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Taxonomy for complexity theory in the context of maternity care

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ABSTRACT

Background: The linear focus of 'normal science' is unable toadequately take account of the complex interactions that direct health care systems. There is a turn towards complexity theory as a more appropriate framework for understanding system behaviour. However, a comprehensive taxonomy for complexity theory in the context of health care is lacking.
Objective: This paper aims to build a taxonomy based on the key complexity theory components that have been used in publications on complexity theory and health care, and to explore their explanatory power for health care system behaviour, specifically for maternity care.
Method: A search strategy was devised in PubMed and 31 papers were identified as relevant for the taxonomy.
Findings: The final taxonomy for complexity theory included and defined 11components. The use of waterbirth and the impact of the Term Breech trial showed that each of the components of our taxonomy has utility in helping to understand how these techniques became widely adopted. It is not just the components themselves that characterise a complex system but also the dynamics between them.

Contents

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Introduction

Debates about the best approach to health care provision are persistent and contentious within and between countries across the world. For many high and medium income jurisdictions, discussions about the quality of health care have become heavily colonised by concepts of risk and safety, where risk of an adverse event is only seen to be acceptable when it is reduced to the lowest (infinitely small) level. Management of risk in health care tends to be seen as a simple linear 'input/output' process, in which screening identifies those at increased risk and then treatment eliminates the risk. Much of the evidence for this approach is based on 'large trials with simple protocols' (Peto et al., 1995). However, this assumes that the relationship between a particular risk factor and a specific adverse event is predictable, simple, linear, and generalisable to a wide range of contexts and individuals. It also assumes that removal of a risk factor for one condition does not increase risk for another one.

The flaws in this approach are evident, for example, in the growing controversy over the unintended consequences of routine screening for breast cancer for women (Autier et al., 2011; Roukema, 2013), and in the increasing concern about the longer term (and even epigenetic) potential for adverse effects associated with the continuing rise in the use of caesarean section for an ever wider list of indications in maternity care (MacDorman et al., 2008; Dahlen et al., 2013; Witt et al., 2014). Both seem logical, as a means of preventing adverse events. In the event, both have been shown to have unintended consequences in practice, both for individuals (iatrogenic mortality and physical, psychological emotional morbidity need for further treatment, and decreased quality of life), and for society, in terms of diversion of health resources, and economic consequences (Van der Steeg et al., 2011; Moynihan et al., 2013; Witt et al., 2014).

As knowledge accumulates about the lack of generalisability of trials evidence when it is extended to actual practice (Worrall, 2010; Humphreys et al., 2013), there is a growing critique of the so-called (current) 'normal science' approach (Kuhn, 2000). Although, large simple trials may work in certain tightly controlled contexts, the highly circumscribed interventions tested in such studies (often on carefully selected samples of service users) cannot cope with the messiness of real life in most practical situations (Enkin, 2006; Treweek and Zwarenstein, 2009). Politically, strongly positivist risk-averse health care is perceived by some to delimit the expertise of professionals, depersonalise care provision, and increase litigation risk and consequent health care costs (Reinders, 2008; Goodman and Norbeck, 2013). More recently concerns about disrespect and abuse in health care across the world have illustrated the moral and ethical consequences of the scientific-bureaucratic turn in health care (Bernstein and Fundner, 2002). In this interpretation, the excessive reliance on rule-based and protocol driven health care based on population trials evidence leads to a lack of concern for individual needs and circumstances. This, in turn, leads to emotional burnout for health care professionals who can no longer do the kind of vocational caring they came into their profession. Emotionally burnt-out professionals cease to see patients as people, and, in the scientific-bureaucratic context, they begin to treat them as units, to be processed. This strips out compassion, and allows disrespect and abuse to flourish.

Practitioners and researchers who want to reverse this phenomenon have turned to a number of theories to try to take account of the wide range of factors that might influence the specific situation of one specific individual, and their encounter with a clinician and health care system. For example, recent analyses have included realist research and experience based co-design (Pawson et al., 2005; Bate and Robert, 2006; Robert, 2007). Many of these emerging theories have their roots in aspects of complexity theory, either explicitly, or, more often, implicitly (Pawson, 2013).

Complexity theory emerged as a way of understanding and taking account of discrepant findings in physics. It specifically marked a shift from classic linear science as exemplified by Einstein's theories, towards the more dynamic, unpredictable physics of thermodynamics (Prigogine, 1997; Holden, 2005). It has been used in many different fields, for example, to improve weather prediction, to explain phenomena in economics, biology, and to understand social systems. In his book 'Complexity & Postmodernism' Cilliers (1998) explained how systems work based on complexity theory. He described complex adaptive systems as non-linear systems in which diverse agents interact with each other and are capable of undergoing spontaneous self-organisation. Since 2001, when the British Medical Journal launched a series of articles on complexity in health care (Fraser and Greenhalgh, 2001; Plesk and Greenhalgh, 2001; Plsek and Wilson, 2001; Wilson et al., 2001), there has been a growing debate around the use of the theory in the health care context (Reid, 2001; Paley, 2007; Sturmberg, 2007; Dattée and Barlow, 2010; Greenhalgh et al., 2010; Paley and Eva, 2011; Sturmberg et al., 2012).

The rather dense concepts that underpin complexity theory have been expressed in a range of metaphors and phrases. These include 'small in, large out', 'the whole is more than the sum of the parts' or 'tipping points'. The over use of some of these terms has led to accusations of naivety against those attempting to use complexity theory in a range of settings. Although there is a concept analysis in this area (Holden, 2005) and some previous publications offer an overview of a number of components in the light of health care (Chaffee and McNeill, 2007; Sturmberg and Martin, 2009), a comprehensive taxonomy for complexity theory in the context of health care has not been published to date.

Taxonomy is the practice and science of classification. It brings together the key characteristics of a concept, defines these characteristics and puts them together in a relationship scheme. This can be a hierarchical scheme, but may also be a network structure. A taxonomy can be used as a practical heuristic to assess the degree to which the theory has been effectively translated into fields, such as health care. Identifying a taxonomy of complexity theory for health care is a potentially significant contribution to the search for something beyond simple linear solutions. This paper therefore aims to answer two questions;

1. What are the key complexity theory components that have been used in publications on complexity theory and health care?
2. Do they have explanatory power for health care, and specifically for maternity care?

Maternity care was chosen as a paradigm case for the taxonomy for four reasons. It affects millions of women, neonates and

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families every year. It is a field in which debates around the risks and benefits of risk-aversion for the well-being of mothers and their babies are especially heated, persistent, and polarised (Cahill, 2001; Chervenak et al., 2013). It was the first health care area to systematically use the classic EBM technique of systematic reviews of randomised controlled trials to create a standardised evidence base for care, and, as such, it was the foundation for the creation of the Cochrane Collaboration. Finally, it is one of the first health care areas to trigger a serious critique of the kind of evidence that is generated by classic systematic reviews (Dickenson and Vineis, 2002). As an illustration of this turn, in the last few years, one of the key authors in the original pregnancy and childbirth reviews collaboration has founded a group that seeks to temper the hegemony of such evidence, seeing that context and individuals matter as much as pure trials data (Enkin, 2006).

The work was carried out as part of European COST Action IS0907: Childbirth – Cultures, Concerns, and Consequences: creating a dynamic EU framework for optimal maternity care (http://www.cost.eu/domains_actions/isch/Actions/IS0907).

Methods

Development of a taxonomy of complex systems

A simple, parsimonious search strategy was devised, using the search phrases: 'complexity theory', 'complexity science' and 'complex adaptive systems'. We did not impose any design or quality limits on included papers, as, for this phase of the study, we were interested in how the term was used, and not in the interventions or outcomes associated with it. Research, discussion and opinion papers were included if they met two criteria:

1. A focus on organisational aspect of health care systems.
2. Inclusion of at least some description of complexity theory.

One database, 'PubMed' was searched at the outset. No date restrictions were imposed. The search was initially run in December 2013. A draft taxonomy was produced, and then an updated search was run between January and June 2014, to check the comprehensiveness of this first iteration. Language restrictions were also not used, as the COST network for this study included individuals who could translate most European languages, and other non-European languages that tend to be fairly widely published, such as Chinese. Finally, reference back-chaining took place of all the studies included in the selected articles. The analysis comprised a descriptive account of the components of complexity theory mentioned and described in each paper. These components and their descriptions were summarised in a matrix. The study team subsequently debated the findings and came to consensus for the taxonomy.

Exploration of the explanatory power of the taxonomy

To explore the explanatory power of the taxonomy, two examples from controversial areas of maternity care were selected. In both cases, the adoption and spread of the technique is not easily explained by rational trials-based theories. One, waterbirth, is counterintuitive (most mammals do not use water for labour and birth) and has been subject to very little formal RCT research, but, despite intense initial controversy, it has been adopted into practice in many birth settings over the last 10 years. The other, elective CS for term breech was adopted almost universally over a two-year period after one large RCT was published. Counter to evidence based practice, even in the settings similar to those in which the trial had not shown benefits, and where CS may in fact carry more risks to mother and baby, this technique is now the norm. The evolution of these practices into maternity care is not easily explained by linear EBM-type science, and so they provide a useful test of complexity theory as an alternative and possibly more powerful means of understanding change in health care organisation and practice over time.

The data from these two exemplars are presented in two different ways. The uptake of waterbirth is mapped directly to the taxonomy, to illustrate the utility of each component. The move towards caesarean section for breech presentation is presented as a case study, to demonstrate how the elements of the whole taxonomy can work together.

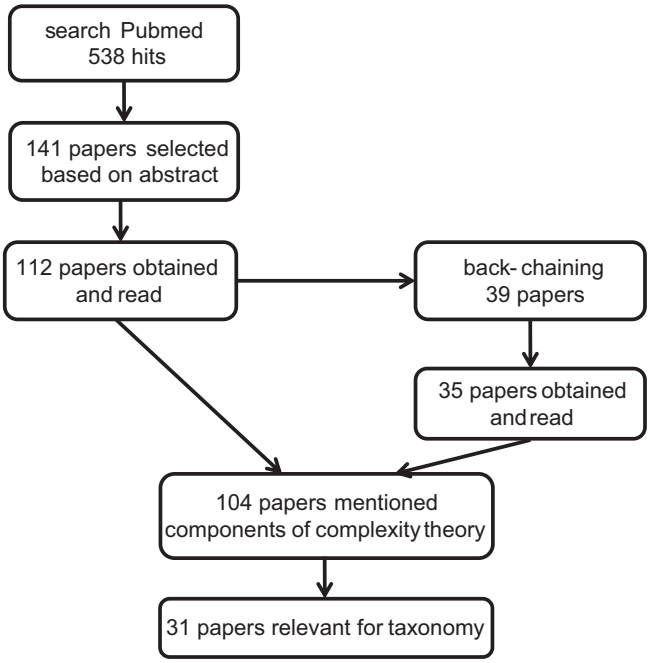

Fig. 1. Search for taxonomy on complexity.

Table 1
Number of times components were mentioned.

Components	Number of papers in which mentioned (n = 104)
Interconnection	89
Emergence	72
Non-linearity	69
Self-organisation	66
Unpredictability	58
Co-evolution	36
Feedback loops	35
Open boundaries	22
Initial conditions	22
Attractors	19
Simple rules	18

Findings

The original search generated 538 hits. On the basis of the abstracts, 141 papers were selected that seemed to fulfil the inclusion criteria. Of these selected papers, 112 full text articles could be obtained. An additional 39 papers were located by back-chaining of which 35 could be obtained. All the 147 papers were read for (1) focus on organisational aspect of health care systems, (2) description of complexity theory, complex systems, complex adaptive system, (3) mention and description of components of complexity theory (Fig. 1).

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Table 2
Characteristics of the papers used for the taxonomy.

Author/title	Year country	Type of study	Aim of the study	Field
Albanese M., et al. Physician practice change I: a critical review and description of an Integrated Systems Model.	2009 USA	Discussion paper	To develop an Integrated Systems Model (ISM) to enhance change in physician practice, this practice is seen as a CAS.	Medical practice.
Albrecht G., et al. Complexity and human health: the case for a transdisciplinary paradigm.	1998 Australia	Discussion paper	To construct a framework for analysing health processes. Complexity theory was seen as a construct to understand dynamic systems.	Coronary disease care.
Anderson R.A. and McDaniel R.R. Jr. Managing health care organisations: where professionalism meets complexity science.	2000 USA	Discussion paper	To examine the intersection of professionalism and complexity science as a source of new insights to improve health care.	Management and leadership in health care organisations.
Boustani M., et al. The challenge of supporting care for dementia in primary care.	2007 USA	Literature review and case study	To describe the complexity theory and its application to improve dementia care within primary care systems.	Primary care clinics for dementia care.
Brannon S.D., et al. North Carolina's direct care workforce development journey: the case of the North Carolina New Organisational Vision Award Partner Team.	2009 USA	A single-case, qualitative study	To describe an approach to address the long-term care workforce crisis by encouraging positive workplace practices in long-term care settings. These settings were seen as CASs.	Long-term care settings, e.g. nursing homes.
Bujak J.S. Culture in chaos: the need for leadership and followership in medicine.	1999 USA	Discussion paper	To introduce complexity theory as an approach to revive the dissolving physician culture and offer leadership for change.	Medical practice.
Chaffee M.W. and McNeill M.M. A model of nursing as a complex adaptive system.	2007 USA	Discussion paper	To examine how complexity science can be applied to the profession of nursing.	Nursing.
Clancy T.R. Navigating in a complex nursing world.	2004 USA	Discussion paper	To explore how nurse administrators may use the complexity theory to navigate through an unpredictable world.	Nursing.
Crabtree B.F., et al. Primary care practice transformation is hard work: insights from a 15-year developmental programme of research.	2011 USA	Overview of findings from a research programme	To describe the learning process from using a mixed methods design for a research programme aimed at enhancing quality of care in primary care practices. These practices were seen as CASs.	Primary health care practices.
Edgren L. The meaning of integrated care: a systems approach.	2008 Sweden	Discussion paper	To increase understanding of integrated care in health and social services. These services were seen as CASs.	Health care organisations.
Gatrell A.C. Complexity theory and geographies of health: a critical assessment.	2005 UK	Discussion paper	To assess the 'added value' of complexity theory for health geography.	Health geography.
Holden L.M. Complex adaptive systems: concept analysis.	2005 USA	Concept analysis	To explicate the concept of complex adaptive systems through an analysis that provides a description, antecedents, consequences, and a model case.	Nursing.
Jayasinghe S. Conceptualising population health: from mechanistic thinking to complexity science.	2011 Sri Lanka	Discussion paper	To promote complexity science as a way to understand and improve population health.	Population health.
Kannampallil T.G, et al. Considering complexity in healthcare systems.	2011 USA	Discussion paper	To develop research approaches for studying complex health care environments based on interrelatedness of system components.	Health care systems.
Lessard C. Complexity and reflexivity: two important issues for economic evaluation in health care.	2007 Canada	Discussion paper	To promote complexity and reflexivity as two important issues for economic evaluations in health care.	Health care organisations.
Martin C. and Sturmberg J. Complex adaptive chronic care.	2008 Canada	Discussion paper	To propose a framework (*Complex Adaptive Chronic Care*) that makes sense of the nature of chronicity and its multiple dimensions beyond disease.	Care models for chronic diseases.
McDaniel R.R. Jr., et al. Surprise, Surprise, Surprise! A complexity science view of the unexpected.	2003 USA	Discussion paper	To expand traditional views on surprise in health care organisations with a perspective based on complexity theory.	Unexpected events in health care organisations.
Miller W.L., et al. Practice jazz: understanding variation in family practices using complexity science.	2001 USA	Discussion paper	To use complexity theory to interpret the process and content of family practice.	Family practice.
Minas H. Leadership for change in complex systems	2005 Australia	Discussion paper	To examine clinician leadership for change from the perspective of the complexity theory.	Mental health system.
Paley J. Complex adaptive systems and nursing.	2007 UK	Discussion paper	To outline some of the key ideas in the theory of complex adaptive systems.	Nursing.
Paley J. The appropriation of complexity theory in health care.	2010 UK	Response to articles in the BMJ 2001	To debate the meaning of a number of principles of the complexity theory.	Health care systems.
Patel A.M., et al. Complexity science: core concepts and applications for medical practice.	2008 USA	Discussion paper	To help physicians understand the basic concepts of complexity science and how it might be applied to medical practice.	Medical practice.
Plsek P.E. and Greenhalgh T. Complexity science: The challenge of complexity in health care.	2001 USA/UK	Discussion paper	To explore new approaches to clinical practice, organisational leadership, and education, based on complexity science.	Health care systems.
Plesk P. Complexity and the adoption of innovation in health care.	2003 USA	Discussion paper	To examine the meaning of complexity in health care and how complexity affects the generation and spread of innovations.	Health care systems.
Rhydderch M., et al. Organisational change theory and the use of indicators in general practice.	2004 UK	Discussion paper	To understand organisational change and quality improvement in general practice by using the complexity theory.	General practice.
Rickles D., et al. A simple guide to chaos and complexity.	2007 Canada	A glossary	To give a glossary on the concepts of complexity and chaos.	Health care systems.
Rowe A. and Hogarth A. Use of complex adaptive systems metaphor to achieve professional and organisational change.	2005 UK	Discussion paper	To explore professional and organisational change in a programme for public health nurses by using the complexity theory.	Public health.

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Table 2 (*continued*)

Author/title	Year country	Type of study	Aim of the study	Field
Sturmberg J.P. and Martin C.M. Complexity and health–yesterday's traditions, tomorrow's future.	2009 Australia / Canada	Discussion paper	To bring forward the need to understand health care from a complexity theory perspective.	Health care systems.
Sweeney K. and Kernick D. Clinical evaluation: constructing a new model for post-normal medicine.	2002 UK	Discussion paper	To explore complexity theory as the basis of a new model for medicine and define its characteristics.	Medical practice.
Sweeney K.G. and Mannion R. Complexity and clinical governance: using the insights to develop the strategy.	2002 UK	Discussion paper	To show how understanding of complex adaptive systems can help the process of implementing clinical governance.	Clinical governance in health care services.
Trenholm S. and Ferlie E. Using complexity theory to analyse the organisational response to resurgent tuberculosis across London.	2013 UK	Qualitative case study	To analyse the English National Health Service (NHS)'s organisational response to resurgent tuberculosis by using the complexity theory.	Health care organisation.

In total, 104 papers mentioned various components of complexity theory. We identified the following components as most commonly mentioned: interconnection, feedback loops, self-organisation, simple rules, open boundaries, emergence, co-evolution, attractors, initial conditions, non-linearity and unpredictability (Table 1). Occasionally components as adaptability, dynamism, far from equilibrium states, and fractals were mentioned.

Subsequently, 31 of these 104 papers were identified as relevant for the taxonomy as they offered definitions of the components. These were included in the final analysis. The characteristics of these papers are given in Table 2. Most of these papers based their components and the description of these components on a number of other authors. The most commonly mentioned were Jantsch (1972), Capra (1982), Prigogine and Stengers (1984), Lewin (1993) Cilliers (1998) and Plsek and Greenhalgh (2001).

The update of the search yielded an extra 29 hits. Two articles, one from the USA and one from Australia, added new insights to the taxonomy (Greene et al., 2014; Sturmberg et al., 2014). Greene et al. (2014) presented a person-focused model of care that addressed the challenge of providing high-quality care while facing the burdened of unsustainable expenditures. Our draft taxonomy took account of all the elements of the model described in this paper. Specifically, the paper describes interconnection in three classes; that is, (a) among the mental, social, and physical dimensions of a patient's health (the intrapersonal CAS), (b) among all stakeholders with each other, including the patient (the interagent CASs), and (c) between each stakeholder and the patient's health, which is the output of the model. Sturmberg et al. (2014) provides an historical overview of complexity theory and its impact on general practice. All the components included in the paper were included in our draft taxonomy. These two additional papers confirmed the comprehensiveness of the taxonomy.

Taxonomy

On the basis of the 31 studies located by our original search, we developed a taxonomy that included and defined 11 components of complexity theory (Table 3). Table 3 sets out each of these in turn, along with a description of that component, and of how it is expressed in the shift towards the use of waterbirth in maternity care. The case study example of the response to women at term with a baby presenting in the breech position is then given, to illustrate the integration of these components in a Complex Adaptive System.

Within a taxonomy, components of a concept are also put together in a relationship scheme. As the example of the impact of the Term Breech trial given above demonstrates, the components are strongly interconnected. The links can be distinguished at three levels: (1) components at the system level: which trigger (2) a process characterised by certain components: leading to (3) an outcome which has a number of characteristic components (Fig. 2).

Discussion

Some components of complexity theory appear to be more generally present in the related health care literature than others. Interconnectivity, emergence, non-linearity and self-organisation, are described from the beginning in the general theory (Cilliers, 1998) and are present in nearly all of the literature. Other characteristics of complex systems described by Cilliers are mentioned less often, such as feedback loops, open boundaries and initial conditions. Explicit definitions of the components are rare, although, implicitly, the same meaning seems to be recognised by different authors. However, some components, such as attractors, seem to be open to ambiguity. For example, Paley and Eva (2011) commented that the whole concept of attractors is often misinterpreted as an 'intentional' phenomena, when, in fact, it originates in mathematics as an algebraic descriptor of certain endpoints or end states in a system (such as the point where a pendulum comes to rest). In this paper, we have translated this concept into an end state, where the system is still flexible, but within a more or less defined rage.

The taxonomy we have created is slightly different from the recent overview of properties of complex adaptive systems presented by Sturmberg et al. (2014). Their aim was to provide an historical narrative review of the coevolution of general/family practice and systems sciences. The study describes how complexity theory was integrated into the literature on general/family practice over the past decades. They present a short overview of relevant components, mentioning self-organisation, open boundaries, emergence, coevolution, attractor, and non-linearity as properties in complex adaptive systems. In the description of these properties, interconnectivity, feedback loops, initial conditions and unpredictability also come forward. Simple rules is not stated as a component. Additionally, they identify two other properties 'pattern of interaction' and 'adaptation and evolution'. 'Pattern of interaction' is described as all parts in a system involve repetitive processes. These processes are repeated ('fractal') in every layer of a specific system. This can be seen as a further specification of the interaction described in the component interconnectivity and feedback loops. 'Adaptation' is described as the process of change due to changes in the environment, whereas 'Evolution' is described as the persistence of a change into the future. Both can be linked to the process that emerges from interconnected systems. We did not come across these components in the other literature of our study.

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Table 3
Taxonomy of complex systems.

Components	Description of the component	Example: Establishing waterbirth as a birthing option
Interconnection (Sturmberg et al., 2014; Trenholm and Ferlie, 2013; Jayasinghe, 2011; Kannampallil et al., 2011; Albanese et al., 2009; Sturmberg and Martin, 2009; Edgren, 2008; Martin and Sturmberg, 2008; Patel et al., 2008; Boustani et al., 2007; Chaffee and McNeill, 2007; Lessard, 2007; Gatrell, 2005; Holden, 2005; Minas, 2005; Plsek, 2003; Sweeney and Kernick, 2002; Sweeney and Mannion, 2002; Miller et al., 2001; Anderson and McDaniel, 2000; Bujak, 1999)	Complex systems have a dynamic range of agents (e.g. people) that cannot be understood as the simple sum of the individual characteristics. The people interact together through (local) interdependent relationships and free flow of information. Each of them is also connected to various other systems. Interconnectivity is evident when a system or group becomes self-organising and when new and creative responses to change emerge. The responses are not planned, and, if asked, no one in the group can explain exactly how they came about.	The waterbirth movement originally gained momentum in the 1980s. At this time, a critique of the so-called 'industrialist' model of childbirth prevalent in the 1970s was emerging, as women's activist groups like the NCT and AIMs began to gain political attention in the UK, and, through these catalysts, childbearing women, maternity care staff (mainly midwives), service providers, media, birth activists, and politicians with an interest in this area began to build networks and communities of practice focused on change in maternity care. Around the same time, waterbirth also became popular in the Netherlands, mainly as an opportunity for pain relief that didn't require a hospital birth. Simultaneously, a movement (stichting Lichaamstaal: www.stichtinglichaamstaal.nl) – rooted in social welfare - started to promote different ways of giving birth to stimulate early bonding between parents and children. In Iceland the first waterbirth was a home birth in 1987 but in 1997 some small birth units in the country started to offer waterbirth (Blöndal, 2009). Women who had used baths and showers for relief, usually at home births, and midwives who had observed the benefits of this, started to share knowledge and information about birthing in water. New, appealing and easily accessible material was used to disseminate ideas, such as DVDs, illustrated books and conferences. As international networks of childbearing women and midwives developed over the next 20 years, and as experience of waterbirth was shared, interest in the practice spread through linked networks to other countries across the world.
Feedback loops (Edgren, 2008; Rickles et al., 2007; Gatrell, 2005; Holden, 2005)	Interconnectivity facilitates feedback loops in which the positive and/or negative effects of a particular action or change are fed back to the people in the network. This feedback affects the way these people behave in the future, also in the connection with one another.	Initially, waterbirth was resisted by powerful members of the medical profession, on the grounds of infection risk, and this resistance fed rapidly into strong medical networks. However, these were networks that were largely closed to those outside the medical profession, so resistance was constrained, in contrast to the more open networks of women, midwives and birth activists. The conversation shifted as waterbirth became more popular among women, midwives and doctors. A circulated debate started that got the media involved. Each time strong protagonists gained a more powerful voice, which enabled them to begin publishing audit data, adding in more evidence with each loop. This reinforced various conversations on important values going on in different countries.
Self-organisation (Sturmberg et al., 2014; Trenholm and Ferlie, 2013; Crabtree et al., 2011; Kannampallil et al., 2011; Paley, 2010; Brannon et al., 2009; Sturmberg and Martin, 2009; Edgren, 2008; Martin and Sturmberg, 2008; Boustani et al., 2007; Chaffee and McNeill, 2007; Paley, 2007; Rickles et al., 2007; Gatrell, 2005; Minas, 2005; McDaniel et al., 2003; Sweeney and Kernick, 2002; Miller et al., 2001; Plsek and Greenhalgh, 2001; Albrecht et al., 1998)	Interconnectivity also stimulates self-organisation as a spontaneous process in which people mutually adjust their behaviour to cope with changing internal and external demands. Over time, new structures and patterns emerge without hierarchical direction.	A bottom-up approach resulted in a movement to change birth, using a variety of initiatives that challenged the paradigm of birth at the time and presenting new approaches. These new approaches were facilitated with philosophical and practical information, involving all the stakeholders. The waterbirth movement wasn't planned as a campaign. As individuals became experienced, they spread the information. The eventual 'norms' for the use of waterbirth were not pre-planned.
Simple rules (Albanese et al., 2009; Patel et al., 2008; Chaffee and McNeill, 2007; Minas, 2005; Plsek, 2003; Plsek and Greenhalgh, 2001)	Internalised principles or values that drive a common direction of travel among the people in a complex system, but that are general enough to provide space for shared action and innovative change. The simple rules guide the self-organisation and emergent responses. They are not easy to determine.	A number of simple rules could be coherent with offering waterbirth as an option. The combination of 'Ensure that routine technological and monitoring approaches to childbirth cannot be performed'. 'Enable maximum pain relief without using pharmacological drugs' and 'Provide a space in which the woman can respond intuitively to the demands of her labour' might be such a set of rules. This is coherent with the rising demands from women across the world about their right to choose and have influence on what was happening to them in labour, as well as their adverse reaction to birth getting too technical.
Open boundaries (Sturmberg et al., 2014; Jayasinghe, 2011; Kannampallil et al., 2011; Albanese et al., 2009; Edgren, 2008; Chaffee and McNeill, 2007; Lessard, 2007; Paley, 2007; Rickles et al., 2007;	The boundaries of complex systems are indistinct and fuzzy, and systems cannot be separated from their environment. People, information, and ideas move easily across these boundaries. Membership of systems	The use of waterbirth evolved within and between different interconnected systems such as the humanising childbirth movement, the normal birth movement, healthy start to life movement and

Table 3 (*continued*)

Components	Description of the component	Example: Establishing waterbirth as a birthing option
Minas, 2005; Plsek and Greenhalgh, 2001; Anderson and McDaniel, 2000)	change and individual agents are part of several systems at the same time.	women's movements in general. There was significant shared membership between these movements, and this intensified with the rise in social media. Members also belonged to more formal systems, such as health care institutions, midwifery and nursing educational establishments, and commercial organisations. These crossed country and institutional borders. Free flow of information through the media (especially, more recently, social media) helped to make information on waterbirth widely accessible. Easy dissemination across countries was possible as image and video sharing across media routes became easier.
Emergence (Sturmberg et al., 2014; Trenholm and Ferlie, 2013; Crabtree et al., 2011; Jayasinghe, 2011; Kannampallil et al., 2011; Albanese et al., 2009; Sturmberg and Martin, 2009; Edgren, 2008; Patel et al., 2008; Boustani et al., 2007; Chaffee and McNeill, 2007; Lessard, 2007; Rickles et al., 2007; Gatrell, 2005; Holden, 2005; Minas, 2005; Rowe and Hogarth, 2005; Clancy, 2004; Rhydderch et al., 2004; McDaniel et al., 2003; Plsek, 2003; Sweeney and Kernick, 2002; Miller et al., 2001; Anderson and McDaniel, 2000)	A complex system develops (emerges) over time, adapting flexibly in response to internal and external challenges. Emergence is enhanced by diversity because of the greater interaction and richer patterns. This results in new patterns of behaviour through spontaneous self-organisation, in which the whole is greater than the sum of the parts.	Waterbirth was seen highly contentious and alternative at the outset. In the early 1980s while women laboured in baths at home, it was not done in hospital, except in Pitiviers, in France. In 1983 an article was published on births in water in France (Odent, 1983). Spread was relatively slow. However, as the conversations multiplied across the various networks, and as experience of early adopters fed into those networks, acceptance accelerated in certain countries. In 1993, official UK government documents supported waterbirth as a means of pain relief for labour (Department of Health UK, 1993), but it was still unusual. In 2013, 8% of women in the UK responding to a national survey of women's views used a pool when their baby was born (NHS, 2013), and it is increasingly main stream in a range of other countries. Activists in Spain are currently using waterbirth as a nexus for changing highly technocratic birth practices.
Co-evolution (Sturmberg et al., 2014; Crabtree et al., 2011; Albanese et al., 2009; Brannon et al., 2009; Sturmberg and Martin, 2009; Edgren, 2008; Martin and Sturmberg, 2008; Boustani et al., 2007; Chaffee and McNeill, 2007; Lessard, 2007; Paley, 2007; Rickles et al., 2007; Minas, 2005; McDaniel et al., 2003; Plsek, 2003; Sweeney and Kernick, 2002; Miller et al., 2001; Plsek and Greenhalgh, 2001; Bujak, 1999)	The complex system co-evolves with its environment, because it is embedded in other systems. Co-evolution is a process of mutual transformation, initiated by continuous change in the environment which requires new responses and approaches. The evolution of each of these complex systems influences and is influenced by, the evolution of other systems.	The waterbirth movement co-evolved with the women's movement, where women wanted more control over what was happening during birth and to their bodies. It was influenced by, and influenced other movements, such as 'Changing childbirth', the 'Normal birth movement', 'Humanising birth movement' and "stichting Lichaamstaal". It was associated with an increase in prominence of midwife-led care.
(Strange) Attractor (Sturmberg et al., 2014; Kannampallil et al., 2011; Paley, 2010; Chaffee and McNeill, 2007; Lessard, 2007; Rickles et al., 2007; Rowe and Hogarth, 2005; Clancy, 2004; Plsek, 2003; Sweeney and Kernick, 2002; Plsek and Greenhalgh, 2001; Albrecht et al., 1998)	A strange attractor is the new, fairly stable set of behaviour patterns in which a system settles after a period of turbulence. This new situation is likely to be temporary as the system will adapt again when changes take place. An attractor dictates the boundaries of the pattern in which a system evolves when changes are going on. The system operates within certain parameters ('phase space'), though exactly how it will be operating and evolving at any given time is not predictable in detail. Eventually, the system will settle down in a balance, fundamentally different (strange) from the original situation.	After a period of discussion and resistance, the option of labouring in water is now a part of standard care in many birthing settings. Although it is occasionally debated for its effects and safety, it is mostly well accepted and its use persists in a balanced dynamic stage. Giving birth in water is more contentious, and this forms a boundary in some settings. The boundaries to eligibility of women to labour and birth in water are much less fixed, as some settings have strict eligibility rules that leave some women outside of the 'phase space' in which labour and birth in water can happen.
Initial conditions (Kannampallil et al., 2011; Edgren, 2008; Lessard, 2007; Rickles et al., 2007; Gatrell, 2005; Holden, 2005; Anderson and McDaniel, 2000)	A complex system has a history. This history constitutes the initial conditions that influence whether changes occur or not, how the system evolves and co-creates the system's present behaviour. Initial conditions function as one of the attractors for a complex system.	Dissatisfaction with the way technology was taking over birth, and the wish for non-medical pain relief and normal birth created a movement for waterbirth. It was seen as an attractive option for non-technological pain relief. New but not strange, the use of something both women and care providers were familiar with in another context, associated with comfort. It was acceptable in different cultural contexts (home – hospital, obstetricians – midwives, France – Russia). In the climate of women's emancipation and as part of the humanising childbirth action, the waterbirth movement was an initiative to empower women to take back control over their birth.
Non-linearity (Sturmberg et al., 2014; Trenholm and Ferlie, 2013; Jayasinghe, 2011; Albanese et al., 2009; Sturmberg and Martin, 2009; Edgren, 2008; Chaffee and McNeill, 2007; Lessard, 2007; Paley, 2007; Rickles et al., 2007; Gatrell, 2005; Plsek, 2003; Plsek and Greenhalgh, 2001; Bujak, 1999)	Small changes can have large, non-proportional effects on the whole system (and vice versa). This is the popular notion of 'tipping points'. When this happens, the cause and effect relationships are not directly evident or linear. Changes are sensitive to initial conditions.	Two individuals are credited with popularising waterbirth (Igor Tjarkovsky in Russia in the 1970s and Michel Odent in France in the 1980s). However, there was little real attention to their work until the early 1990s, when the networks of activists and others noted above became more established, and when resistance to technocratic childbirth became more widespread. The limited audit information available

Table 3 (*continued*)

Components	Description of the component	Example: Establishing waterbirth as a birthing option
		was rapidly disseminated and taken up through these networks, causing widespread and rapid changes in some settings, but not others. The spread and uptake was not predictable, and tipping points continue to occur in settings that are newly responding to the movement to normalise childbirth (as in the Spanish case).
Unpredictability (Trenholm and Ferlie, 2013; Albanese et al., 2009; Chaffee and McNeill, 2007; Paley, 2007; Rickles et al., 2007; Minas, 2005; Rhydderch et al., 2004; Sweeney and Kernick, 2002; Plsek and Greenhalgh, 2001; Anderson and McDaniel, 2000)	Because of random disturbances, non-linearity of changes and emergent behaviour that is sensitive to initial conditions, the detailed behaviour of any complex system is unpredictable over time. Accurate detailed planning is impossible.	Given the fact that birth in water is relatively counter-intuitive, it demands a certain amount of equipment, and time to set up the pool each time and to clean it afterwards, and it challenged very strongly entrenched ways of managing childbirth, adoption was by no means predictable. Adoption has also resulted in the unexpected development of new technologies, such as waterproof wireless doptones, meaning that women and babies at higher risk can potentially make use of waterbirth.

Case study example: Maternity care as a complex adaptive system, the impact of the Term Breech Trial.

Complex adaptive systems can only be fully understood in the relationship between the components. An overall illustration of the interconnectedness of the components is the emergence and impact of the Term Breech Trial (Hannah et al., 2000) had on maternity care for women with term pregnancies when their baby was presenting in the breech position.

Brief summary of the Term Breech Trial and responses to it

The Term Breech Trial was a very large multicountry, multicentre RCT that demonstrated an increase in the risk of NND for babies born to women randomised to spontaneous labour rather than elective CS when they were at term with their babies in the breech position. Sub-analysis by country showed that this effect was present for high-income countries, but not for low-income countries in the study. Despite this, an audit of the participating centres two years after publication of the results found that most centres (92.5%) had changed clinical practice to planned caesarean section for most or all term breech (Hogle et al., 2003), although the risks and resource implications outweighed the benefits for low income countries. A separate two year follow up of a sample of those in the trial showed that the total of deaths and serious morbidity between the two arms of the study was not significantly different for high and low income countries combined (the numbers were too small to see a differential effect between these two settings) (Whyte et al., 2004). In the light of a desire to reduce neonatal mortality and concern about the potential adverse effects of rising CS rates across the world, support for and challenges to the results have been mounted based on longitudinal data sets from a range of maternity care settings and countries. Some settings have moved to a more liberal approach, but most continue to strongly advise CS for all women who have babies presenting by the breech.

Response to the Term Breech Trial: an illustration of maternity care as a Complex Adaptive System

Care providers all over the world are increasingly connected and challenged by a constant stream of information from research publications indicating new ways to improve care (**interconnectivity, open boundaries**). Furthermore, research teams are more and more jointly engaged in conducting multicentre studies, such as the Term Breech Trial. This interconnectivity facilitated a fast distribution of the Term Breech Trial results. Professionals discussed the research results in different contexts such as local networks, online forums, conferences and meetings. They debated the meaning of new evidence for everyday practice, integrating individual experiences with single cases, and adjusting their opinions based on the discussions (**feedback loops**). Usually, evidence-based results only slowly find their way to everyday practice, gradually changing each provider's conduct of care. In the case of the Term Breech Trial the findings were adapted unusually quickly in obstetric care, settling in a new pattern of behaviour in clinical practice (**strange attractor**). Possibly, because there was already a feeling of discomfort among many clinicians and service users around vaginal breech birth (**initial conditions**), coinciding with a climate in health care focused on safety and highest possible risk management in every aspect of care (**simple rules**). A new norm among professionals was established spontaneously (**emergence**), offering caesarean section as the safest option for breech birth well before guidelines were officially reviewed and adapted (**self-organisation**). In countries where the obstetric system interacts with a strong midwifery care system (**open boundaries**), e.g. the Netherlands, external cephalic version (ECV) in case of a breech presentation also was revalued (**co-evolution**). This single study led to a substantial change in behaviour resulting in a chain reaction where caesarean section became the norm in the case of a breech presentation, having a huge effect on the number of caesarean sections being done (**non-linear**). As a reaction some women opted out of the system, choosing home birth or even unassisted birth to avoid a caesarean section (**unpredictability**).

Waterbirth is, on the face of it, strongly counter to the prevailing hegemony of routine technocratic monitoring and intervention in childbirth. However, we have shown that each of the elements of our taxonomy has utility in helping to understand how waterbirth has become widely adopted in many countries over the last few decades, despite an almost complete lack of formal randomised trial evidence in this area. We have also shown how the elements described in the taxonomy can equally explain the very rapid adoption of caesarean for term breech in all settings in the belief that it is based firmly on the gold standard for evidence based medicine, the large multicentre trial with a simple protocol, even where the resulting evidence does not in fact support such widespread adoption.

The chronological 'tipping point' for both of these events happened more or less simultaneously, and within the same health care area, partly with the same actors, even though the theoretical and philosophical roots for each of the techniques are very different. In both cases, 'cause and effect' analyses based on

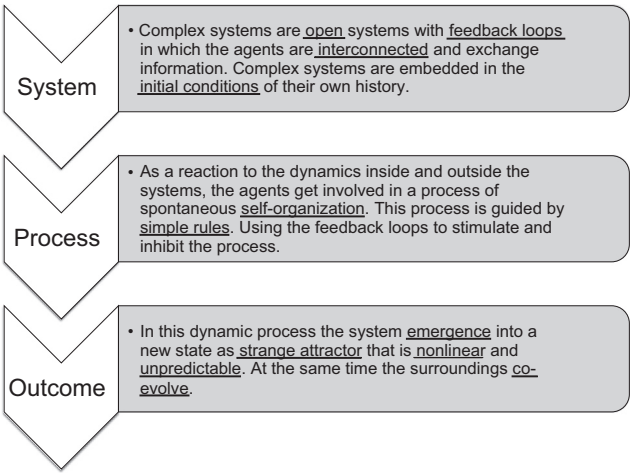

Fig. 2. Relationship scheme of the taxonomy of complex systems.

'rational man' type theories (Coleman and Fararo, 1992) cannot really make sense of what happened, and, particularly, for the rapidity and wide distribution of the system shift. We suggest that using the taxonomy might allow for a more structured appraisal for such changes in maternity care systems in the future. Both to understand change retrospectively, but, maybe more importantly, to begin to analyse patterns that might more closely predict the likelihood and direction of change in the future.

Conclusion and implications for practice/research

In our literature review, a number of components were identified as characteristic for complexity theory and complex systems. Put together, they create a taxonomy of complexity theory that can be used to identify organisations as complex systems, and to explore phenomena within them. However, it is not just these components themselves that characterises a complex system but also the dynamics between them and the fact that they are repeated ('fractal') in every layer of a specific system.

More research is needed to unpack the nature of the 'black box' of complex systems to identify successful concepts and elements of change in maternity care specifically, and health care more widely. Understanding system components and self-organizing processes may explain why certain management practices work better than others. Beyond the theoretical examples we presented in this article, further research needs to assess the impact of an approach based on complexity theory in turns of individual and clinical care, and to explore whether the insights from applying this taxonomy can help those who are active within systems to create effective initial conditions that are more likely to lead to positive systems change. Conflict of interest The authors declare that there is no conflict of interest.

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