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Fresh Insights into System Dynamics Methodology- Developing an abductive inference perspective

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Abstract:

Issues relating to System Dynamics (SD) method and the validation of SD models are an important preoccupation of SD practitioners. It is argued that these issues are debated within the framework set by *deductive* logic which is appropriate for closed systems, but not for open systems as typically found in management decision making. Using the early Forrester- Ansoff and Slevin debate as a prime example (Forrester, 1968; Ansoff and Slevin, 1968), it is shown that while Ansoff and Slevin argue from the position of deductive logic which assumes certainty and no environmental change, Forrester is arguing from an abductive inference framework in which action results from a best available hypothesis resulting from the development and use of an SD model within a broader learning-decision making framework.

In addition, it is argued that the familiar events-patterns-structure tool used in SD is a structured approach to the abduction process. An implication of these arguments is that debates relating to SD methodology need to shift emphasis from the *validation* of models to debates on *evaluation* of the model development process, the implementation of strategies based on model-based thinking, and the associated outcomes.

Introduction.

The relevance of abductive inference- the process of forming hypotheses- to System Dynamics (SD) methodology has been raised previously by Ryan (1996) and Barton (1999).

This paper provides a further explication of this relevance. Specifically, it provides:

- An introduction to the logic of abductive inference and its relevance to describing the management process.
- A re-interpretation of the methodological debate between Forrester and Ansoff and Slevin (Forrester, 1968; Ansoff and Slevin, 1968)
- An interpretation of the Events- Patterns of Events- Structure framework used in SD as an application of abductive inference.
- Implications for interpreting the role of the SD model within a complete learning structure with an increased emphasis on evaluation.

Abductive Inference.

Abductive inference is a mode of inference which, along with deduction and induction dates back to Aristotle but was largely overlooked by Western philosophers, and generally confused with induction, until the late 19th century. At this time, the founder of American pragmatist philosophy, Charles Sanders Peirce (1839 -1914), started to establish abduction as a cornerstone of his philosophical framework:

"Abduction consists in studying facts and devising a theory to explain them".
(CP 2: 270).

For Peirce, abduction represented a highly creative and perceptual act, not to be confused with induction:

Deduction proves that something must be; Induction shows that something actually is operative; Abduction merely suggests that something may be.
(CP 5.171)

In this sense abduction bears a strong resemblance to the "speculative leap" in Einstein's model for constructing a scientific theory (Figure 1). (Holton, 1998: 28-56).

Einstein described the jump from the observed facts to the set of "Axioms of Fundamental Principle"- the fundamental hypothesis, as a "Speculative leap based on hunch, conjecture, inspiration, and guesswork….We are dealing, after all, with the private process of theory construction or innovation, the phase not open to inspection by others and indeed perhaps little understood by the originator himself. But the leap to the top of the schema symbolizes precisely the precious moment of great energy, the response to the motivation of “wonder” and the “passion of comprehension”.” (Holton, 1998: 31)[1]. It is this type of “speculative leap that sets abduction apart from induction.

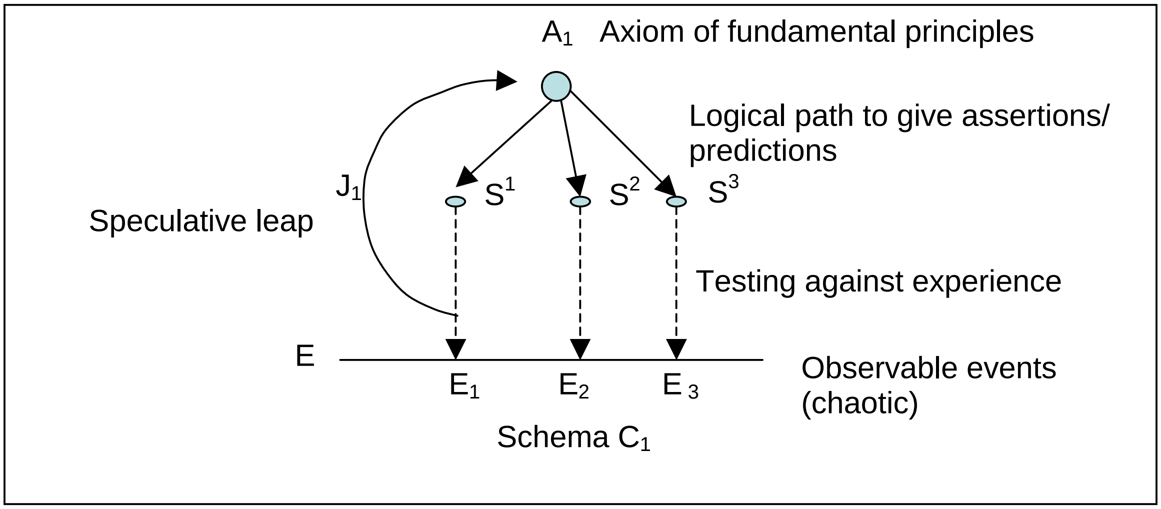

Figure 1. Einstein’s Model for Constructing a Scientific Theory

In addition to Einstein’s theory of relativity, this “speculative jump” is what characterizes the great developments in science such as Euclid’s elements, Galileo’s re-conception of the planetary system, the Newtonian model, and Descartes’ framework of thought.

While not at such a grand level (but some might debate this!), such “speculative leaps” are what characterize the deep insights (Senge, 2006) that help conceptualize the seminal SD models like Forrester’s models of corporate growth, urban dynamics, and world resource dynamics. (Forrester, 1975).

But in a rather unique manner, SD’s events- pattern- structure methodology and the use of simulation modeling to guide the search for a causal explanation for an observed dynamic phenomena represented by reference modes, provides a framework that supports this search process for deep insights. We can identify this process of hypothesis formation as abduction.

While the origins of abduction can be traced to Greek dialectic, it was revived by Peirce (1877, 1878) who used it with deductive and inductive inference to develop a theory of inquiry. Peirce recognized abduction as the most important of the three modes of inference and central in his attempt to develop a complete philosophical architectonic[2].

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[1] Consequently, abduction is associated with the process of synthesis, a foundation stone of systemic thought.

[2] Peirce never completed a final statement of his architectonic but several researchers have attempted to construct one from Peirce’s extensive writings. For example, Hausman (1993) argues that Peirce’s pragmaticist architectonic provides:

- A theory of meaning- the pragmatic maxim.

“There are in science three fundamentally different kinds of reasoning, Deduction (called by Aristotle {synagögé} or {anagögé}), Induction (Aristotle's and Plato's {epagögé}) and Retroduction (Aristotle's {apagögé}, but misunderstood because of corrupt text, and as misunderstood usually translated abduction). Besides these three, Analogy (Aristotle's {paradeigma}) combines the characters of Induction and Retroduction.” (CP 1: 65)

Indeed, Peirce later identified abduction as being at the heart of pragmatism and reflected on his fascination with the (cognitive) process by which we are capable of isolating a relatively small number of plausible hypotheses to account for observable facts.

While in his earlier writings, Peirce seemed to use abduction and retroduction as synonyms, he later articulated abduction as “hypothesis formulation and selection” and retroduction as “hypothesis testing and elimination” (Rescher, 1978: 41). Rescher describes the taxonomy of Peirce’s overall inductive conception of science as shown in Figure 2 and identifies it with Popper’s (later) refutationist model of scientific inquiry.

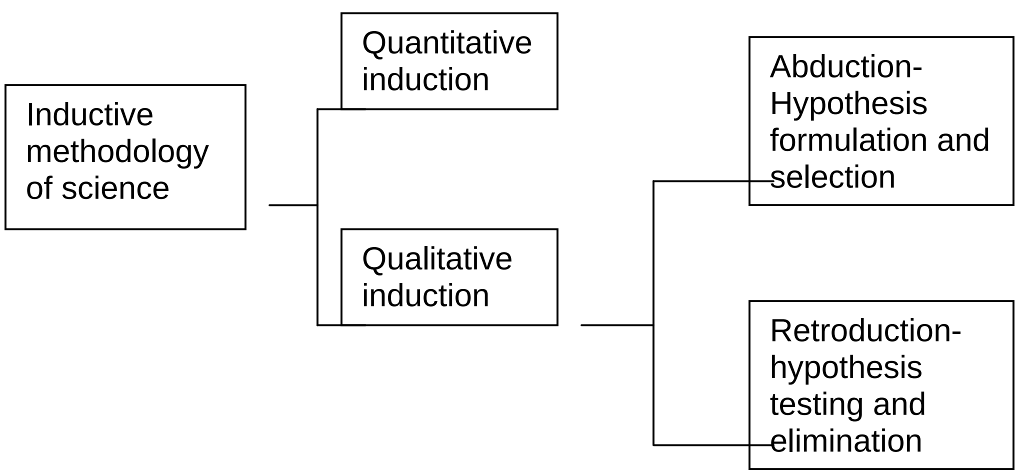

Figure 2: Peirce’s Taxonomy of Inductive Methodologies (Rescher, 1978:41)

Abductive inference is most concisely described along with deductive inference and inductive inference as one of three possible variations to the “modus ponens” argument.

Deductive Inference:

- A method of inquiry acknowledging the role of a “community of inquiry” and applying three rules of inference- abduction, deduction and induction.
- A phenomenology consisting of three categories that provide the basis of semiotics.
- A theory of continuity which Peirce (1892) in Houser and Kloesel (1992: 312-313) called “synechism and tychism” and which Hausman (1993) describes as “evolutionary realism”.

$P \rightarrow Q$
<u>P is true</u>
$\therefore$ Q is true

This is the most familiar form of inference and is accepted as the most rigorous form of argument. For example, if we assume the premise that: “contracting reduces costs”, and we contract, then costs will be subsequently reduced. In practice, such an argument will raise an immediate objection from the observer who will note that this premise is overly simplistic and that, in particular, several enabling conditions are necessary before the hypothesis could be deemed true. That is, P is a conditional (Bayesian) statement. Furthermore, both P and Q are likely to conjunctions of several statements (vectors).

Modus ponens also extends to the most rigorous form for testing hypotheses using proof by contradiction. This form is known as “modus tolens”:

$P \rightarrow Q$
<u>Q is false</u>
$\therefore$ P is false

Inductive Inference:

P is true
<u>Q is true</u>
$\therefore$ $P \rightarrow Q$

In this case, we are asserting a conclusion based on a pattern of data relating to P and Q. For example, if we observe that cost reductions appear to follow contracting, we might conclude that contracting *causes* the cost reduction. In fact, the cost reduction might have more to do with increased productivity of computers, than the advent of contracting. Nevertheless, induction is a vital process for attempting to empirically support hypotheses.

Abduction:

$P \rightarrow Q$
<u>Q is true</u>
$\therefore$ P is true

While this is the least rigorous form of inference, it is the only form that can generate new knowledge.

The following abstracts detail how Peirce uses the three modes of inference to constitute a “logic of inquiry”. It is this logic that forms the basis of Dewey’s experiential learning model (Dewey, 1910) and its extant versions including, for example, Kolb (1984), Shewhart (1939) and Deming (1950), and (Argyris, 1985)

Peirce starts by describing abduction as:

"*the provisional adoption of a hypothesis, because every possible consequence of it is capable of experimental verification, so that the persevering application of the same method may be expected to reveal its disagreement with facts, if it does so disagree. For example, all the operations of chemistry fail to decompose hydrogen, lithium, glucinum, boron, carbon, nitrogen, oxygen, fluorine, sodium, . . . gold, mercury, thallium, lead, bismuth, thorium, and uranium. We provisionally suppose these bodies to be simple; for if not, similar experimentation will detect their compound nature, if it can be detected at all. That I term retroduction."*
(CP1: 68)

But Peirce warns:

"Retroduction does not afford security. The hypothesis must be tested.
This testing, to be logically valid, must honestly start, not as Retroduction starts, with scrutiny of the phenomena, but with examination of the hypothesis, and a muster of all sorts of conditional experiential consequences which would follow from its truth. This constitutes the Second Stage of Inquiry. For its characteristic form of reasoning our language has, for two centuries, been happily provided with the name Deduction". (CP 2: 470)

The purpose of Deduction, that of collecting consequents of the hypothesis, having been sufficiently carried out, the inquiry enters upon its Third Stage, that of ascertaining how far those consequents accord with Experience, and of judging accordingly whether the hypothesis is sensibly correct, or requires some inessential modification, or must be entirely rejected. Its characteristic way of reasoning is Induction. This stage has three parts. For it must begin with Classification, which is an Inductive Non-argumentational kind of Argument, by which general Ideas are attached to objects of Experience; or rather by which the latter are subordinated to the former. Following this will come the testing-argumentations, the Probations; and the whole inquiry will be wound up with the Sentential part of ***the Third Stage, which, by Inductive reasonings, appraises the different Probations singly, then their combinations, then makes self-appraisal of these very appraisals themselves, and passes final judgment on the whole result".*** (CP 6: 472)

The final sentence has been made bold to emphasise the importance of "appraisals" using what we can now identify as practices of single and double-loop learning (Argyris and Schön, (1974). This can be enhanced to include Flood and Romm's (1996) "triple loop" learning which adds consideration of "power relationships", and to include ethical and aesthetical considerations (for example, unintended consequences).

In summary, Figure 3 describes Peirce's model of inquiry as conducted by a "community of inquiry".

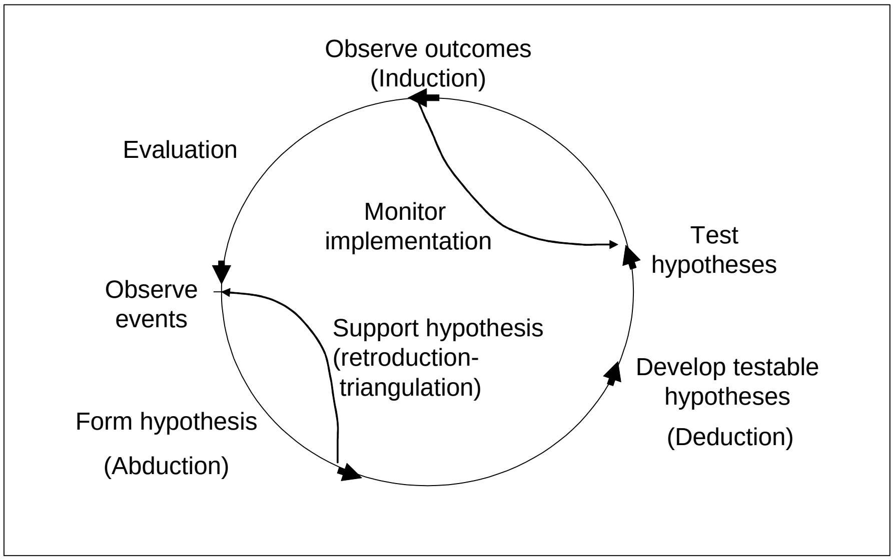

Figure 3. Peirce's System of Inquiry

Management as Abduction:

Forrester's early work identified the shortcomings of management science and operations research as it was being practiced in the 1950s. For example, Forrester (1961) described the search for optimal solutions as "misleading" and "often results in simplifying the problem until it is devoid of practical interest". Management science "must accept the world as it is, not as an idealized abstraction that fails to be meaningful. It must search for improvement, not hold out for the optimum and perfection. It must use the information that is available, all that is pertinent, but, like the manager, it cannot wait for measurement of everything that one might like to know. It must be willing to deal with "intangibles" where these are important. It must speak in the language of the practicing manager".

These sentiments are supported by the decline in rational approaches to problem solving such as those proposed by Kepner and Tregoe (1965). Despite an apparent rationality, these approaches have lost out to the "alternate approaches actually employed by managers on the job" Wagner (2002:45). On a broader front the feasibility and desirability of rationality and certainty has been fundamentally questioned by Toulmin (2001), Searle (2001) and others.

In management, it is becoming increasingly acknowledged that people make decisions on the basis of their "best" hypothesis. Of course, what is meant by "best" is subjective. From studies of decision making under extreme pressure as occurs with emergency services, Klein (1998) concludes that:

"We have found that people draw on a large set of abilities that are sources of power. The conventional sources of power include deductive logical thinking, analysis of probabilities, and statistical methods. Yet the sources of power that are needed in natural

settings are usually not analytical at all- the power of intuition, mental simulation, metaphor, and storytelling. The power of intuition enables us to size up a situation quickly. The power of mental simulation lets us imagine how a course of action might be carried out. The power of metaphor lets us draw on our experience by suggesting parallels between the current situation and something else we have come across. The power of story-telling helps us consolidate our experiences to make them available in the future, either to ourselves or to others. These areas have not been well studied by decision researchers"[3].

This supports the contention that experience with the use of "micro worlds" (Senge, 2006) may prove to be effective management training.

Klein's conclusions also support the importance of better understanding how hypotheses are formed leading to action- the abductive process. Already, there is a growing recognition of the role of abduction in decision making:

- Abduction forms the basis of artificial intelligence methodology (Josephsen and Josephsen, 1996)
- Abduction has been proposed as the philosophical basis to strategic thinking (Powell Thomas, 2001, Powell, 2002, Powell, 2003, Powell, 2006)
- Abduction has been associated with clinical judgment and decision making in medicine (Montgomery, 2006).

In AI work in areas like medicine, hypotheses need to be formed based on the best available evidence and within a prescribed time frame. Appropriate action is then taken on the basis of this hypothesis and outcomes observed. In medicine this corresponds to the adoption of an appropriate treatment regime and seeing whether or not the patient recovers. (Josephsen and Josephsen, 1996). In this context Josephsen and Josephsen define abduction as "..*inference to the best explanation*..a form of inference that goes from the data describing something to a hypothesis that best explains or accounts for the data. Thus abduction is a kind of theory-forming or interpretative inference" and "the basis to diagnostic reasoning".

Josephsen and Josephsen quote Charniak and McDermott (1985) as "characterizing abduction as variously modus ponens turned backward, inferring the cause of something, generation of explanations for what we see` around us, and inference to the best explanation. They write that medical diagnosis, story understanding, vision, and understanding natural language are all abductive processes". Josephsen and Josephsen take abduction to be "a distinctive type of inference that follows this pattern pretty nearly:

> *D* is a collection of data (facts, observations, givens),
> *H* explains *D* (would, if true, explain *D*),
> <u>No other hypothesis can explain *D* as well as *H* does.</u>
> Therefore, *H* is probably true.

[3] The authors are indebted to Dr Geoff McDonnell for introducing them to the work of Klein and to the later reference to Montgomery.

The core idea is that a body of data provides evidence for a hypothesis that satisfactorily explains or accounts for that data (or at least it provides evidence if the hypothesis is better than explanatory alternatives)".

These themes are further articulated in clinical practice by Montgomery (2006).

Powell (2001), Powell (2002), Powell (2003), Powell et al (2006) examine the logical and philosophical foundations of the hypothesis that competitive advantage leads to superior performance. Powell finds that even this widely accepted pillar of strategic thinking has many interpretations and ambiguities. He concludes, however, that "contemporary theories of competitive advantage may find justification in the epistemologies of abductive inference and a pragmatic, instrumentalist theory of truth".

On a lighter side, abduction has also been recognized as the logic of detective work as practiced by Sherlock Holmes (Copi, 1953).

At a more serious level, abduction, if applied inappropriately, can lead to gross error as described by Argyris' "Ladder of Inference" (Ross, 1994). In this case, a (false) assumption is continuously reinforced by what you observe to the extent that you block out other possible explanations. As a consequence you take actions which you believe are soundly based, but are in fact wrong. (Such reasoning can also be used to explain the careless adoption of management "fads" and their subsequent failure).

By demonstrating how different policy decisions can result from using dynamic, compared to static decision-making frameworks, Andersen (1980) emphasizes the importance of declaring the world view that frames the abductive process. Again refer to Figure 1 (above).

To minimize the likelihood of errors arising from narrow perspectives and incorrect interpretations of data, it is important to attempt to validate the hypothesis using as many approaches as possible (triangulation). These may typically include interviews, case studies, cognitive mapping, and, of course simulation modelling. Simon and Sohal (1996) refer to this process as being "generative" research.

While management might aspire to base action on testable hypotheses of the type associated with deductive inference, the reality is that simple inferences of the type $P \rightarrow Q$ do not adequately reflect the complexity of human and social systems and of the fallible behaviour of individuals.

In fact, management is about taking action based on a "best hypothesis", at a point in time, which may reflect great urgency. The manager, having taken action, then intervenes in the resulting outcomes to make any corrections necessary to achieve the desired goals. Indeed, these goals may be unclear at the outset and only gain clarity through on-going experience.

Consequently, it is observed that management relates most strongly to abductive inference, with deduction and induction providing secondary roles- deduction in transforming hypotheses into their logical consequences, and induction as a means of empirical support.

The Validity of SD Models- The Forrester- Ansoff/ Slevin Debate.

Richardson (2006) provides an excellent summary of the meaning of "validation" and validation processes. Significantly, Richardson titles his presentation: "Model Validation as an **Integrated Social Process**" (our emphasis) and cites the definition established by Forrester (1973), and Forrester and Senge (1980):

"Validation is a process of establishing confidence in soundness and usefulness of a model".

It is contended that Richardson's account is in agreement with the application of retroductive inference. However, it is argued that critics of such frameworks are in fact arguing from a position of deductive logic.

Consequently, the debate is at cross purposes. This can be demonstrated by reference to the classic debate in 1968 between Forrester, and Ansoff and Slevin. While Ansoff and Slevin (1968) argue from the perspective of deductive logic, Forrester (1968), although presumably not aware of the abductive framework, argues from an abductive logic point of view. This observation is further strengthened from later contributions, particularly Forrester and Senge (1980).

Following Forrester's publication of the article "*Industrial Dynamics- A major breakthrough for decision makers"* (Forrester, 1958), (and the subsequent publication of the book Industrial Dynamics (Forrester, 1961), Ansoff and Slevin (1968) (A&S) published "*An Appreciation of Industrial Dynamics*". After outlining the method of Industrial Dynamics, A&S conclude that "(T)o this point the approach would raise few objections from a majority of practicing management scientists interested in simulation. They would cheerfully admit to being "industrial dynamicists"". But from that point on, A&S become less supportive noting the following areas of discomfort:

- The use of descriptive data within the context of a completely quantitative model
- The use of the model as a "tool for enterprise engineering" and not as an instrument for forecasting
- An apparent paradox to a models implementation in whereby "(W)hile insisting on reduction of model *content* to fully quantitative terms, he argues that model validation should not meet this requirement".
- The possibility that any two modelers coming to different conclusions in answer to the same strategic problem.
- Problems with "quality assurance" in the construction of models.
- Establishing "dynamic validity" with historical time series, but with no objective measure of what constitutes "good fit".

- An assumed ability for the model to cover all “facets’ of reality and to quantify all related variables and a reliance on the “properties” of the Dynamo compiler.
- A perception that Forrester failed to “ formalize the processes of abstraction of data from managers and to provide tests of validity of the information obtained”.
- The possibility that the “information feedback viewpoint” may be more appropriate for some areas of business (such as production and distribution) and less appropriate to areas like marketing. Consequently, there is a possibility that the problem is adjusted to fit the modeling approach and not the reverse.
- How can an Industrial Dynamics model be judged as being more beneficial than any other quantitative method?

Finally, A&S pose the question of whether or not Industrial Dynamics constitutes a feedback “theory” of the firm.

In a later issue of Management Science, Forrester (1968) addressed each of these points under the headings:

- What is Industrial Dynamics?
- Areas of Usefulness
- Structure
- Feedback Loops
- Quantification in Models
- Sources of Information.
- Validity of Models
- Time and Cost.

At this point only Forrester’s discussion of validity will be considered, although his discussion of the importance of the theory of structure is of particular significance to the more complete learning structure discussed later in this paper.

Forrester argues that controversy over validity “seems to arise from confusion about the nature of proof and about the avenues available for establishing confidence in a model”. He stresses two points: firstly, the importance of linking validity to “purpose”, and secondly, “to realize the impossibility of proof…. There is no absolute proof but only a degree of hope and confidence that a particular measure is pertinent to linking together the model, the real system, and the purpose” (Forrester, 1968: 614). This statement supports his earlier argument (Forrester, 1961: 123) that “Any “objective” model validation procedure rests eventually at some lower level on a judgment or faith that either the procedure or its goals are accessible without objective truth[4]”.

In the terms of logical inference, it becomes increasingly clear that Forrester is presenting an *abductive* argument, that is, forming a hypothesis that constitutes a best “theory”, and acting on it, while A&S are talking from a perspective defined purely within the realm of

[4] This quotation was brought to the authors’ attention in a question from Tim Quinn to the SD Society’s list serve on March 1, 2006

deductive inference. That is, A&S were basing their theory validation process on the logic of modus tolens. Testing validity on the basis of making correct forecasts is a logic appropriate to *closed* systems in which agents are not purposeful. But management is about working in *purposeful open* systems (Ackoff and Emery, 1972). In such systems agents *endogenise* the information provided by forecasts and adjust their behaviors accordingly, either to meet the forecast (for example, meeting sales "forecasts"), or to ensure that the predictions are not met (for example, if you continue to not observe the traffic when crossing the road, I might forecast that you will get run over! So what do you do?).

It is now a matter of history that each of the points raised by A&S has been addressed many times within the SD literature (recent examples include Barlas, 1996; and Homer 1996, 1997). Unfortunately, much of this literature continues to debate the issues within a frame set by deductive logic. Consequently, despite some excellent arguments, they never seem to quite escape the inevitable consequences that deductive logic sets for validation. Reframing the debate using abductive logic changes this.

An Abductive View of SD Method.

SD modelling has traditionally been expressed as a form structuralism, in which an underlying structure is sought that explains a *pattern* of events, which in turn has been brought to our attention as a single event. This description of SD method clearly aligns with one of Peirce's most often quoted descriptions of abductive inference: (CP 5: 181)

"The surprising fact, C, is observed.
But if A were true, C would be a matter of course.
Hence, there is reason to suppose that A is true".

In this instance, C is the pattern of events (the "surprising fact") drawn to our attention from an initial event, A is an expression of a causal hypothesis obtained by developing an SD model representing the structure that best describes a pattern of events (A $\rightarrow$ C) and A is the basis for possible future action.

The SD model constitutes "our best hypothesis" upon which we take action. In this sense, various inputs to the modeling process plus simulation experiments constitute the *triangulation* process for building *confidence* in the hypothesis. None of these processes constitutes a *validation* of the model in the sense of deductive logic and modus tolens.

Consequently, the recognition that SD modeling is part of an abductive process, and that the model represents the hypothesis consequent upon the abductive process, places a new level of support for arguments *against* a refutationist stance in which it is deemed possible to formulate a hypothesis that is capable of being refuted through empirical testing. (See Bell and Bell, 1980).

Furthermore, as Emery and Emery (1997) explain in great detail, abduction is founded in "ecological learning" where "ecological learning and retroduction define the logic of discovery". These are ideas associated with *open* systems thinking, and not as Jackson and Keys (1984) argue, partly on the basis of highly flawed definitions of simple and complex systems, as a technique for "simple-unitary" (closed) systems. That is, situations in which "the problem solver can easily establish objectives in terms of system(s) in which it is assumed a problem resides…(and where)… it is also taken for granted that there is little or no dispute about these". (Flood and Jackson, 1991: 37).

Accepting the argument that SD modeling is an abductive process raises the question of how this relates to the rest of SD methodology. Forrester (1992) provides an insight into what constitutes an effective methodology. In his review of System Dynamics after 35 years:

"The ultimate success of a system dynamics model investigation depends on a clear initial identification of an important purpose and objective. Presumably a system dynamics model will organize, clarify, and unify knowledge. The model should give people a more effective understanding about an important system that has previously exhibited puzzling or controversial behavior. In general, influential system dynamics projects are those that change the way people think about a system. Mere confirmation that current beliefs and policies are correct may be satisfying but hardly necessary, unless there are differences of opinion to be resolved. Changing and unifying viewpoints means that the relevant mental models are being altered. But whose mental models are to be influenced? If a model is to have impact, it must couple to the concerns of a target audience. Successful modeling should start by identifying the target audience for the model".

Although Forrester does not explicitly mention "action", presumably, it is implied that changing mental models will present itself in changed behaviour (or intended behaviour). Elsewhere, Forrester states that the "purpose of SD is to enable managers to take more informed action".

This suggests any System Dynamics methodology must cover the following bases:

- Definition of problem/ purpose (related to 'puzzling or controversial behavior)
- Identification of stakeholders
- Development of model that identifies feedback behavior
- Learning (single loop learning)
- Changing mental models (double-loop learning)
- Taking action

Expressions of SD methodology including Richardson and Pugh (1981), Wolstenholme (1990), Lyneis (1999), and Sterman (2000) illustrate the type of processes currently used to meet Forrester's goals. (See Figures 4 to 6)

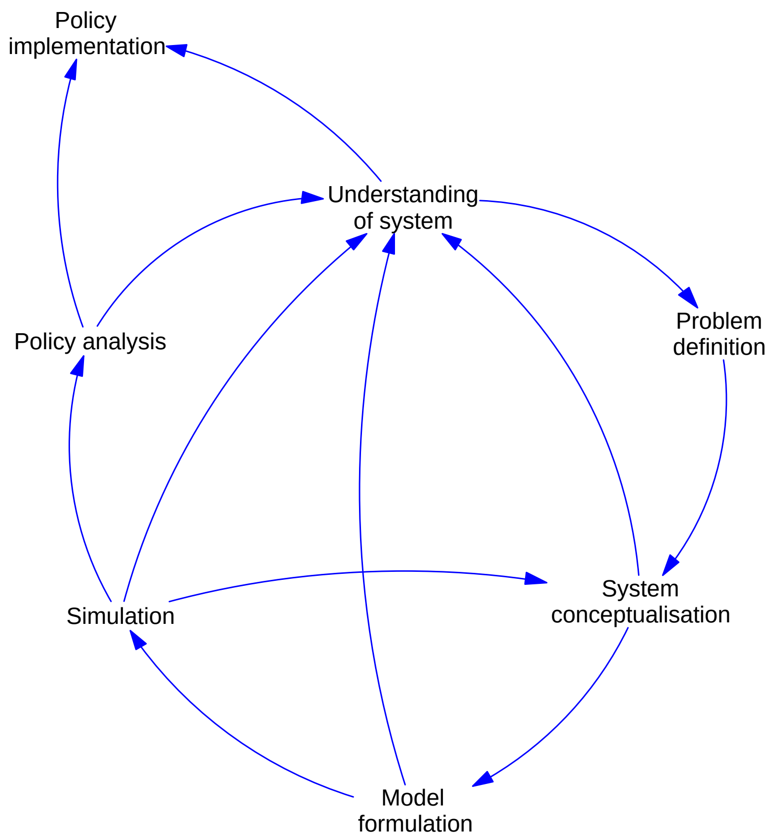

Figure 4: Richardson and Pugh (1981)

Richardson and Pugh's model is stronger in its articulation of the model building and simulation phases with a repeated cycling back to improvements in "understanding the system". But little detail is shown regarding the policy analysis and policy implementation phases except to emphasize that (successful) policy implementation requires both sound policy analysis and a good understanding of the system.

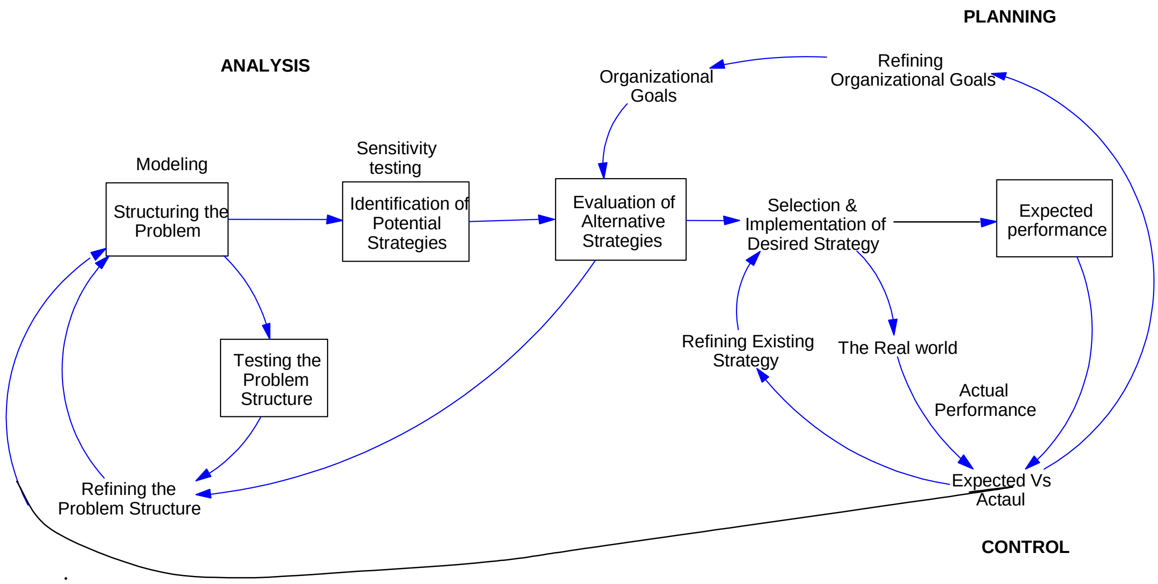

Figure 5: An Iterative View of Strategy (Lyneis, 1999)

Lyneis (1999) defines a four-phased approach:

Phase	Description	Main Objective
1	Business structure analysis	Clearly define problem of interest
2	Development of a small, insight-based model	To understand the dynamics of the business by exploring the relationship between the system structure and behaviour over time & educate client
3	Development of a detailed, calibrated model	The purpose of this phase is to: • Assure that the model contains all of the structure necessary to create the problem behaviour • Accurately price out the cost-benefit of alternate choices • Facilitate strategy development and implementation • Sell the results to those not on the client's project team.
4	On-going strategy management system and organizational learning	Develop an iterative view of strategy, compared to the traditional episodic view (that only involves analysis and planning).

This structure emphasizes the iterative (learning) nature of analysis, planning, and control, where the (reflexive) learning is driven by the gap between actual and desired performance.

Wolstenholme (1990: 4) summarises his methodology under the headings of Qualitative and Quantitative System Dynamics as follows:

Qualitative SD (Diagram construction & analysis phase)	Quantitative SD (Simulation phase)	
	Stage 1	Stage 2

Purpose:
• To create and examine feedback loop structure of systems using resource flows, represented by level and rate variables and information flows, represented by auxiliary variables.
• To provide a qualitative assessment of the relationship between system processes (including delays), information, organizational boundaries and strategy.
• To estimate system behaviour and to postulate strategy design changes to improve behaviour
	Purpose:
	• To examine the quantitative behaviour of all system variables over time.
	• To examine the validity and sensitivity of system behaviour to changes in
	  o Information structure
	  o Strategies
	  o Delays/uncertainties.
		Purpose:
		• To design alternative system structures and control strategies based on:
		  o Intuitive ideas
		  o Control theory analogies
		  o Control theory algorithms.
		In terms of non-optimising robust policy design.
		• To optimize the behaviour of specific system variables.

Table 1. Wolstenholme's (1990: 4) Methodology

Again there is an emphasis on model building and the analysis of system behaviour, but again, very little on implementation.

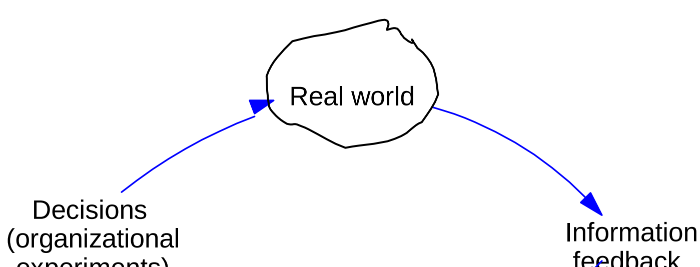

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Figure 6: Sterman's Version of SD Methodology (Sterman, 2000).

Sterman's framework shows the SD modeling activity embedded in a "real world" system. It is arguable that his representation most faithfully captures the way in which the modeling activity influences mental models and hence real word behaviour.

Taking these albeit abbreviated representations of SD methodology (and it is totally unfair to separate them from more detailed descriptions!), it is reasonably easy to correlate the model building steps with Peirce's abductive stage of forming a hypothesis. Similarly, those phases associated with simulation experiments can be identified with deductive logic- outcomes resulting from the logic expressed by model are studied, and Peirce's inductive phase can be correlated with those steps in which policy outcomes are studied.

On face value these expressions of SD method may seem to go far enough. But do they? The critical point in Forrester's statement of desired outcomes is the need to change "mental models" as the primary means of changing system behaviour. Senge's (2006) learning model attempts to address this, particularly by introducing Argyris and Schön's (1974) concept of single and double learning. And to this we really need to add Flood and Romm's (1996) "triple loop" learning to cover the power, ethical and aesthetic issues. As indicated above, the importance of this stage is pre-empted in Peirce's description of the inductive phase:

…by Inductive reasonings, appraises the different Probations singly, then their combinations, then makes self-appraisal of these very appraisals themselves, and passes final judgment on the whole result".

From Peirce's perspective, changing "mental models" changes a person's sense of reality and hence, in accordance with his "pragmatic maxim", that person's possible actions steps, either conscious or unconscious.

But in total, it is argued that this process constitutes the operation of a "community of inquiry" in the sense described by Peirce and advocated in different terms by Forrester. Sterman's (2000: 850) description of the process is most apt:

"Validation is intrinsically social. The goal of modeling, and of scientific endeavour more generally, is to build shared understanding that provides insight into the world and helps solve important problems. Modeling is therefore inevitably a process of communication and persuasion among modelers, clients, and other affected parties. Each party ultimately judges the quality and appropriateness of any model using his or her own criteria".

In other words, an SD model constitutes a synthesis created by an abductive process performed by a "community of inquiry".

A More Complete Description of SD Methodology?

The above discussion leads one to propose a description of the SD methodology that uses Peirce's system of inquiry (Figure 3) to better address Forrester's (1987) requirements:

Phase 1: Establishing the problem: Awareness/ scoping

- Novel event is noticed and a pattern revealed
- Establish importance of determining structural cause of this pattern
- Identify stakeholder interests
- Form a "community of inquiry" and a research team
- Define strategic intent for project expressed as reference modes

Phase 2: Developing a hypothesis (abduction)

- Develop an SD model (s) and associated causal structure
- Use triangulation to build confidence in this "best hunch"
- Use simulations to identify most effective policy setting (Retroduction?)

Phase 3: Define strategies based on causal hypothesis (Deduction)

Phase 4: Implement strategies and monitor performance. Intervene to make corrections as new data/information is revealed

Phase 5. Evaluation (Inductive phase)

- Use triple loop learning to evaluate project
- Form recommendations for future inquiry

Phase 6: Iterate

These phases are further represented in Figure 5.

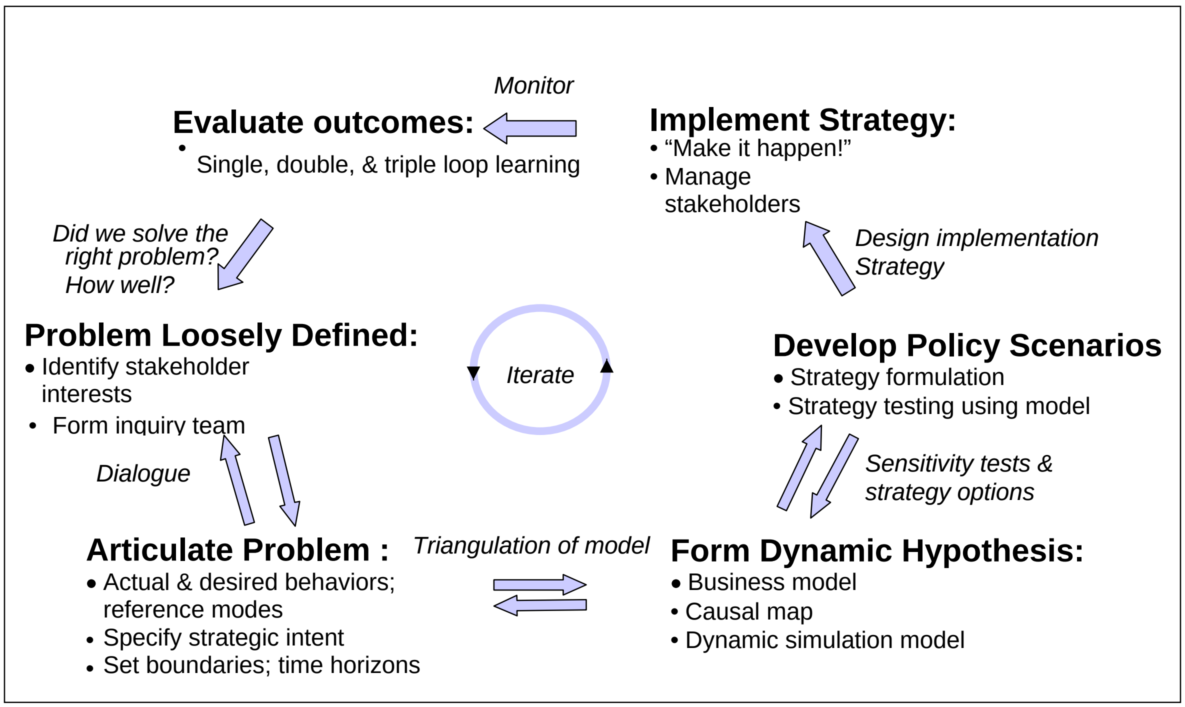

Figure 5: An Enhanced SD Methodology

Conclusion.

It has been argued that interpreting the structural basis to SD modeling as an abductive process sheds new light on SD methodological debates. Furthermore, when integrated into Peirce's system of inquiry, a generic learning structure can be proposed for SD methodology which involves action steps taken on the basis of a "best" causal hypothesis, and a renewed emphasis on evaluation.

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