. By contrast, Darwinian experimentation in its ideal-typical form is less concerned about the planning of interventions and much more concerned about encouraging variation and observing outcomes ("letting a thousand flowers bloom"). While in some instances Darwinian experimentation is intentionally triggered (bringing it closer to the logic of controlled experimentation), in other cases interventions may not be planned at all, and simply observed post hoc, because society itself is perceived as experimental (Gross and Krohn, 2005). For generative experimentation, interventions certainly require pre-planning, but there is often an expectation that changing conditions and surprises will have to be addressed in an adaptive fashion. Learning arises not only by observing whether outcomes satisfy expectations, but also by observing the process of adaptation itself. Following Böschen (2013), one might say that each logic has a different "evidentiary culture."

We regard these three logics of experimentation as ideal-typical in the Weberian sense (Weber, 1949, 90). In many practical cases, however, experimental strategies that align or combine these logics in different ways can be identified. Callon (2009) has called for greater attention to how laboratory and real (in situ) experiments–work together to produce innovation. A good example of combining logics of experimentation for environmental problem-solving is provided by Felson and Pickett (2005), who describe "designed experiments" that create an alliance between controlled and generative experimentation in urban ecosystem management. They point to the difficulty of achieving experimental controls in urban ecologies and note that landscape designers use "… experimentation primarily as a creative and exploratory tool" (2005, 549). They argue that urban landscape designs create

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[8] We thank Colin Koopman for this suggestion.

Table 2
Comparison of the three logics of experimentation.

	Controlled experimentation	Darwinian experimentation	Generative experimentation
Characteristics	• Search for valid inferences about cause and effect • Setting controlled as much as possible • Findings aim for external validity • Deductive	• Oriented toward variation through many trials • Identifies "best practices" but also expects many failures • Variation more important than control • Inductive	• Iterative refinement of prototype with goal of "success" • Discovery and design of new solutions • "Success" often depends on meeting stakeholder expectations • Abductive
Allowance for failure	• High (researcher should not influence outcome)	• Very high (few variations will be successful)	• Low (researchers strive for success)
Innovations vs. routine	• Both	• Both	• Innovations
Observational vs. interventional	• Intervention at the beginning	• More observational than interventional	• Continuous improvement of intervention
Examples	• Randomized control trials • Natural and quasi-experiments	• Parallel experimentation and benchmarking • Rapid experimentation • Simulation experiments	• Design experiments • Exploratory pilot projects • Problem-driven iterative adaptation

opportunities for controlled ecological experiments, either in ways that contribute to design or where experiments are nested within designs.

In some cases, a certain type of experimentation may be best described as a hybrid of experimental logics. Darwinian experimentation values large numbers of sequential or parallel experiments, but says little about the structure of individual experiments. Hence, it may be compatible with either controlled or generative experimentation. In an article on evolutionary approaches to intentional change, Wilson et al. (2014) describe "Darwinian machines"—created by open-ended "variation-and-selection" mechanisms that produce complex adaptive systems. Ultimately, their strategy advocates combining many small RCT experiments with "variation and selection" best practice generation. The literature on democratic experimentalism was described above as adopting a Darwinian logic promoting parallel experimentation. But like generative experimentation, democratic experimentalism also envisions a continuous iterative process of refinement; means and ends are not fixed but flexibly adjusted in a deliberative and collaborative setting (Dorf and Sabel, 1998; Sabel and Zeitlin, 2010, 2012; Overdevest et al., 2010). Thus, it becomes clear that actual practices of experimentation often combine different ideal-typical logics.

Adaptive management also to some extent combines logics. The basic conception of an experiment in the adaptive management literature is one of controlled field experiments (Lee, 1999). However, the term "adaptive" is used to stress "learning by doing" and the need for iterative experimentation in the face of ecosystem uncertainty and change (Walters and Holling, 1990). This iterative learning by doing is consistent with the logic of generative experimentation. By emphasizing the importance of social learning, the literature on adaptive governance (as opposed to management) goes a step further toward a generative logic (Folke et al., 2005; Dietz et al., 2003). With its emphasis on stakeholders collaboratively learning about governance practices, Karkkainnen notes that adaptive governance regards institutional arrangements as "an experiment to be tested and improved continuously over time." (2003, 954). This discussion of adaptive management and adaptive governance leads us to a more direct consideration of the issue of learning.

4. Epistemic and Political Learning

A key implication of our typology of experimental logics is that these logics have different uses in different contexts. A controlled approach may be valuable to those who want to isolate causal claims, but a Darwinian or generative approach may be more valuable for encouraging systemic innovation or generating new solution concepts. And since environmental problem-solving often has multiple objectives, stakeholders may also want to combine these logics. Appreciating the strengths and limitations of these alternative logics, and the possibilities for combining them, enriches a strategy of experimentalism.

In this section, we return to the idea of promoting a wider agenda for experimentalism as a strategy for environmental problem-solving. This agenda can be unified around a simple but powerful idea: all logics of experimentation imply the intention to learn from some intervention. However, the potential breadth and potency of this agenda can be realized by drawing a distinction between epistemic and political learning. *Epistemic* learning is learning that expands or refines our scientific knowledge of the world—both of the natural world and the social world. By contrast, *political* learning is learning that leads stakeholders to alter their preferences, goals, frames, and commitments (May, 1992; Sabatier, 1988). While political learning is also arguably about knowledge, this knowledge tends to be more self-referential and not primarily about authoritative causal claims. Our goal in drawing this distinction is more instrumental than theoretical. We believe it is important for calling attention to a wider range of purposes for experimentation and for appreciating the different ways that controlled, Darwinian and generative experimentation may be used.

Post-normal science perspectives in ecological economics clearly recognize the political dimensions of knowledge and have explored the possibilities of "extended peer review" to engage wider groups of stakeholders in scientific decision-making (Funtowicz and Ravetz, 1994). It is useful to consider these issues, however, specifically in relation to different types of experimentation. Epistemic and political learning are often in tension in experimental strategies related to environmental problem-solving and any assumption that authoritative knowledge claims will trump political interests by "speaking truth to power" is often tenuous (Haas, 2004). As a number of adaptive governance case studies suggest, experimentation often fails politically (Allen and Gunderson, 2011; Susskind et al., 2012). Furthermore, as the adaptive "co-management" literature has made clear, adaptive experimentation typically takes place in collaborative multi-stakeholder settings (Armitage et al., 2008) that require significant attention to "social learning" (Reed et al., 2010; Blackmore, 2007; Pahl-Wostl et al., 2007).[9] This literature also finds that "shadow networks"—informal networks of cooperation—are important for building support for successful transitions to adaptive governance (Olsson et al., 2006). These points suggest the importance of explicitly attending to political learning.

In a paper on experimentation for urban water sustainability, Bos and Brown (2012) argue that technical experimentation has been used more widely in comparison with governance experimentation. Following Gross and Krohn (2005) in conceiving of society as "self-experimental," we note that stakeholders may engage in governance experiments for

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[9] Our view is that "political learning" is a more encompassing term than "social learning" because it reminds us that stakeholders often have different political preferences and agendas. Learning to work with others is just one dimension (a social dimension) of political learning.

the purpose of epistemic or political learning or both. Epistemic learning is the purpose if the goal is to generate scientifically-validated knowledge claims about a certain governance system. Does this governance arrangement produce significant reductions in pollution? Does it lead to higher fish populations? The goal is political learning if stakeholders seek to understand whether the governance system suits their political agendas or whether it allows groups to work together in new ways. Do these new pollution regulations impose high transaction costs on my firm? Can I pay the mortgage on my boat if transferable fishing quotas are adopted? Political learning may also depend on systematically collected data. But it is often a form of experiential knowledge evaluated according to the satisfaction of the stakeholder. Nair and Howlett (2014) note that policy experiments depend on the interests and attitudes of stakeholders, and not just on technical factors. Strong political support, they argue, is necessary for the successful scaling up of pilots in the water sector.

Our purpose in drawing this distinction between epistemic and political learning is not to erect some sharp distinction between facts and values. We know that these types of learning are often mixed in practice. To the contrary, our goal—a Deweyian and a transdisciplinary agenda – is to understand how "facts" and "values" can productively co-exist in experimental work and to push the conception of experiment beyond its typically narrow association with producing "facts." Our point is that experimentation can be used to facilitate political learning as well as epistemic learning. One of the values of distinguishing the three logics of experimentation is that it helps us to make some of the implications of this argument more transparent.

Where the goal is epistemic learning, politics is often understood as a confounding factor. Neutral experiments can be "hijacked" to advance the political goals of particular constituencies (Popa et al., 2015; Brodkin and Kaufman, 2000; Ettelt et al., 2015). Politics can also introduce biases into the design and execution of experiments. This may be particularly a challenge for controlled experimentation, which is deeply concerned about experimenter bias. Even where experimental design can minimize such biases, the political commitment to experiments is often tenuous. The literature on adaptive management, for example, finds that it is often challenging to forge a priori agreement among the stakeholders with different political agendas and, if agreement is achieved, for stakeholders to follow through on the experiment when the results run counter to their interests (Walters, 2007; Allen and Gunderson, 2011). Gunderson and Light (2006), for example, describe the difficulty of a priori agreement on experimental conditions in the Everglades, where stakeholders prevented an experiment from being conducted in the first place. Susskind et al. (2012) describe the later situation: experiments on the management of the Glen Canyon dam were successfully conducted, but the implications for management of the dam were then ignored. Despite these challenges, a number of scholars have usefully explored the conditions for successfully bringing stakeholders together around adaptive management experiments (Stringer et al., 2006; Jacobson et al., 2009; Arnold et al., 2012).

While politics may present a challenge for epistemic learning, it is useful to envision how experiments may also be used to create opportunities for political learning. Consider the Darwinian logic of democratic experimentalism or laboratory federalism. Both of them counsel granting local units the autonomy to experiment. One rationale for this autonomy is that local units have different political contexts. In a review of climate change policy experiments in U.S. states, Shobe and Burtraw (2012) argue that policy autonomy allows states to craft climate change policies that reflect local tastes and political interests. This contextualization may lead to either weak or strong climate change policies. However, in a context where states are not required to engage in climate change policy innovation, Engel (2015) argues that laboratory federalism has allowed some states to adopt "scale innovations" that address the political risks of climate change policy. Thus, Darwinian experimentation may create opportunities for political learning.

Generative experiments may also create openings for political experimentation. Using such experiments to discover "what works" may be about discovering solution concepts that satisfy competing political interests. From this perspective, the iterative updating associated with generative experiments may reflect the constant negotiation necessary to move toward a solution that satisfies different stakeholders. Gross (2010) provides a good example of this in his analysis of an ecological restoration project in Chicago. This experiment was partially about negotiating what type of restoration satisfied different constituency groups.

An important point to make about political learning in this context is that not all stakeholders need to learn the same thing. There is no presumption that there is some objective truth out there to be learned. Rather, learning is relative to one's own set of perspectives, attitudes, interests and concerns. Stavins (1998) describes the political learning about the U.S.'s tradable permit system for SO_2, part of a "grand policy experiment" in market-based regulation. He describes how some environmental groups—despite initial suspicion—came to a more favorable view of market-based instruments as the result of this experiment. The development of emissions trading in the U.S. had many features of a generative experiment in political learning. Voß (2007) describes the journey of this emissions trading from "gestation and proof-of-concept" in the shadow of the U.S. Clean Air Act, through early "prototyping" in the U.S. Acid Rain Program, followed by a gradual mainstreaming of the concept through a program known as Project 88. During this journey, the idea of emissions trading evolved from a highly contested concept to a relatively institutionalized and widely imitated policy instrument. The point here is not that everyone came to fully embrace emissions trading, but that the political understanding of emissions trading changed through iterative experimentation.

Just as we argued that logics of experimentation might be effectively combined, strategies of epistemic and political learning may also need to be joined. Indeed, some would argue that this is essential. As Gelcich et al. (2010) note in the context of fisheries management, "[m]ost current approaches to governance and management do not adequately link social and ecological processes and have demonstrably failed to halt or reverse environmental decline at a global level" (2010, 16794). They describe a successful transformation of the governance of Chilean fisheries that built on small-scale and demonstration-scale experiments to produce both scientific knowledge about fisheries and a change in the perceptions and preferences of fishers. Greater reflexivity about the logics of experimentation may suggest opportunities for using and combining them in order to reinforce epistemic and political learning.

5. Conclusion

Interest in how experimentation might be used to improve environmental problem-solving has been bubbling up across a range of areas of interest to ecological economists, including resource valuation, water governance, sustainable innovation, climate change, and ecological restoration. This diverse experimentalist agenda encompasses multiple conceptions of experimentation. To discourage talking past one another and to encourage greater reflexivity about the strengths and limitations of different styles of experimentation, this paper reviews the different meanings entailed by the basic concept of experiment. Building on Pragmatist philosophy as a framework for appreciating this diversity, the article identifies three distinct logics of experimentation that differ with respect to their aims. Controlled experimentation aims to discern causal effects and to do so it seeks to carefully control different factors that may influence experimental outcomes. Darwinian experimentation aims to increase systemic innovation and to do so it strives to increase variation. Generative experimentation aims to create solution concepts and to do this it endeavors to iteratively and adaptively refine these concepts. Awareness of these different logics can lead to greater appreciation of the strengths and weaknesses of different experimental problem-solving strategies and may also illuminate opportunities for combining them in a complementary fashion.

Expanding the breadth of an experimentalist agenda for environmental problem-solving implies moving experiments from the laboratory into the real-world. Doing so presents both challenges and opportunities. Politics, for example, is typically understood to be a major constraint on experimentalism. However, drawing inspiration from John Dewey's extension of experimentalism to democracy and to ethics, an expanding experimentalist agenda may also present new opportunities for encouraging political learning. Drawing a distinction between epistemic and political learning is not intended to erect a dualism between facts and values. Rather it is intended to serve as a practical distinction that helps navigate the complex challenges of contemporary environmental governance. Reflexivity about how different logics of experimentation can cultivate both epistemic and political learning may help us better address the major challenges that environmental problem-solving now faces.

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Appendix A. Supplementary data

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