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Systems thinking in public health: a bibliographic contribution to a meta-narrative review

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Abstract

Background Research across the formal, natural and social sciences has greatly expanded our knowledge about complex systems in recent decades, informing a broadly inclusive, cross-disciplinary conceptual framework referred to as Systems Thinking (ST). Its use in public health is rapidly increasing, although there remains a poor understanding of how these ideas have been imported, adapted and elaborated by public health research networks worldwide.

Method This review employed a mixed methods approach to narrate the development of ST in public health. Tabulated results from a literature search of the Web of Science Core Collection database were used to perform a bibliometric analysis and literature review. Annual publication counts and citation scores were used to analyse trends and identify popular and potential 'landmark' publications. Citation network and co-authorship network diagrams were analysed to identify groups of articles and researchers in various network roles.

Results Our search string related to 763 publications. Filtering excluded 208 publications while citation tracing identified 2 texts. The final 557 publications were analysed, revealing a near-exponential growth in literature over recent years. Half of all articles were published after 2010 with almost a fifth (17.8%) published in 2014. Bibliographic analysis identified five distinct citation and co-authorship groups homophilous by common geography, research focus, inspiration or institutional affiliation.

As a loosely related set of sciences, many public health researchers have developed different aspects of ST based on their underlying perspective. Early studies were inspired by Management-related literature, while later groups adopted a broadly inclusive understanding which incorporated related Systems sciences and approaches.

Conclusion ST is an increasingly popular subject of discussion within public health although its understanding and approaches remain unclear. Briefly tracing the introduction and development of these ideas and author groups in public health literature may provide clarity and opportunities for further learning, research and development.

Keywords: Health systems, health systems research, public health, systems thinking, social sciences

Introduction

The recognition and desire to understand patterns in systems all around us has stimulated a rapidly growing body of knowledge which is increasingly being applied to the field of public health. The study of complex phenomena and systems has evolved across

multiple disciplines and research streams over time to form an overlapping set of sciences with a common philosophical basis (Castellani 2014). At its root lies an alternative viewpoint that seeks to redress a commonly perceived traditional scientific bias towards Reductionism (Mitchell 2009). Instead, emphasis is placed on the

Key Message

- Systems Thinking is an increasingly popular subject of discussion within public health although its understanding and approaches remain unclear. Briefly tracing the introduction and development of these ideas and author groups using network maps of public health literature may provide clarity and opportunities for further learning, research and development.

relationships between the parts that form a physical system in addition to understanding the individual parts and their environment separately (National Cancer Institute 2007).

The exploration of complex systems in modern Western scientific literature is often traced back to the field of Cybernetics, an interdisciplinary science related to the study and control of systems governed by regulatory feedback (Midgley 2003). In particular, the study of biological systems, open to their environment and regulated by homeostatic principles, led to a broadly proposed and widely applied mid-twentieth century 'General Systems Theory' (Von Bertalanffy 1968).

Over subsequent decades, research across the formal, natural and social sciences has greatly expanded our knowledge about systems to include a broad range of related concepts and theories. Abstract mathematical studies have contributed widely to adapted theories of Chaos (Lorenz 1994), Control (Iglesias and Ingalls 2010) and Complexity (Morris 2012), while applied mathematical modelling techniques have spurred the development of Operational Research (OR) and spawned new fields such as Systems Biology (Westerhoff and Palsson 2004).

Further empirical studies of physical and biological systems have revealed notions of 'self-organization' and 'emergence', observed from the molecular (Westerhoff and Palsson 2004) to the social scale (Luhmann 1995). An emphasis on relationships has also advanced our understanding of networks, initially investigated by sociologists and later aided by natural scientists to explore clustered 'small world' and fractal 'scale-free' patterns in complex systems such as the globalized society, the human body and the internet (Freeman 2004).

The knowledge generated from studying complex systems in multiple disciplines has fed into the development of a cross-disciplinary "conceptual framework" referred to as Systems Thinking (ST) (National Cancer Institute 2007). Systems Thinkers often contend that complex systems such as the immune system or the global economy cannot fully be understood by simply analysing their constituents. Rather, they argue the importance of incorporating the study of often non-linear and dynamic relationships between networks of 'agents' and the environment surrounding a conceptual Complex Adaptive System (CAS) (Mitchell 2009). Through the collective self-organization, adaptation and co-evolution of these networks of agents, Systems Thinkers propose that whole-system characteristics distinctly 'emerge' which cannot be understood solely by studying the agents themselves (Gu *et al.* 2009).

An increasing awareness of networks combined with better instrument sensitivity and growing private sector demand has influenced the development of much scholarly and popular literature around these concepts. The appeal of adopting a Systems view and adapting Systems ideas to the applied field of *public* health seems natural given its traditional focus on complex social-scale interventions. However, there remains a poor understanding of the use and development of these abstract ideas in public health academic literature. This review aims to contribute by bibliographically tracing and analysing trends and clusters in the evolution of Systems Thinking

as it has been imported, adapted and elaborated by public health research networks worldwide. Its value lies in its replicable bibliographic method and the identification of subject citation & co-authorship networks.

At the outset, it may prove useful to direct our readers' attention to pre-existing semantic ambiguities within Systems Thinking that have been imported into public health. As in any new research, there has been much dispute about the definition and boundaries of the term Systems Thinking, particularly from experts in the Operational Research community. Initially used by first generation System Dynamics modellers to imply 'System Dynamics Thinking' and later incorporated by a third-generation qualitative OR simulation approach entitled 'Critical Systems Thinking', the term has been recently propagated by numerous scholars outside of OR to imply a broad and inclusive definition of all ideas and approaches relating to complex systems (National Cancer Institute 2007). On the other hand, there are several scholars identified in our study who have historically used terms other than Systems Thinking such as 'Complexity Theory' (Wilson and Holt 2001) or 'CAS Theory' (Malaz 2010) which complicated our attempt to review the literature, although the bibliographic method employed ameliorates this limitation to some extent. The scope of our review did not include OR-related terms, which constitute a well-established tradition of inquiry with significant although nascent contributions to public health literature synthesized in a recent focused review (Carey *et al.* 2015)

Method

Literature search

This review employed an inductive mixed methods approach to narrate the introduction and development of ST in public health, guided by citation and co-authorship network diagrams based on a literature search result from the Reuters Web of Science Core Collection database, a citation index of over 12 000 peer-reviewed journals and 50 000 books across 250 disciplines. A scoping review was initially conducted to identify a number of terms popular and commonly used in ST in order to populate a search string while generic terms such as 'complexity' and 'system' were avoided to increase specificity. Relating the ideas to public health, broadly inclusive terms were used in an attempt to capture the full scope of research being conducted.

As indicated earlier, specific OR terms such as 'Critical Systems Thinking' were not included in the final search string to limit the scope of this review to manageable proportions. While various Systems Sciences such as OR modelling and Network Analysis may have generated higher order System Thinking insights that would inform a full Meta-Narrative Review, we lacked the capacity to conduct full-scale reviews of these established approaches into our study. The final search string was 'systems thinking' OR 'complex adaptive system*' OR 'complexity science*' OR 'complexity theory'

OR 'non-linear dynamic*' AND 'health' OR 'health system' OR 'public health'. The tabulated results were downloaded and used to perform a bibliometric and bibliographic analysis to map the field and its authors, followed by a content review.

Bibliometric and bibliographic analysis

Within the field of Library & Information Science, scholars have developed methods to tease out relationships and clusters of literature by statistical analysis of citation links and co-authorship. The time-based bibliographic mapping of a direct citation network is referred to as 'algorithmic historiography', devised by Garfield and Sher in the 1960s (Garfield *et al.* 2003). A direct citation forms a directional and un-weighted tie from a citing publication to an earlier cited one and the method is used to provide a 'genealogical' graphical representation of a scientific history. This is based on the assumption that "the bibliographic information contained in a collection of published scientific articles is sufficient for the purpose of recapturing the historiographic structure of the field" (Garfield *et al.* 2003). It was also used here to identify potential 'landmark' publications and their bibliographic antecedents and descendants. For the visualization and analysis of these citation networks, the 'CitNetExplorer' programme was used (van Eck and Waltman 2014).

The annual publication counts and citation scores for matched and un-matched versions of the dataset were used to identify popular texts. Annual counts were calculated using Microsoft Excel based on a dataset filtered by the manual application of inclusion and exclusion criteria. Un-matched citation scores include citation links with publications not within the search string results. This helped to identify popular and grey literature indirectly related to the literature search. The matched dataset was then used to generate citation network diagrams that visualized connections between publications over time. Through an iterative process of exploration, a 'visualization of similarities' (VOS) clustering algorithm was used to identify several citation clusters and lead authors to guide the narrative review. The VOS technique is a validated alternative to the commonly used multidimensional-scaling and hierarchical clustering combination method (van Eck and Waltman 2006).

Literature review

The narrative is loosely ordered chronologically to provide historical and relational context. Instead of attempting to catalogue the entire breadth of systems ideas applied to public health, this review focused on highly connected or 'central' nodes within groups and clusters of articles and authors in order to characterize several research fronts that dominate the 'over-arching storyline' in our dataset (Greenhalgh 2008). Their influence was determined by a combination of citation scores, VOS clustering and content review. In addition to network-based identification of relevant literature, a manual search of the tabulated dataset was undertaken using an inclusion and exclusion criteria. The dataset was reviewed iteratively in a sense-making process of gradual knowledge development.

The final inclusion criteria for the content analysis were the following:

- Articles related to public health, utilising the WHO definition of 'all organized measures (whether public or private) to prevent disease, promote health and prolong life among the population as a whole' (WHO 2016).
- All original and review articles related to ST within the public health domain based on title and abstract review. Those regarded as 'unsure' were marked and explored by full text review where possible.

Exclusion criteria were the following:

- any publications not related to public health;
- any publications not related to the study of complex systems or Systems Thinking;
- any publication not in the English language;
- any book reviews;
- conference abstracts;
- publication duplicates.

Results

Results tree

Our search string related to 763 publications searched in the Thomson Reuters WoS Core Collection Database. Filtering resulted in the exclusion of 208 publications: 177 were not related to public health, 18 were not related to ideas about complex systems or Systems Thinking, six were not accessible in the English language, three were book reviews, a further three were conference abstracts and one was duplicated. The remaining 555 publications were analysed alongside citation and co-authorship network diagrams, with a focus on eliciting research groups and citation clusters. Citation tracking was conducted using CitNetExplorer in an iterative process to add two grey publications.

Publication count analysis

Using Microsoft Excel, we created a bar chart displaying annual publication count with a line graph overlaid displaying percentage relative cumulative frequency. The general trend indicates that there has recently been a near-exponential growth ($R^2 = 0.9365$) in the literature around this particular subject, although overall counts remain modest. The first article in the dataset was published in 1994, a management thought piece on the relevance of mathematical Chaos and Complexity theories in 'Total Quality Management'. Growth in the literature between 1994 and 2006 was relatively slow, accounting for only 20% of the filtered dataset. Half of all articles were published after 2010 and almost a fifth (17.8% or 99 articles) published in 2014, the highest recorded annual publication count (Figure 1).

Top 20 cited publications

The dataset was analysed using CitNetExplorer for citation tracking, tracing references-of-references and identifying popular publications among authors in citation lists of the dataset, revealing a citation map composed of 830 'node' articles. We focused on clusters and identified the 20 most cited publications by authors in the dataset (Plsek and Greenhalgh 2001; Plsek and Wilson 2001; Cilliers 1998; Wilson *et al.* 2001; Fraser and Greenhalgh 2001; De Savigny and Adam 2009; Institute of M and Committee on Quality of Health Care in A. 2001; Senge 1990; Capra 1996; McDaniel and Driebe 2001; Leischow and Milstein 2006; Waldrop 1992; Holland 1998; Serman 2006; Miller *et al.* 2001; Kauffman 1995; Anderson *et al.* 2005; Miller *et al.* 1998; Trochim *et al.* 2006; Leischow *et al.* 2008) which also revealed academic and grey literature not identified in the original search results (see Figure 2). Twelve of the top 20 were peer-reviewed academic publications; two were institutional reports and six were popular scientific, management thinking and philosophy books. A content review helped to identify groups of authors and articles which included several of the top 20 most frequently cited. To clarify, a numbered ranking system has been used in parallel to the referencing system in this article, with the '#'

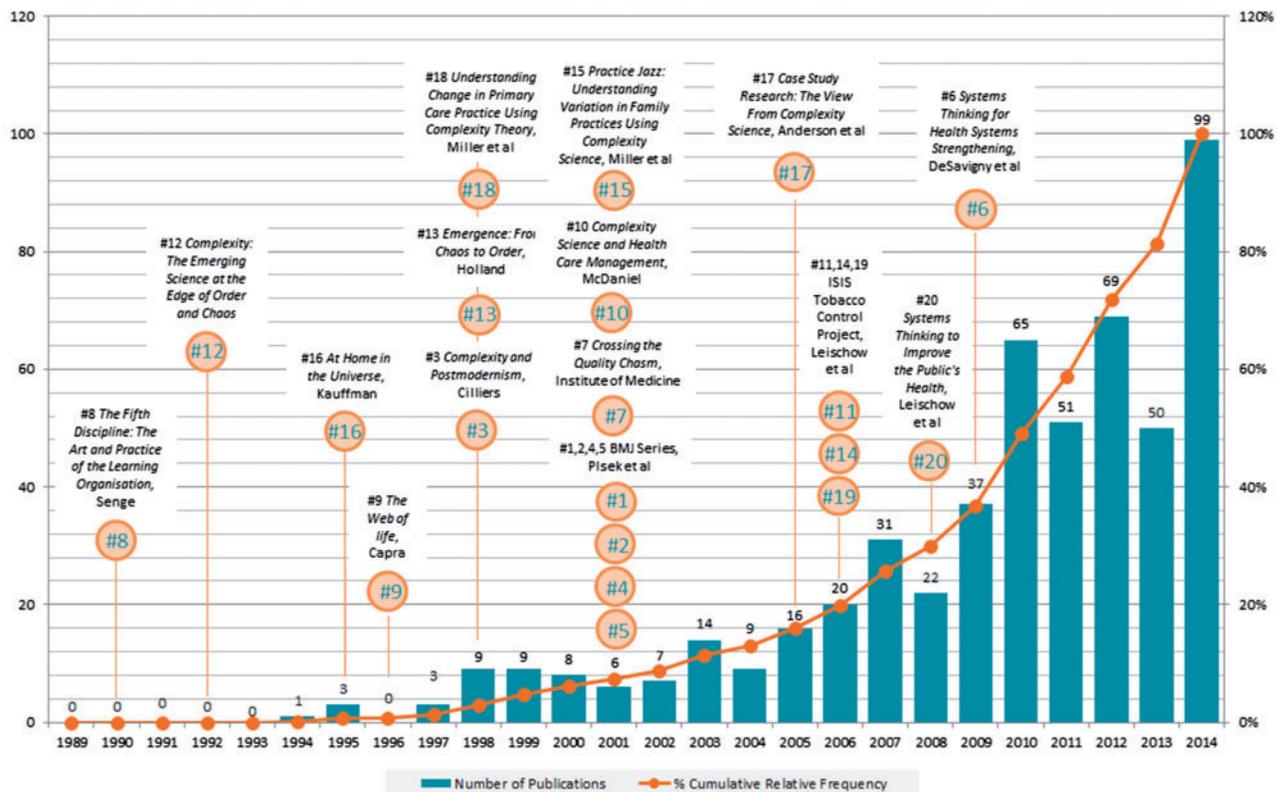


Figure 1. Top 20 citations, annual publication count and % cumulative relative frequency of articles in dataset (1994–2014)



Figure 2. Search results tree

symbol used to refer to citation ranking in the top 20 list, while superscript numbers refer to the bibliography.

The earliest academic Top 20 text (#18) (Miller *et al.* 1998) was published in 1998 and followed up by others in 2001 (#10) (McDaniel and Driebe 2001) and 2005 (#17) (Miller *et al.* 2001) from authors representing a research group studying organizational management and change in the US primary healthcare system inspired by ‘Complexity Theory’ (Miller *et al.* 1998). Similarly, the 4 most frequently cited academic articles in the top 20 were published in 2001 in the BMJ (#1, 2, 4 and 5) (Plsek and Greenhalgh 2001; Plsek and Wilson 2001; Wilson *et al.* 2001; Fraser and Greenhalgh 2001) and constitute a highly cited series introducing leadership, management and education-related ‘Complexity Science’ (Plsek and Greenhalgh 2001) to healthcare professionals. A third set of

publications (#11, 14 and 19) (Leischow and Milstein 2006; Sterman 2006; Trochim *et al.* 2006) in the American Journal of Public Health in 2006 described insights from a transdisciplinary ‘Initiative on the Study and Implementation of Systems’ (ISIS) project, which sought to test a collection of Systems ideas to explore a complex international tobacco-control public health network; this was followed up with another Top 20 article by the authors in 2008 (#20) (Leischow and Milstein 2006).

Of the two institutional reports, the first (#7) (De Savigny and Adam 2009) was published by the US Institute of Medicine in 2001 and promoted innovative change in the healthcare system with a section on CAS written by Plsek, one of the BMJ Series authors. The other report (#6) (De Savigny and Adam 2009) is a 2009 introductory primer on ST published by the WHO’s ‘Alliance for Health Policy and System Research’ (AHP SR), which also promoted ST along the 4 ISIS project approaches.

The remaining six texts (#3, 8, 9, 12, 13 and 16) (Cilliers 1998; Senge 1990; Capra 1996; Waldrop 1992; Holland 1998; Miller *et al.* 2001) identified in the Top 20 were all written in the 1990s by authors affiliated with the Santa Fe institute, a popular interdisciplinary research organization promoting systems research. They conveyed cross-disciplinary ideas about complex systems observed in a number of disciplines through the use of metaphors and analogies. The popularity of the books among our dataset’s authors warrants further exploration but was outside the scope of our review.

Bibliographic narrative review

Our bibliographic analysis identified at least five distinct and prominent citation or co-authorship groups, homophilous by common

authorship, geography, research focus, inspiration or institutional affiliation (Table 1).

US Primary Care (USPC) Group

The earliest research group identified was formed of US-based healthcare management academics. Among them were Miller, Crabtree, McDaniel and Stange, authors of the (#18) publication ‘Understanding Change in Primary Care Practice Using Complexity Theory’(Miller *et al.* 1998). The authors claimed inspiration from a popular bestselling Management Thinking book by Wheatley entitled ‘Leadership and the New Science’(Wheatley 1992) to develop a ‘complexity model of practice organization’(Miller *et al.* 1998) and later worked with Anderson to develop an associated case-study methodology (#17) (Anderson *et al.* 2005). Their intention was to understand ‘resistance to change’, a well-documented but poorly understood phenomenon affecting many family practices in the “turbulent and difficult” era of US Managed Care (Miller *et al.* 1998).

Miller *et al.* applied Wheatley’s leadership framework, itself inspired by mathematical Chaos theory principles, to conceptualize a CAS as a combination of internal models which they visualized with Venn-like diagrams. They further employed analogies of ‘Attractors’, another abstract Systems concept, to signify competing visions or desired end states illustrated as dots in the Venn field. Like many Systems Thinkers, they described CAS characteristics such as non-linearity, nested systems, emergence, self-organization and adaptive co-evolution using rich metaphors of lines and shapes to analyse individual and organization-level behaviour. Subsequent articles introduced terms such as ‘bifurcations’(Prigogine *et al.* 1984) from Chaos Theory and metaphysically explored concepts such as surprise, creativity and learning (McDaniel *et al.* 2003; Crabtree 2003).

The authors’ work represents the earliest identifiable research group in our dataset focusing on CAS-inspired Healthcare Management, adapted during a wave of popular book releases by many Systems scholars at a time of large-scale transformation in the US public health system. Citation tracing and content review revealed descendant publications by their colleagues who build on this highly metaphorical conceptualization to initially adapt case study methods (Anderson *et al.* 2005) and later use simulated Agent-Based Modelling (Leykum *et al.* 2012) to understand clinical environments. Our analysis of this co-authorship network also revealed a weak link between the US Primary Care Group and another more heterogeneous network of authors with some highly central actors (Figure 3).

Forum on systems and complexity in medicine and healthcare

Linked by co-authorship to two US Primary Care Group members, Martin and Sturmberg are identified as highly central actors in a diverse research group homophilous by affiliation with the Journal of Evaluation in Clinical Practice’s multidisciplinary ‘Forum on Systems and Complexity in Medicine and Healthcare’, of which the late ‘Complexity and Postmodernism’ (1998) philosopher Paul Cilliers was series editor (Cilliers 1998). Cilliers was identified in the top 20 (#3), while Sturmberg and Martin were found to be a prolific pair of authors metaphorically exploring complex systems in family practice.

The Forum is a loose, heterogeneous network of researchers, including scholars from the US Primary Care Group and the BMJ Series, with varying research interests relating to primary care and public health. In a 2011 article, of the 56 publications cited by Sturmberg as the Forum’s contribution the pair was found to have

Table 1. Co-authorship groups identified within the research network on Complexity and Systems Thinking in public health. The varying characteristics or co-authorship groups formed several distinct research streams studying complex systems in public health

Group	Lead authors	Geography	Institutional affiliation	Research focus	Basis of understanding	Empirical methods
US Primary Care Group	Miller, McDaniel and Anderson <i>et al.</i>	United States	University of Texas at Austin, University of North Carolina at Chapel Hill	Organisational Change in Primary healthcare	<i>Leadership and the New Science</i> , Wheatley (1992)	Case study
BMJ series	Plsek and Greenhalgh <i>et al.</i>	United Kingdom	University College London	Leadership, Healthcare Management, Learning	Management Thinking	-
Forum on Systems & Complexity in Medicine and Healthcare	Martin and Sturmberg <i>et al.</i>	International	Journal of Evaluation in Clinical Practice	Varied including Primary Care	Philosophy & Management Thinking	Various
Initiative on the Study and Implementation of Systems	Leischow, Best and Sterman <i>et al.</i>	International	National Cancer Institute	Tobacco Control	Inclusive of all Systems Ideas	Systems organising; system dynamics; system networks; systems knowledge
WHO Alliance for Health Policy and Systems Research	DeSavigny and Adam <i>et al.</i>	International	World Health Organisation	LMIC Health Systems	Inclusive of all Systems Ideas	Systems organising; system dynamics; system networks; systems knowledge

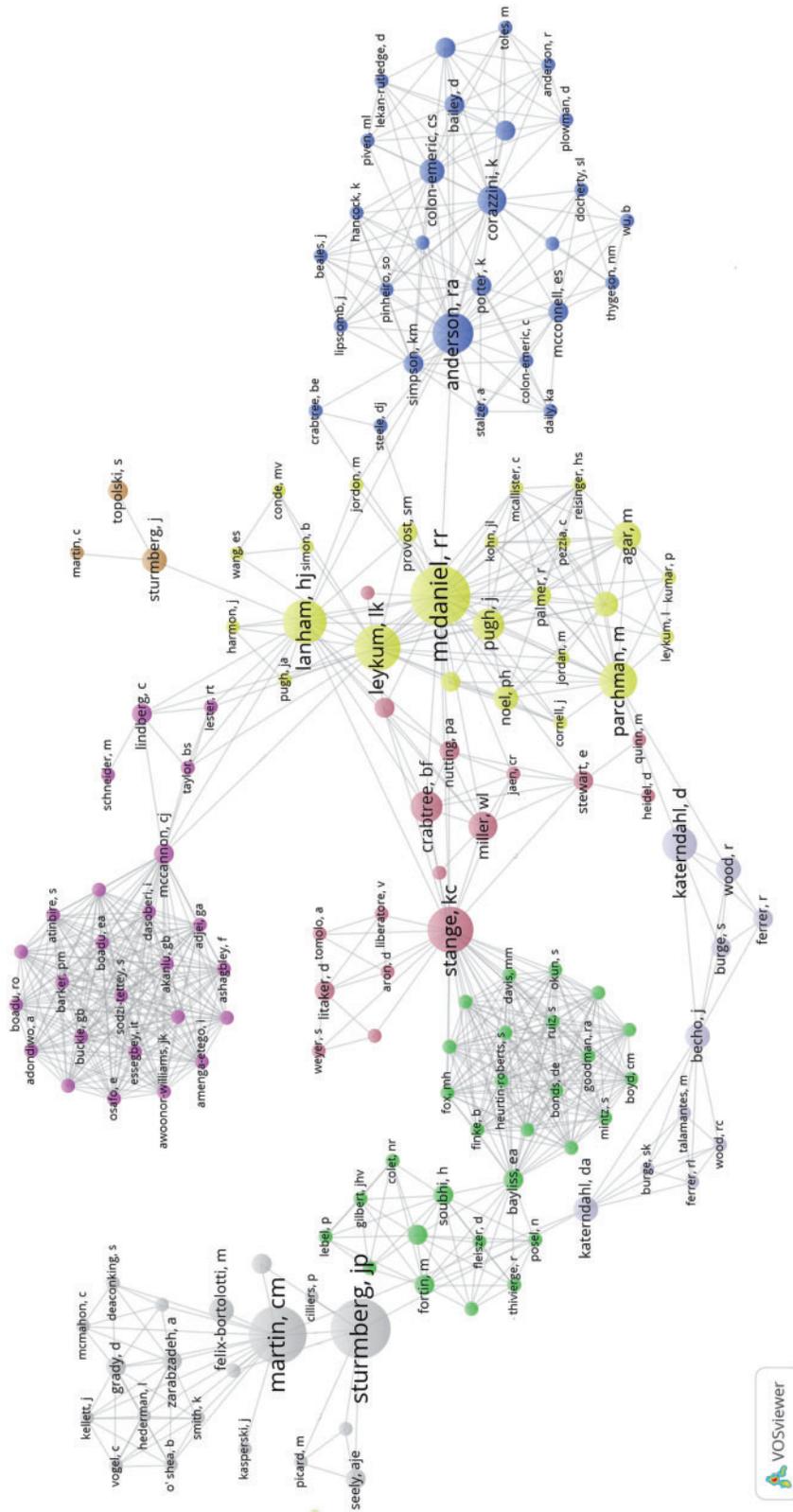


Figure 3. This network diagram illustrates co-authorship ties between groups of researchers within the dataset. Node size is related to the betweenness centrality measure of the author, i.e. the number of times an author directly bridges the shortest path between two researchers. This diagram visualises ties between the 'US Primary Care Group' and several authors from the 'Forum on Systems & Complexity in Medicine and Healthcare' group

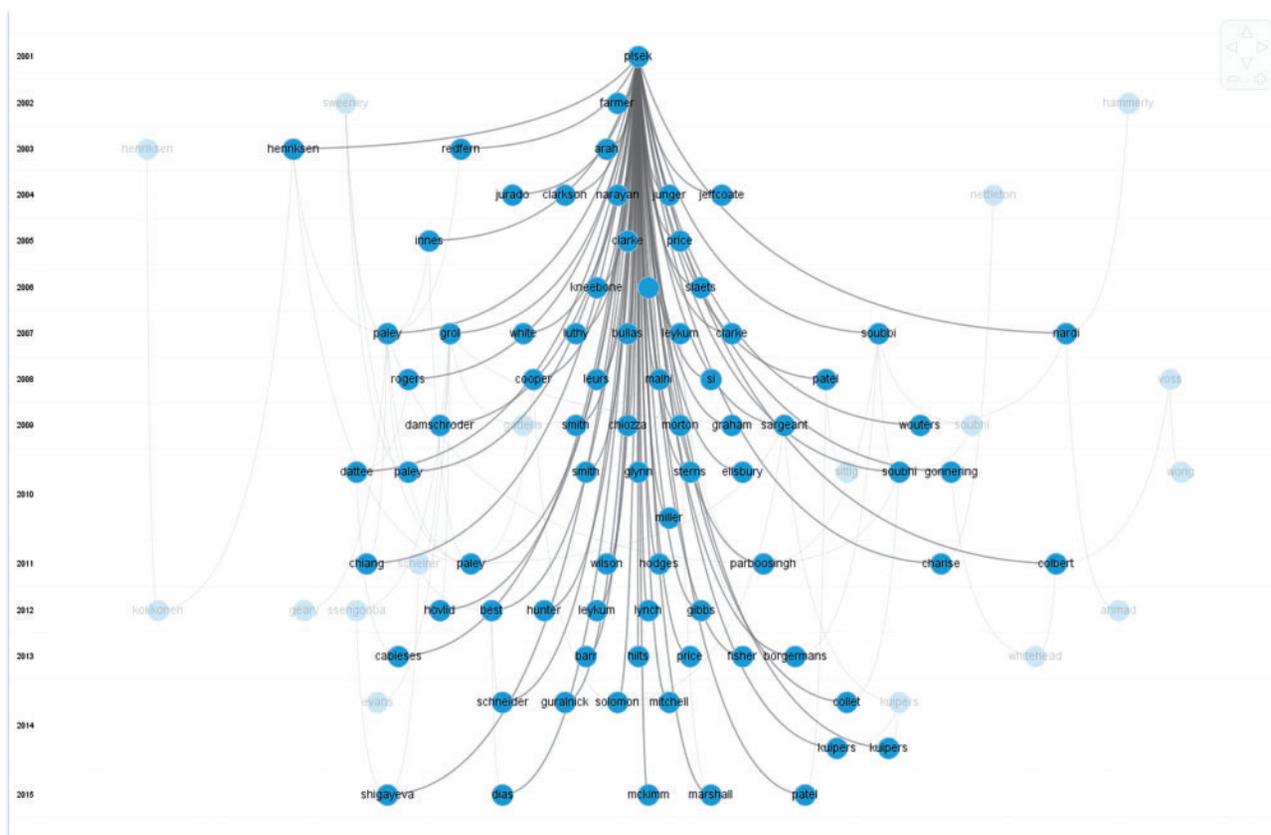


Figure 4. Citation network diagram visualizing the BMJ series primary landmark paper and descendent articles

co-authored a combined 21 (37.5%) (Sturmburg and Martin 2012). In keeping with its late editor’s specialism, the Forum’s work is characterized by an extensive use of metaphors and analogies adapting abstract Systems ideas and principles from other disciplines to public health. Such adaptation can often be prone to misrepresentation, resulting from ‘export’ and ‘context’ effects when transferring concepts from one discipline or context to another (Cabrera 2008) It is, therefore, important to empirically validate these ideas as the authors themselves suggest in their own historical review (Sturmburg et al. 2014), although doing so remains a significant challenge.

Citation tracing also revealed the pair to have co-edited an introductory ‘Handbook of Systems and Complexity in Health’, a compendium of 51 articles published in 2013 with Forum members and several other experts (Sturmburg and Martin 2013). The handbook aimed to address a pressing need for greater explanatory literature and promotes this highly metaphorical use of systems theories and methods as they relate to healthcare and public health.

BMJ series

The BMJ Series was published in 2001 by American and British authors Plsek, Greenhalgh, Wilson, Holt and Fraser following the introduction of a large-scale regulatory change in English health system performance management known as the ‘National Service Framework’. In further similarity with the US Primary Care Group, the articles echoed prevailing metaphorical conceptualizations of CAS at the social scale inspired by Management Thinking: with internalized agent rules, fuzzy boundaries, non-linearity, unpredictability and analogies of ‘Emergence’. However, the ‘Attractor’ concept was re-interpreted by this group to signify an idea closer to

‘underlying motivation’ rather than a ‘vision’ as proposed by the US Primary Care Group (Plsek and Greenhalgh 2001).

Preferring the term ‘Complexity Thinking’ (Plsek and Greenhalgh 2001) to Systems Thinking, the BMJ authors utilized broadly accessible language to explore leadership, healthcare management and learning from a complex systems perspective for an audience of healthcare professionals. The ideas resonated greatly with readers and a large number of descendant publications such as those illustrated below (Figure 4) sought to adapt the introductory concepts to their particular field of inquiry. Further variation in understanding attributable to ‘export’ and ‘context’ effects from transferring Systems ideas has contributed to increased confusion and calls for caution by critics who point to a lack of empirical validity in a nascent science (Paley 2010).

The authors have defended their highly popular contribution (Greenhalgh et al. 2010), highlighting the subsequent elaboration of their ideas in other publications while arguing the need for greater epistemological development and advocating the use of novel social science methodologies such as the Meta-narrative (Greenhalgh et al. 2005) and Realist Review (Best et al. 2012) developed by Greenhalgh et al. The latter method’s application to a local Canadian health system in 2012 also relates this group by co-authorship to the next.

The initiative on the study and implementation of systems (ISIS) project

The ISIS tobacco control project was a US National Cancer Institute (NCI) funded four-year multinational transdisciplinary supply-side tobacco-control initiative. Inspired by the adoption of Systems approaches in other economic sectors, its initial aim was to study

the public health tobacco-control system and address common systemic challenges such as fragmented or duplicated efforts, limited integration of research and a lack of co-ordination among providers (Best *et al.* 2007). The researchers developed a broadly inclusive and unifying viewpoint championing Systems Thinking, described as a ‘conceptual framework’ or worldview that transcended Reductionist, Critical Realist and Constructivist perspectives and on which basis multiple related Systems approaches have been developed. The project’s methodological scope eventually expanded to incorporate four major approaches: Systems Organising, System Dynamics, Network Analysis and Knowledge Management applied at the international scale with the aid of participatory structured conceptualization methods such as ‘concept mapping’, a statistical clustering method for semantic statements (Kane and Trochim 2007). The project eventually shifted its focus from the application to tobacco-control towards understanding ‘approaches to integrated systems thinking’ and ‘how to apply systems thinking to improve health outcomes’ (Best *et al.* 2007).

The ISIS tobacco-control project contributed several articles to the top 20 list of publications in 2006 (#11, 14 and 19) (Leischow and Milstein 2006; Sterman 2006; Trochim *et al.* 2007) and followed up with an expansive monograph entitled ‘Greater than the Sum’ (Best *et al.* 2007). In promoting Systems Thinking, the authors sought to unify the varying perspectives, vocabulary and understanding among the related Systems sciences. They also identified several cross-cutting methodological features with common processes, technologies and analytical techniques that could improve future mixed methods Systems research. This conceptual framework and its four key approaches were recently adopted at a global scale by the WHO in a bid to promote a better understanding of health systems and their interventions, particularly in Low and Middle Income Countries (LMICs) (De Savigny and Adam 2009).

WHO AHPSR group

The WHO Alliance for Health Policy and Systems Research (‘Alliance’) is an institutional body promoting ‘Systems Thinking for Health Systems Strengthening’ interventions, most notably through its Top 20 flagship report published in 2009 (#6) (De Savigny and Adam 2009) and subsequent clusters of articles exploring various Systems approaches (Adam 2014). The report married together the six-building block WHO Health System framework with the ISIS tobacco-control project’s conceptualization of Systems Thinking and its emphasis on the four prominent Systems approaches (Organising, Dynamics, Networks and Knowledge) in an introductory primer co-edited by De Savigny & Adam.

The primer was followed by special supplements published in 2012 and 2014. The first elaborated on the application of Systems ideas to the health system and its existing frameworks, promoting use through case study examples (Adam and Savigny 2012). The latter series was a larger collection of studies conducted by a network of scholars worldwide exploring the use of these approaches to better understand health systems in LMICs. Entitled ‘Advancing the Application of Systems Thinking in Health’, it promoted mixed-methods research combining qualitative aspects of System Dynamics and Network Analysis with social science methods such as Realist Evaluation and its variants (Adam 2014; Bishai 2014; Peters 2014).

The adoption and promotion of Systems Thinking by the WHO has contributed a significant portion of new empirical literature at a coarser meso–macro-scale in comparison with earlier micro–meso study. The use of the 2007 WHO health system framework has also emphasized geographical health systems in the group’s applied

research which differs from earlier issue-focused systems such as the tobacco-control system. Its authors acknowledged that Systems approaches are not limited to the four commonly mentioned and highlight a number of useful Systems ideas, methods and tools applicable to complex problems in health systems worldwide (Peters 2014).

Discussion

In this review, we inductively traced the bibliographic evolution of Systems Thinking from articles within our dataset, identifying an early stream of public health ST research which was heavily influenced by Management Thinking frameworks inspired by complex system attributes such as ‘non-linearity’, ‘co-evolution’ and ‘emergence’ observed in the formal and natural sciences. These visionary mental constructs were adapted to public health in response to systemic problems at a time of uncertainty in both the US and UK health systems, most prominently by the USPC and BMJ groups during the late 1990s and the early 2000s.

These higher order abstractions have influenced how public health experts view their research environment and understand what happens in populations. As illustrated in Figure 4, the ideas resonated strongly with a wider public health community who considered them plausible and useful for framing observed biopsychosocial and ecological patterns on a social scale. Subsequently, several authors, including those from the more philosophical ‘Forum on Systems and Complexity’ group, have metaphysically developed these analogies and re-interpreted existing frameworks and methods from a complex-systems perspective or ‘complexity lens’.

Communicating visions through metaphors and analogies adapted from the natural sciences is a consistent trend that has continued in the social sciences with the development of Systems Thinking, from its roots in biology-inspired Cybernetics to the evolution of System Dynamics modelling, which began by adopting terms used in electrical and fluid systems. While there has been much ontological adaptation and some competing metaphysical discussion, we note a paucity of empirical public health research validating, refining or refuting these mental constructs within the dataset. This finding is corroborated in similar recent reviews (Carey *et al.* 2015; Sturmberg *et al.* 2014; Thompson *et al.* 2016)

Certainly the study of complex systems to generate ‘knowledge-about-systems’ is not a novel pursuit, with decades of empirical research and theoretical development improving our understanding based on specific underlying perspectives predominantly relating to network structures and dynamics at the social scale. More recently, scientists have proposed refinements to modelling methods and devised novel approaches conducive to studying complex social systems. However, their application to public health is a nascent phenomenon which requires further practice, experimentation and development (Carey *et al.* 2015)

In a broader stream of research, the 4-year NCI ISIS study proposed an inclusive conceptual framework for Systems Thinking with a ‘definition-of-all’ that has provided a common basis for future cross-disciplinary methodological development. Its adoption by a multilateral global institution such as the WHO has enabled greater variation in research environments which have until recently been dominated by micro–meso scale study in Western health systems. As researchers explore combinations of borrowed systems approaches to study aspects such as agents, structure, signals, dynamics, boundaries, scale, time and degree of complexity from multiple perspectives, the framework will evolve further to its adapted context in

public health and may contribute to a more generalizable mental model or theory of Systems Thinking (Cabrera *et al.* 2008)

Our broad yet superficial inductive approach to bibliographically visualize the development of Systems Thinking is one of the several recent reviews attempting to explore this literature (Carey *et al.* 2015; Sturmberg *et al.* 2014; Thompson *et al.* 2016) While others have reviewed the application of ‘complexity theory’ or ‘systems sciences’ to particular fields such as Health Services Research or Primary Care, our ‘Systems Thinking’ review differed most significantly in its methodology and broad scope. However, we were unable to conduct a full interdisciplinary meta-narrative content review. This may yet be possible with further refinement and we encourage others to corroborate and add to our findings in a future study.

Based on our review, we argue a need to balance adapted theory with empirical study beyond unidisciplinary mathematical modeling or network analysis and encourage scientists to conduct further interdisciplinary studies in order to acquaint themselves with unfamiliar methods and combinations. We advise a greater emphasis on synthesising higher order mental constructs with high-quality empirical evidence in order to refine existing definitions and adapted models to public health systems. While the multiplicity of competing permutations may pose a methodological challenge in achieving consensus, at this early stage, they may also elucidate valuable correlations and help to refine methodologies and validate system attributes in particular circumstances to produce replicable and valid knowledge.

Ethical approval

Obtained via London School of Hygiene & Tropical Medicine Ethics Committee.

Conflict of interest statement. None declared.

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