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THE 2 FEEDBACK LOOP AXIOM: WHY PARTICIPATORY SYSTEMS METHODS FAIL AND ARE INAPPROPRIATE FOR COMPLEX SYSTEM PROBLEMS

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Abstract
It has been widely assumed in systems disciplines and systems professional practices that there are no intrinsic limits on individuals' abilities to mentally understand and address complex systems situations. This paper describes how this assumption is mistaken and the implication for systems research, systems science, theories, methods, and practices.

This paper identifies an explicit, biologically based cognitive bound on individuals' abilities to mentally predict system behaviours and outcomes. It identifies this bound applies when system behaviours are shaped by two or more feedback loops.

The analysis develops through exploring the central and essential role of prediction in addressing system problems, understanding system behaviour, and managing complex systems situations. As part of this exploration, the author draws attention to the existence of a widely held individual subjective delusion that such a bound on predicting systems outcomes does not exist and does not limit the ability of individuals to understand and predict behaviours and outcomes of such systems regardless of the evidence otherwise.

The author suggests the above faulty assumption and concurrent delusion has led to systems professionals and others mistakenly claiming to be able understand and make valid decisions about complex systems when they are physically unable to do so.

The implications of this 2-feedback loop limitation on human mental abilities to understand and managed impact several traditional assumptions of systems theories and practices. Firstly, this limitation on individuals' abilities to mentally understand complex systems, and correctly predict systems behaviours when they derive from 2 or more feedback loops, means it is obviously of no advantage to ask multiple people, who are all incapable of understanding such system and predicting their behaviours if these are shaped by feedback loops beyond the 2-feedback loop boundary.

This, then, obviously defines a boundary on the validity and applicability of participatory and consultative systems methods that ask individuals or groups about their understandings and suggestions for interventions because participants biologically based lack of ability to correctly predict means such methods are invalid beyond the 2-feedback loop boundary.

Secondly, for the above reason, it is suggested the two-feedback loop boundary provides a more appropriate basis for the definition of *complex system* and defines the boundary and difference between complex and merely complicated systems.

Keywords
Biological limitations on human cognition, limits to systems thinking, complex systems, bounds on the validity of participatory and collaborative systems methods.

1 | Introduction

As outlined in the abstract, this paper draws attention to the uncritically presumed and widely held assumption that it is always within human biological cognitive abilities to be able to mentally understand any system and to mentally predict outputs and outcomes for that system. At most, it is taken that some systems may be harder to understand than others, and hence require more effort or skill to so two-feedback; or, that information and rationality is bounded, and hence it is sufficient for humans to do the best they can. This uncritically presumed human mental ability to be intrinsically able to understand and manage any system is foundational to participatory and collaborative Systems Science methods.

Attention to the limitations to the human ability to undertake systems thinking, and even identifying the idea that there may be limitations to systems thinking, has been widely overlooked except for a small cohort of authors. In the early days of System Dynamics, Forrester (1971) broadly identified the existence of human limitations in relation to complex social systems that involve ‘multi-loop non-linear feedback systems’ and argued this is why it was necessary to create computer-based Systems Dynamic modelling because,

‘The human mind is not adapted to interpreting how social systems behave…Evolutionary processes have not given us the mental skill needed to properly interpret the dynamic behavior of the systems of which we have now become a part… The human mind is not adapted to sensing correctly the consequences of a mental model. The mental model may be correct in structure and assumptions but, even so, the human mind — either individually or as a group consensus — is most apt to draw the wrong conclusions. ... This inability of the human mind to use its own mental models is clearly shown when a computer model is constructed to reproduce the assumptions held by a single person. … Then, it usually happens that the system that has been described does not act the way the person anticipated.’.

Later, drawing attention to the lack of attention in Systems Science to the essence of Forrester’s earlier comments, Sweeney and Sterman (2000) reported on the widespread lack of evaluative research on the limits of systems thinking and the widespread assumption that humans can successfully undertake Systems Thinking (if taught well) regardless of limitations and that such human Systems Thinking is always beneficial. Their conclusion, which support this paper, is that system thinking performance *‘deteriorates rapidly (relative to optimal) when even modest levels of dynamic complexity are introduced, and that learning is weak and slow even with repeated trials, unlimited time, and performance incentives’*.

In the latter part of the last century, there were many attempts to model human decision making, such as that of Brehmer (1992). Such decision making was identified as being problematic, but the most that was gained in theory terms from these attempts was that decision making and prediction was made difficult by feedback loops.

Sterman has been amongst the most prolific researchers in this realm since the 1980s, especially in terms of testing human system thinking abilities, e.g. via the beer supply game problem popular with students (Sterman, 1989). Others have followed a similar path to Sterman in identifying that human abilities in understanding systems and predicting outcomes via systems thinking are limited. For example, Doyle, Radzicki, & Trees (2007) state,

“Human failure to control the behavior of such dynamically complex systems in desired ways has been demonstrated by case studies and experiments on human subjects in a wide variety of domains, including urban planning [Forrester 1969; Dörner, 1996], inventory control [Sterman 1989], resource management [Moxnes 1998], medical care 270 J. K. Doyle et al. [Kleinmutz and Thomas 1987], and forest fire control [Brehmer 1989]. In all of these domains experimental subjects have been found to have great difficulty anticipating side effects and predicting the long-term impacts of their decisions, often resulting in severe negative consequences for the human actors in the system. Another common finding in these studies is the inadequacy of subjects’ internal mental representations of the systems they are trying to control, often referred to as “mental models.”

Or from Moxnes (2000), “*My studies ... indicate that misperceptions of feedback are more devastating to human decision making than biases in heuristics dealing with uncertainty.”* Moxnes quotes Tversky and Kahneman (1974 p. 1124) *‘‘People rely on a limited number of heuristic principles which reduce complex tasks to simpler judgmental operations.’’*. As Forrester and others, including the author, have identified, in complex systems the outcomes of these simpler judgmental operations are most often wrong.

Missing, in general, however, from the Systems Science literature to date has been critical review of the implications of the above biologically based human limitations in systems thinking and, specifically, analysis relating to five factors:

- The essential role of the activity of ***prediction*** in all aspects of systems theory and practices
- Identifying and defining ***specific bounds*** of human limitations to understand and predict outcomes.
- Differentiating between actual physical bounds on systems thinking as displayed by evidence, and individuals’ human subjective mistaken beliefs otherwise.
- Issues of *validity* of systems processes in relation to such bounded human limitations (i.e., the validity of the processes as opposed to whether actors are mistaken).
- The implications of lack of ***validity*** for systems methods and theories and Systems Science as a field

It is these five factors that this paper addresses. The paper identifies and defines a specific biological bound at two feedback loops for valid human systems thinking for understanding and predicting the behaviours of systems.

This means that it is simply **invalid** to use systems methods that ask individuals or groups to understand systems and predict their future states (and the related decision-making that depends on such prediction) when the system’s behaviour is shaped by two or more feedback loops. By implication, participatory and collaborative Systems Science methods are invalid for systems whose behaviour is shaped by two or more feedback loops.

To recap, in short, this paper challenges the previous widely held unjustified that there is no intrinsic biological boundary to human cognitive ability to understand systems and predict their behaviours. This paper specifies such a bound defining it as systems with two or more feedback loops and provides practical tests of this claim. Further, the paper identifies a widespread individual subjective delusion by systems practitioners and others that such a bound on their cognitive ability does not exist. It uses the above tests to demonstrate the existence of this subjective cognitive delusion, the existence of which is supported by problematic system management behaviours identified by Dörner (1990) that,

'Humans have a strong tendency to guard their opinion of their own competence in acting. ... it can lead to deformations in the thought process. To maintain a high opinion of one's own competence, people fail to take notice of data that show that their hypotheses are wrong. Or they act 'ballistically' and do not check the effects of their actions so as to maintain the illusion of having solved the corresponding problems by means of their action."

All the above have significant implications for the field of Systems Science as currently practiced and theorised.

The paper then teases out the implications of the above for the validity of participatory and collaborative systems methods and practices. The boundary identified in the paper as the Two-Feedback Loop Limitation Axiom, delimits the validity of participatory and collaborative Systems methods and practices in Systems Science to situations whose behaviour is shaped by less than two feedback loops.

This identification of a boundary for validity of social methods of systems thinking and action is existentially significant for Systems Science because most interesting problems in the world, in health, business, governance, law, policymaking and defence are those whose behaviours are shaped by two or more feedback loops. These kinds of multi-feedback loop situations are the situations this paper identifies are unsuited to participative and collaborative systems methods because such approaches are not valid for those classes of systems. The paper notes that, problematically, in systems thinking traditions, these system with large numbers of feedback loops are primarily the situations in which participative and collaborative methods are most often and most widely used – in part because using such social methods is more economical than undertaking formal systems modelling.

Additionally, the paper draws attention to another similarly significant problem for Systems Science that results from the identification of subjective delusion by systems practitioners and others that they can understand, and predict behaviours of, systems whose behaviour is shaped by two or more feedback loops.

To temporarily jump to a later part of the paper, the test is straightforward it comprises the following, of which the overall process echoes the similar process of testing of Sterman and others:

- Create a real-world example of a systems problem with two or more feedback loops whose behaviour can be mathematically modelled.
- Ask individuals to mentally explore the system.
- Ask whether the participants feel that they have understood the system and are able to predict its behaviours (most say yes)
- Ask them to predict system behaviours given specific conditions and compare that with calculated answer (typically around 100% of participants are wrong).

The outcomes of the above confirm the occurrence of the delusion that humans can understand practical systems problems and predict outcomes regardless of feedback loops.

When the above process is repeated for systems of differing levels of feedback, it is evident there is a clear boundary of human competence between one and two feedback loops. Many humans can mentally understand and predict the behaviour of systems with one feedback loop. Some cannot. The absolute cognitive boundary occurs at two feedback loops.

Finally, the paper draws attention to the obvious benefits of using the two-feedback loop boundary as the definition of ***complex system,*** and as the definition of the boundary between a ***complicated systems*** situation and a ***complex systems*** situation**.**

To recap, the paper first draws attention to the essential role of prediction of outputs in the validity of managing and theorising about systems in Systems Science and other systems realms. It then outlines findings of biological limitations in human abilities to mentally predict system outputs for systems with two or more feedback loops. As a rider, the paper also describes the human mental delusion of being able to mentally predict such outcomes, and how this delusion can be made visible. Having established this human biological limitation to predict system outcomes at the boundary of two feedback loops, the paper then outlines the implications for Systems Science and for defining different classes of systems, i.e., the paper describes the following:

- Why prediction of outcomes is central to the validity of systems methods and theories.

- That humans are biologically unable to predict the outputs of systems with two or more feedback loops.
- That humans have a mental delusion that they can mentally predict the outputs of systems with two or more feedback loops. This is revealed by a simple method.
- The validity of participative and collaborative systems methods is limited to systems with less than 2 feedback loops.
- The two-feedback loop boundary provides a better definition of 'complex systems' than current definitions.

The ideas presented in this paper were first explored by the author in the late 1990s and have been published in part in the phd-design discussion list at JISCMail and in part in papers such as (Love, 2010a, 2010b)

2 | The Essential Role of Prediction in the Validity of Systems Science Methods

One way of epistemologically exploring Systems Science as a discipline and testing for the validity of its concepts, theories, methods, and practices is to ask which specific activities are ***essential*** for systems science to exist and essential for its methods and theories to implications be epistemologically and practically valid.

Following the above approach indicates that the primary function of ANY theory or analytical method intended to help understand or manage a system is to provide a means of *predicting* what outcomes will result from management or control decisions or interventions in the system. Inspection of systems processes, theories and methods reveals the activity of *prediction* is the core essential element for all aspects of Systems Science as a discipline and for the validity and utility of systems thinking, theories, methods, and practices.

This central and essential role of *prediction* in systems science is found not only in the functioning of all systems, it is a core foundations of human thought, feeling, decision making and action associated with systems– including how the human brain and feeling systems function (see, for example, Bar, 2009; Bubić, von Cramon, & Schuboltz, 2010; Hipolito & Kirchhoff, 2019; Maldonato & Dell'Orco, 2012; Yon, Heyes, & Press, 2020). For humans, prediction is the foundation of all human-related activity: internal and external. For example, recent research debunks the traditional idea that thinking consists of sensing and then processing what is sensed. Instead, the recent evidence has required a shift of understanding to the idea that the primary purpose of the brain is prediction and that what we see, hear and think are in fact predictions of the brain based on its current best evidence and modified continuously moment by moment in light of new evidence.

In short, ALL systems depend for their functioning on *prediction* in all the various mechanisms that form the basis of changes to systems elements, and our understanding, theorising, and managing of such changes. The ability of prediction is what makes the difference between a system and a category.

That is, *prediction* is the essential component of all aspects of Systems Science. Current Systems Sciences theories, methods and practices focus almost exclusively on one form of prediction: *prediction of outputs*, i.e., mechanical predictions of changes in behaviour or states of the system or its elements. It does this primarily and exclusively by using *causality* as the basis for prediction. In short, the validity of all theories, methods and practices of systems science depends on the validity, accuracy, and effectiveness of their ability to predict the behaviour of systems and the outcomes consequent on that behaviour.

Immediately, this elevates into view a variety of questions, often overlooked, presumptively or by ignorance, whose answers are essential to understanding the limits of validity of systems theories, methods, and practices. Such questions include:

- What are the limits to individual humans' abilities to predict the behaviour of systems and the consequent outcomes?
- What are the limits of specific individual systems theories in terms of their prediction of the behaviours of systems and the subsequent outcomes for various kinds of systems?
- What are the limits of specific individual systems methods in terms of their prediction of the behaviours of systems and the subsequent outcomes for various kinds of systems?
- What are the processes for prediction of *consequences* of interventions?
- How do the prediction processes of systems methods operate for step changes in systems?
- How do prediction processes of systems theories and methods apply when the system itself and its purposes, structure, ownerships, and management change during the period of the prediction due to feedback loops?

3 | Biological limits to prediction of outputs of systems

It has long been understood there are practical human limitations to being able to mentally predict the outputs and outcomes of situations. As mentioned earlier, Jay Forrester (1971) identified as a problem that even when people knew the structure of a problem, they most commonly chose interventions that had the opposite effect to what was intended.

Historically, it has been vainly assumed that humans have no limits on their abilities to predict the outcomes of problems. The previous limited identification of restriction of human abilities in understanding and managing systems has been outlined earlier. Additionally, is the question of whether those limitations are primarily based on the mathematical characteristics of the problems themselves. For example, whether the situation is chaotic and therefore outputs cannot be mathematically modelled; whether problems are P vs NP (first defined clearly by Cook (1971); whether the definition of the problem or information to model it is incomplete, a subset of which is the class of 'wicked problems' of Rittel and Weber (Rittel, 1972; Rittel & Webber, 1974, 1984; Rittel & Webber, 1972); or simply whether the problem is indeterminable, undecidable or non-deterministic.

Until recently in the Systems Science, the idea that humans have characteristic and obvious biologically-based cognitive limitations has been relatively overlooked apart from reference to Miller's (1956) relatively simplistic memory bound of 5 +-2. This lack of attention to explicit bounds on human systems thinking abilities is, in many ways, surprising because human activities are obviously biologically bounded in many other ways. For example, there are very few humans over 6.5 meters tall, or can run sub-2-hour marathons, or can, unaided, jump more than two meters into the air. Thus far, identification of human cognitive limitations has primarily been focused on the different forms of memory, bias and distortions, errors in decision making; the difference between limits to representational access (we can represent in mathematical terms) and imaginative access or closure (which we cannot imagine the same thing).

One key difference to the work in this area relating to shared cognition is the difference between *imaginative access to knowledge* of information about a topic (which can easily be shared) and *imaginative correct prediction* of behaviour of a system. The former can be shared because the knowledge can be distributed and only requires suitable communication between those holding the knowledge as in any community of practice. The latter, prediction of the behaviour of a complex system with feedback loops, however, requires ALL the information to be held in a single individual's mind. Shared cognition does not apply in this situation. This is a key reason it is of no benefit to consult multiple individuals – none of whom can predict outcomes. Hence, when individual mental prediction of system behaviours is not possible, it is of no benefit to use participative or consultative systems methods: if everyone cannot predict, then there is no advantage in asking multiple people.

4 | The illusion of prediction of system outputs for systems with two or more feedback loops

As raised earlier, assessing individuals' self-perception of their ability to predict system outcomes indicates widespread subjective delusion by individuals of their ability to understand and correctly predict for systems with two or more feedback loops. Many who mentally incorrectly predict outputs of a system with two or more feedback loops claim they feel confident that they have understood how the system worked and that their prediction is correct.

Simple two feedback loop examples include questions about the filling of bath water or production of beer or flow of vehicles. Such tests have been widely used by management researchers such as Sterman. When participants are asked to mentally predict the future outputs of the system and their confidence in their understanding of the system and their prediction(s) it is found many are confident in their understanding and prediction. Whether their mental predictions are correct or not tests whether they are deluded in their confidence about their understanding and prediction.

Experience shows that the above test shows the phenomenon of the two-feedback loop limitation also occurs widely in relation to situations with only one feedback loop. Indicating that the boundary of this human limitation lies somewhere between 1 and 2 feedback loops.

5 | Implications for consulting individuals about management of systems

There are significant implications for Systems Science of the two-feedback loop law described above. To recap,

- The validity of management and theorising about systems crucially and essentially depends on the ability to predict outputs.
- Humans are biologically limited in the mental ability to predict the outputs of systems whose behaviour is shaped by two or more feedback loops.

One implication is that it is of ***no value*** to ask ANY individuals about their opinions or judgements on the management, understanding or proposed changes to systems with two or more feedback loops. Their mental understanding and prediction will be incorrect and yet they are likely to **falsely believe** that they have understood the system and are able to predict outputs and make correct judgements about the best courses of action.

6 | Validity implications for Participative and Collaborative Systems Methods and Theories

An important validity implication of the above is: **Participative and collaborative systems methods and theories are *invalid* for systems of two or more feedback loops.**

This is why participative and collaborative systems methods do not work, and CANNOT work, for systems involving two or more feedback loops.

For consultation of the opinions and judgments of a group of individuals about a system to be *valid* requires that each of the individuals can validly predict the outputs relating to their suggestions for management, change or analysis of a system's behaviour. This is not an additive process.

If every individual in a participative or collaborative systems process is unable to predict the system and subsystem outputs and the consequent changes, then each of their individual comments **is invalid**. This means that **any aggregation** of suggestions from any group of such individuals is **similarly invalid**.

That is, ALL participative and collaborative methods in Systems Science are **invalid** for systems with two or more feedback loops.

7 | The Two Feedback Loop boundary as a basis for Systems classification and a definition of a 'complex' system

The above analyses suggest the Two Feedback Loop boundary is also a useful-specific boundary definition for classifying complex systems.

There are many definitions of complex systems, and most are poor as definitions in the sense that they must absolutely, unambiguously, consistently, and usefully exclude some entities and exclude others. An example is the definition from MIT and INCOSE (Magee & de Weck, 2004),

"Complex System: a system with numerous components and interconnections, interactions or interdependencies that are difficult to describe, understand, predict, manage, design, and/or change."

This definition would apply to many merely complicated systems. A list of such partial definitions is made available by Ladyman, Lambert and Weisner (2013) who argue that none of the current definitions of what is a complex system are necessary and sufficient as definitions.

As an alternative definition of complex system, the Two Feedback Loop Law boundary is significantly better. It offers a clear and useful definition of complex system because it distinguishes those systems for which humans can mentally predict outcomes (simple and merely complicated systems) from those systems that humans are biologically unable to mentally predict outcomes.

The Two Feedback Loop Law boundary distinguishes those classes of systems for which it is useful and valid to ask the opinions and judgements of stakeholders and others, compared to those systems for which such opinions and judgments are invalid.

The Two Feedback Loop Law boundary forms an absolute, unambiguous, consistent, useful specific and 'necessary and sufficient' basis of classification of complex systems. More, it integrates well with the following hierarchical classification of definitions of system types by the author:

- **Simple systems:** small number of entities and relationships and one or no feedback loops
- **Complicated systems:** high number of entities and relationships and one or no feedback loops
- **Complex systems:** systems with high or small number of entities and relationships with two or more feedback loops and whose behaviours can be predicted mathematically.
- **Chaotic systems:** those systems whose behaviours cannot be predicted in any way.
- **Hyper-complex systems:** those systems whose structures, ownerships, purposes, and motivations are dynamic and outside the bounds of the assumptions required for causally based mathematical modelling. (Hyper-complex systems are defined in a forthcoming publication by the author).

8 | Conclusions and summary

This paper has described the 2 Feedback Loop Law of biological limitation of human cognitive and emotional ability to mentally understand and predict the outputs of systems and subsystems. As a rider, it describes the widespread human delusion that individuals are individually able to understand and predict the behaviour of systems with two or more feedback loops. The analyses reveal the lack of validity (or usefulness) of participative and collaborative methods in Systems Science when applied to systems of two or more feedback loops. Obviously, this conclusion applies to many other fields involving decision-making and design. Further, the paper draws attention to why the 2-feedback loop boundary provides a clear and excellent criterion for defining what is a 'complex system'.

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