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A socio-mathematical definition of innovation – The distinction with ordinary change

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ABSTRACT

Many researchers have defined the concept of innovation, without reaching consensus. But in any case an innovation concerns something new or the process of achieving such a thing. Since 'new' is a subjective qualification, the concept of innovation is weakly defined. As a consequence, the difference between an innovation and not-an-innovation ('ordinary change') stays unclear. This not only hinders the research of innovation and the advancement of innovation theory, but also may lead to costly mismanagement of innovation. To advance the definition of innovation, we distinguish two fundamentally different types of change: the change of the parameters of a system versus the expansion of its dimensions. The first type we identify as ordinary or first-order change and the second type as innovation or second-order change. We explain how our mathematical definition of innovation, combined with social processes of argumentation and discussion, can be operationalized methodically. Using a case of tightening the energy efficiency requirements for newly built houses, a case of business transformation, and a case of decentralization of youth care, we demonstrate how our socio-mathematical definition of innovation helps to study innovation more accurately and to understand the fundamental differences between ordinary change and innovation in their dynamics of planning, acting, and learning. Our socio-mathematical definition positions innovation management next to strategic change management, quality management and standardization management, and is easily applicable for researchers, innovation managers and policy makers.

1. Introduction

Any field of research needs proper definitions of basic concepts. This applies to research on innovation as well. Since Schumpeter (1934) many researchers have defined this concept, but there is no consensus yet on a common definition. In search of a consensus definition of innovation, Singh and Aggarwal (2021) reviewed 208 definitions and found that the word 'new' is the most frequent and consistently used word. An innovation is therefore at least 'something new' or the process of achieving such a thing. Since 'new' is a subjective qualification, the concept of innovation is weakly defined. As a consequence, the difference between an innovation and not-an-innovation ('ordinary change') stays unclear. This not only hinders the research of innovation and the advancement of innovation theory, but also may lead to costly mismanagement of innovation.

The aim of our research is: (1) to advance the conceptualization of innovation by presenting a more accurate general definition that addresses the most relevant element of any definition of innovation: newness, and distinguishes innovation from ordinary change; and (2) to reveal its relevance for theory and practice. Although our focus is on defining innovation more accurately, we also give attention to the consequences of a better definition for the approach of innovation and innovation management.

We firstly review current definitions of innovation and approaches used to define the concept of innovation more precisely (Section 2). Subsequently, we develop the basis of our way out: distinguishing two fundamentally different types of change: the change of the parameters of a system versus the expansion of its dimensions. We identify the first type as ordinary change and the second type as innovation, and explain how the change of a system in its parameters or dimensions can be operationalized methodically in a social process of argumentation and discussion (Section 3). We demonstrate the application of our 'socio-

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mathematical definition of innovation' with three historical cases: (1) tightening the energy efficiency requirements for newly built houses in the Netherlands in the period 1996–2004; (2) transformation in digital business; and (3) decentralization of the youth care in the Netherlands in the period 2011–2015 (Section 4). Finally, we discuss the relevance of our socio-mathematical definition of innovation for theory and practice (Section 5). We close with some conclusions (Section 6).

2. Literature review of definitions of innovation

Searching in the Web of Science, we selected papers with the combination of 'innovation' and 'definition' in the abstract, ranked in terms of relevance. The top 10 papers have been read. For the next 90 papers we started with the abstract only and continued with the entire paper in case the paper seemed to be relevant for providing an accurate definition of innovation. In a few cases we investigated references mentioned in these papers. We focused on literature reviews (Baregheh et al., 2009; Garcia and Calantone, 2002; Hang et al., 2006; Harmancioglu et al., 2009; Oriana et al., 2016; Singh and Aggarwal, 2021; Witell et al., 2016; Varadarajan, 2024; Wolf et al., 2021).

Investigating 208 definitions of innovation, Singh and Aggarwal (2021) found that the word 'new' is the most frequent and consistently used word. An innovation is therefore at least something new or the process of achieving such a thing, which is confirmed by other researchers (Dougherty, 1996; Greve and Taylor, 2000; Poole and Van de Ven, 2004; Quintane et al., 2011; North, 2013; Lopes et al., 2016; Wagner et al., 2016; Godin, 2017; Hochberg et al., 2017; Kogabayev and Maziliauskas, 2017; Granstrand and Holgersson, 2020; Varadarajan, 2024). Since 'new' is a subjective qualification, the difference between an innovation and not-an-innovation ('ordinary change') is unclear, which makes the concept of innovation weakly defined. Our review of the literature shows several ways authors deal with this.

A first way is to ignore the issue, as the review of 238 articles by Harmancioglu et al. (2009) reveals. Many authors characterize the newness aspect simply as 'something new or improved' (Baregheh et al., 2009), 'different from ideas previously implemented' (Varadarajan, 2024), or 'differs significantly from the unit's previous products or processes' (OECD/Eurostat, 2018, p. 20). This does not distinguish innovation from ordinary change.

A second way is to specify *what* is new. This results in the distinction of many classes and subtypes of innovation such as: material innovation, process innovation, product innovation, organizational innovation, social innovation, or systems innovation (Lopes et al., 2016; Garcia and Calantone, 2002). This distinction of classes and subtypes, however, focusses on the definition of a class or subtype of innovation – for instance social innovation (Benzies et al., 2024; Slee et al., 2021), 'deepfake innovation' (Whittaker et al., 2023) or frugal innovation (Hossain, 2018) – but leaves the question of demarcation between the class or subtype of innovation and ordinary change unanswered.

A third approach is to focus on the effects. Wolf et al. (2021) state that the change an invention causes must be novel for this invention to qualify as innovation. Then the newness element of innovation does not concern the invention itself but the change it creates. Other researchers emphasize that such effects should be measurable, such as the raise of profits, market share or customer satisfaction (Schumpeter, 1934; Erez et al., 2013). Literature on responsible innovation (e.g., Stilgoe et al., 2013) has broadened this economic perspective, but without operationalization of newness.

A fourth way distinguishes categories of innovation in terms of degree of novelty. For instance, Varadarajan (2024, p. 713) defines radical (product) innovation as 'the implementation of a novel idea into a new product that offers customers substantially more benefits than existing products and is based on a new technology that is superior to the technology employed in existing products that creates economic value for the innovating firm and functional value for the users of the product'. In contrast, incremental innovation concerns improvement of an existing product and is based on the same technology. Hang et al. (2006) distinguish radical from incremental innovation and disruptive innovation. They see the difference between innovation and ordinary change in the difficulty to positioning innovation in the market and to manage it, so they focus on the business context rather than the contents of the innovation. Oriana et al. (2016) distinguish incremental and breakthrough or radical innovations. The latter are viewed as a broad, arching process of scientific discovery and paradigm shifts (Dosi, 1982; Rogers and Shoemaker, 1983), often characterized by an era of ferment and following convergence into a dominant design or 'standard' (Anderson and Tushman, 1990). These examples illustrate that authors differ in how they define their categories of innovation, but they have in common that they do not define an accurate, general distinction between innovation and 'ordinary change'.

A fifth approach focuses on the process of innovation. If the process occurs as a slow sequence of small steps with a limited reach, 'incremental innovation' is said to be present (Henderson and Clark, 1990; OECD, 2016), in contrast to 'systemic innovation' if the process occurs as a fast, disruptive jump of many elements of a system together (Leifer et al., 2001; Katila et al., 2018). The pace of change and the size of the observed steps, however, depend on the time frame of research and the frequency chosen to sample the progress of the innovation process (Amis et al., 2004). A fast, disruptive jump of many elements together within one year may be qualified as systemic innovation, but when monitoring the progress of the innovation process on a monthly, weekly or daily basis, the systemic innovation may appear the result of a long sequence of small steps. Therefore the distinction between incremental and systemic innovation does not distinguish innovation more clearly from ordinary change.

A sixth way is to specify the broad themes that are related with innovation, for instance the development process, the outcome, and the commercialization of innovation (Schumpeter, 1934). Singh and Aggarwal (2021) distinguish 8 themes innovation is related to and define innovation as: "The operationalization of creative potential with a commercial and/or social motive by implementing new adaptive solutions that create value, harness new technology or invention, contribute to competitive advantage and economic growth". Relating innovation to these broad themes, however, leaves the question of demarcation between innovation and ordinary change unanswered.

The latter is what we are looking for. And indeed, some studies address that distinction, by defining indicators for the degree of novelty relative to familiar or ordinary, or the degree of exploration relative to exploitation by counting the number and type of alliances, patents, or level and type of R&D (Lavie et al., 2010; Rosenkopf and McGrath, 2011; Dziallas and Blind, 2018). But what should then be the caesura? Moreover, anything new without reported economic effects stays out of sight. Hutchison et al. (2015) propose to distinguish between innovation and routine variation, and try to operationalize the differences. Unfortunately, the way they do this is specific to the field they study, surgery, and cannot be generalized to other fields. Garcia and Calantone (2002) state: "*Little continuity exists in the new product literature regarding from whose perspective this degree of newness is viewed and what is new. Although the majority of research takes a firm's perspective toward newness, others look at new to the world, new to the adopting unit, new to the industry, new to the market, and new to the consumer (p. 112). Innovativeness (…) is always modelled as the degree of discontinuity in marketing and/or technological factors' (pp. 112–113)*". Here the question how innovation can be distinguished from ordinary change shifts to the question of "What is discontinuity?" According to Garcia and Calantone (2002, p 113) "*Product innovativeness is a measure of the potential discontinuity a product (process or service) can generate in the marketing and/or process. From a macro perspective, 'innovativeness' is the capacity of a new innovation to create a paradigm shift in the science and technology and/or market structure in an industry. From a micro perspective, 'innovativeness' is the capacity of a new innovation to influence the firm's existing marketing resources, technological resources, skills, knowledge, capabilities, or strategy*" The question however remains how to define a paradigm shift, or how to define the caesura in the change in resources, and how this results in distinguishing innovation from ordinary change.

Overviewing the results of our literature review of definitions of innovation, we conclude that a general, accurate definition of innovation that distinguishes innovation from ordinary change, is missing yet.

3. A socio-mathematical definition of innovation

3.1. *The presence of a dichotomy of change*

The concept of innovation appears weakly defined, and the distinction between ordinary change and innovation is unclear. This may suggest that ordinary change and innovation are part of a continuum of change, in which ordinary change and innovation only differ gradually and where innovation is an accumulation of a lot of ordinary change. In 1974, however, Watzlawick, Weakland and Fisch (Watzlawick et al., 1974) reported that organizations may change in two fundamentally different ways: without or with altering the current basic assumptions or framework. They denoted these types of change as first-order respectively second-order change. Greenwood and Hinings (1996: 1026) also observed the presence of a dichotomy of change and denoted it as convergent change versus radical change: "*Convergent change occurs within the parameters of an existing archetypal template. Radical change, in contrast, occurs when an organization moves from one template-in-use to another*". The innovation literature broadly reports this dichotomy of change and contrasts ordinary change, modification, adaptation, convergent change or variation, to innovation, novelty, radical change, break-through, quantum jump, metamorphosis, transformation, transition, out-of-the-box change, or discontinuity of change (Burns and Stalker, 1961; Kanter, 1983; Cameron and Quinn, 1988; Damanpour, 1991; Gersick, 1991; Orlikowski and Hofman, 1997; Mohrman and Cohen, 1995; Van de Ven et al., 1999; Garcia and Calantone, 2002; He and Baruch, 2009).

3.2. *First-order change versus second-order change of a system*

The description of the dichotomy of change as observed by innovation researchers appears to require 'parameters', 'templates', 'frameworks', 'basic assumptions' and 'the altering of basic assumptions'. Such entities suggest a general modeling technique of physical reality is required. Systems theory (Boulding, 1956; Ashby, 1961; Bertalanffy, 1968; Forrester, 1994; Grewatsch et al., 2023) provides such a general modeling technique. It denotes a set of entities within a specified boundary as a 'system', for instance: a cup of coffee, a computer, a company, a society, an organism, or a network of ecosystems. Systems can be related to other systems and interact. The state of a system can be described mathematically by its state vector, which specifies the state of its characteristic properties at a certain moment of time.

3.2.1. *Example*

Systems theory allows us to describe the change of any system in a formal, mathematical way. We demonstrate this using a simple system consisting of a sheet of paper. If a researcher is only interested in the length and the breadth of the sheet of paper, and not its weight, color, or any other property, its state at time t = 1 can be described by a two dimensional, so called, 'state vector':

$$\begin{pmatrix} a1 \\ b1 \end{pmatrix}$$

where a1 and b1 represent the two characteristic properties of the sheet of paper: its length and its breadth. The sheet of paper can change in two fundamentally different ways.

1. In its **parameters** (= the values noted in the components/entries/elements/cells of the state vector).

$$\begin{pmatrix} a1 \\ b1 \end{pmatrix} \rightarrow \begin{pmatrix} a2 \\ b2 \end{pmatrix}$$

This notation means that the length a1 and the breadth b1 of the sheet of paper at t = 1 change into a length a2 and a breadth b2 at t = 2.

2. In its **dimensions** (= the spaces of values associated with the components/entries/elements/cells of the vector),

$$\begin{pmatrix} a2 \\ b2 \end{pmatrix} \rightarrow \begin{pmatrix} a3 \\ b3 \\ c3 \end{pmatrix}$$

This notation means that the sheet of paper with two characteristic properties: a length a2 and a breadth b2 at t = 2 transforms into a box with three characteristic properties: a length a3, a breadth b3 and a height c3 at time t = 3.

The change of the sheet of paper thus can occur in two fundamentally different ways: in the parameters of its state vector or in its dimensions.

The transformation of the sheet of paper can be visualized in a so called 'Change Process Notation Form' as depicted in Fig. 1, by specifying the sequence of positions of the state vector through time. At the start of the change process at t = 1, the state vector has a position (a1,b1) in a 2-dimensional system space, the so called 'initial system space'. At t = 2 the state vector of the sheet of paper moves towards a new position (a2,b2) within the initial 2-dimensional system space. At t = 3 the state vector moves beyond the initial systemspace into a 3-dimensional system space, specifying the transformation of the sheet of paper into a paper box. The Change Process Notation Form thus visualizes the movement of the state vector of the sheet of paper, within and beyond its initial system space.

3.2.2. *Generalization*

The change of any system X can be described in the same way as demonstrated for the sheet of paper in Figure 1. The construction of the state vector $\boldsymbol{S}(t)$ of X at time 't' starts in the physical domain by identifying its characteristic properties: $\{ cp_i \mid i = 1, 2, \ldots, n \}$. The value of each characteristic property at time 't' can be noted qualitatively or quantitatively as a parameter $cp_i(t)$ of the state vector of X. Consequently, each characteristic property of X in the physical domain is associated with a dimension of the state vector in the mathematical domain.

State vector dimensions	***Movement of the state vector through time t***		
	t=1	t=2	t=3
Length	a1	a2	a3
Breadth	b1	b2	b3
Height	non existent		c3

Fig. 1. *Change Process Notation Form* representing the transformation of a sheet of paper into a paper box, by specifying the movement of its state vector within and beyond its initial system space. 'Yellow' columns specify the state vector position in the system space defined by the 'Green' dimensions in the first column. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

$$\boldsymbol{S}(t) = \begin{pmatrix} cp_1(t) \\ cp_2(t) \\ cp_3(t) \\ \cdots \\ \cdots \\ \cdots \\ cp_n(t) \end{pmatrix}$$

The identification of the characteristic properties of a system is a subjective task. Different researchers will produce different sets of characteristic properties. These differences are often rooted in differences in view of the boundaries of the system, and in differences in telling the change story of the system (Van Maanen, 1988). Discussion between researchers helps to develop a shared view and to gain more insight into the differences that may persist. In section 4 we present a structured approach to develop a shared view on the characteristic properties of a system.

If time changes from $t = t_1$ to $t = t_2$, the state of X changes from $\boldsymbol{S}(t_1)$ to $\boldsymbol{S}(t_2)$. This change of the state vector may consist of.

1. a change of its parameters (='*first-order systems change*'), resulting in a movement of the state vector within its initial system space (= the space shaped by the dimensions of the state vector at $t = t_1$); or
2. an expansion of its dimensions (='*second-order systems change*'), resulting in a movement of the state vector beyond its initial system space

3.2.2.1. Degeneration of the state vector. When a characteristic property of a physical system (e.g. the windshield wiping of a car) functions no more, the system degenerates. Because the nonfunctioning dimension ('windshield wiping') is not removed, the number of dimensions of the system does not change. Consequently, degeneration of the state vector can be viewed as a special case of first-order systems change, by adding a new parameter 'broken' to the initial set of parameters corresponding with the degenerated dimension (e.g. the parameters 'standby', 'interval', 'slow' and 'fast'). Therefore, when a physical system changes, its state vector may either keep moving within its initial system space, in first-order systems change, or may move beyond its initial system space, in second-order systems change.

3.3. Identification of ordinary change with first-order change and innovation with second-order change

Our mathematical definition of first-order change as the change of a system in its parameters and second-order change as the expansion of its dimensions, reflects the dichotomy of change observed by the organization and innovation researchers mentioned in paragraph 3.1, and allows us to identify the change of a system in its parameters with ordinary change, modification, adaptation, convergent change or variation, and to identify the expansion of the dimensions of a system with innovation, novelty, radical change, break-through, quantum jump, metamorphosis, transformation, transition, or out-of-the-box change, discontinuity of change (see Table 1).

As changing the parameters of a vector can never result in the expansion of its dimensions, first-order change cannot transform into second-order change. Therefore, first- and second-order change are not part of a continuum of the same type of change, but are two fundamentally different, singular types of change. Every theory dealing with change needs to take this dichotomy of change into account (DeJong and Degens, 2024).

3.4. The relevance of distinguishing first-order change/ordinary change and second-order change/innovation

In ordinary change, the state vector of an (organizational) system moves within its initial system space. The initial system space is known and can be investigated in more detail if necessary. Therefore, the position of an intended goal of ordinary change can be specified accurately before the change process start, even if the goal is far away as a 'dot at the horizon'. In second-order change/innovation, the intended goal lays beyond the initial system space in unknown system space, and is in fact a presumed goal, an ideal picture, a dream, or a 'dot behind the horizon'. As a consequence, the position of the presumed goal of innovation cannot be specified in detail before the change process starts. The true position of the presumed goal and a path towards it can only be discovered by entering unknown system space followed by experiential (second-order) learning. As a consequence, ordinary change and innovation differ fundamentally in their dynamics of planning, acting and learning, in their management of knowledge, uncertainties and human dynamics. Both theory and practice of innovation need to reckon with these differences. In paragraph 5.3, we will elaborate this in more detail.

3.5. Operationalization

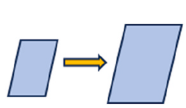
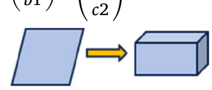
Our mathematical definition of innovation requires an operationalization that distinguishes whether a system changes in its parameters or in its dimensions. This distinction requires not only a mathematical framework derived from systems theory, but also social processes of argumentation and discussion. This results in a 'socio-mathematical definition' of innovation.

Step 1: Develop a shared change story of the system

Usually, observed change is firstly reported and recorded narratively in a free form as a change story, which describes what has changed, how, and why (Van Maanen, 1988). Change stories may also describe intended change or a set of future scenarios.

When studying the change of a system, for instance a coffee cup or the health care system of a country, numerous aspects may be investigated. When describing the change of system narratively in a change

Table 1
Mathematical definition of first-order change/ordinary change versus second-order change/innovation.

	First-order change/ordinary change	Second-order change/innovation
Definition	Change of the parameters of a system	Expansion of the dimensions of a system
Alternative definition	Movement of a system within its initial system space	Movement of a system beyond its initial system space
Mathematical representation	$\begin{pmatrix} a1 \\ b1 \end{pmatrix} \rightarrow \begin{pmatrix} a2 \\ b2 \end{pmatrix}$	$\begin{pmatrix} a1 \\ b1 \end{pmatrix} \rightarrow \begin{pmatrix} a2 \\ b2 \\ c2 \end{pmatrix}$
Visualization		
Alias	Convergent change, variation, adaptation, modification	Radical change, novelty, transformation, transition, metamorphosis, break-through, quantum jump, out-of-the-box change, discontinuity of change

story, however, usually only a few aspects play a role in the description of what changes, when, how and why. Researchers, experts, policy makers, change agents, (innovation) managers, executives will all produce different change stories. Therefore, discussion between these stakeholders of the various change stories is needed to develop a shared vocabulary (Fox et al., 2019), and to construct a shared story of the observed or intended change process and to gain more insight into the differences of view that may persist. This shared change story is the starting point of the operationalization process and prevents researchers to give attention to every researchable aspect of the changing system and as a result be drowned in a multitude of longitudinal data.

Step 2: Specify the boundaries of the changing system

The boundaries of the system at the start of the change process must be specified explicitly. These boundaries may not be changed in step 5, when the change of the dimensions of the system is assessed. For instance, for an organization that only uses cash the introduction of electronic payment will be a change into a new dimension, notwithstanding that beyond the boundaries of this organization electronic payment has been broadly adopted already.

Step 3: Specify the characteristic properties ('dimensions') of the changing system.

From the change story developed in step 1, the characteristic properties or 'dimensions' of the changing system are identified and recorded in the first column of a Change Process Notation Form (CPNF) as shown in Fig. 1. Stakeholders may all produce different first columns. Discussion between them of the differences is needed to develop a shared view and to gain more insight into the differences that may persist.

Step 4: Specify the parameters of the initial state vector.

From the change story recorded in step 1, the parameters of the dimensions of the initial state vector of the changing system are described qualitatively in column 2 of the CPNF. As the change story records narratively the change of the observed system, qualifications as, for instance, 'high', 'low', 'moderate', 'small' or 'big' may be used to specify the parameters of the initial state vector. The specification of column 2 requires discussion between the stakeholders of the (intended) change process to develop a shared view and to gain more insight into the differences that may persist.

Step 5: Describe the observed or intended change process by a set of sequential state vectors and assess whether the initial state vector only changes in its parameters or also in its dimensions.

After having specified the dimensions of the initial state vector in column 1 of the CPNF and the qualitative value of its parameters in column 2, the unfolding change process can be described by a set of sequential state vectors, which can be recorded in the next columns of the CPNF. For each state vector it must be assessed whether it changes into a subsequent state vector only by changing its parameters, or by addition of one or more dimensions. Those who claim the presence of innovation have to convince others that the observed or intended change cannot be described adequately by varying only the parameters of the state vector but requires expansion of its dimensions. For instance, some observers will contend that the replacement of a sugar bag by a sugar stick (in the Netherlands driven by a covenant with the packaging industry to reduce packaging waste) is ordinary change because it is only a variation of the parameter that describes the width of the bag, while other observers will hold that it is an innovation because the sugar bag changes into a new dimension of look-and-feel. If the set of state vectors describing the change process consist of no more than the initial state vector and a state vector describing the end state of the change process, disagreement on the presence of innovation can be reduced by sampling the observed or intended change process more frequently and studying the proceeding of the change process in more detail. Disagreement may remain whether or not innovation is present, but subjectivity will be reduced considerably by discussing the changes in the parameters or dimensions of the state vector of a changing system, instead of discussing the newness, novelty or substantiality of the observed change. The structuring of the set of sequential state vectors in the CPNF helps to handle the longitudinal research data, usually a major challenge (Langley, 1999).

Step 6: Make several cycles of adjustment between the change story and the representation of the change process by a set of sequential state vectors

When transforming the change story developed in step 1 into a set of sequential state vectors, usually more detail is required in telling the change story. For that, return to the basic research data or additional research of the change process is necessary. On the other hand, the distinction of the characteristic properties of the changing system and the specification of the system boundaries helps to reduce the details of the change story and to focus the change story on the key aspects of the change process. The interaction between the narrative description and the mathematical description of the (intended) change process results in mutual improvement of their accuracy, which allows distinguishing innovation more clearly from ordinary change.

4. Demonstrations of the application of a socio-mathematical definition of innovation

We will now demonstrate the application of our socio-mathematical definition of innovation on three historical cases: (1) tightening the energy efficiency requirements for newly built houses in the Netherlands in the period 1996–2004; (2) transformation in digital business; and (3) decentralization of the youth care in the Netherlands in the period 2011–2015. The first case, we will describe in detail, the second in less detail, and the third broadly. With this variety of cases, we stress the general applicability of our socio-mathematical definition of innovation.

4.1. The case of improving the energy performance of houses

4.1.1. Change story

From 1996, newly built houses in the Netherlands had to meet a minimal level of energy efficiency, as part of the governmental policy to reduce CO_2 emissions (De Vries and Verhagen, 2016). A standardized method, agreed between 46 different stakeholders, mainly from the construction industry, was used to calculate the energy performance coefficient (EPC) of a house from its design, based on characteristics such as shape, heating, insulation, and ventilation systems. Only if the calculated EPC met at least the level demanded by the government, a permit to build could be obtained. By tightening the EPC-level, the government could force suppliers of heating, isolation and ventilation systems, architects, construction firms and research institutes, to contribute to the improvement of the energy performance of newly built houses. This would stimulate suppliers of technologies for, for instance, heating, isolation and ventilation to invest in further innovation. In the observed period of 9 years, the required EPC-level was tightened three times. In the periods that the EPC-level was not tightened, the architects and construction companies only made relatively small changes in their houses, for instance, by optimizing the shape of the fans of ventilation systems, by making the parts of a yet applied heating system more compact, or by thickening the insulation of roofs. During this periode, new types of heating, insulation and/or ventilation technology were introduced, for instance solar boilers, heat pumps, rigid plastic foam as insulation material, active ventilation and reuse of heat. Sales of these increased at the moments of tightening of requirements.

Tightening of the EPC-level not only stimulated the development and use of new technologies, but also triggered to use new techniques, for instance modular building with modules that incorporate integrated energy systems. The tightening also forced the forming of networks of cooperation within a sector that is characterized by 'stand-alone' actors (e.g., architects, construction companies, suppliers) who were used cooperate per project but have other cooperation partners in the next project. The tightening of requirements triggered them to establish lasting cooperation, and initially informal cooperation changed into formalized cooperation. In addition, the knowledge base for building houses expanded with new knowledge on, for instance, solar heating, geothermic information of the deep grounds of cities, modular building design and construction, or the legal shaping of network organizations.

4.1.2. *Translation of the change story into a set of sequential state vectors*

The change story above of tightening the energy efficiency standard for newly built houses, tells about the change process of a system consisting of the set of newly built houses in the Netherlands, the surrounding organizations of design, supply and construction, public policy and standardization. To enhance our view of the change process, we

State vector aspects / ***State vector dimensions***	***Movement of the state vector through time***							
	1996	1997	1998	1999	2000	2001	2002	2003
Standardization								
Energy performance coefficient	1.4	1.4	1.2	1.2	1	1	1	1
Heating technology								
Gas condensing boiler	4%	7%	0%	0%	0%	0%	0%	0%
* *improved efficiency*	92%	83%	50%	54%	10%	12%	25%	4%
* *optimized sizes of its parts*	0%	6%	40%	44%	60%	75%	35%	92%
Solar boiler	4%	4%	10%	2%	20%	0%	15%	0%
Heat pump	nonexistent				10%	13%	25%	4%
Isolation technology								
Rock wool	100%	100%	90%	80%	70%	50%	30%	20%
Rigid plastic foam			10%	20%	20%	20%	30%	20%
* *increased thickness*	nonexistent		nonexistent		10%	30%	40%	60%
Ventilation technology								
Natural inlet, mechanical outlet	100%	83%	60%	63%	5%	7%	0%	15%
* *optimized fans*	0%	17%	30%	35%	65%	42%	75%	70%
Inlet compensation for wind pressure	nonexistent		3%	0%	0%	3%	8%	0%
Exchange of heat between outlet and inlet	nonexistent		7%	2%	30%	48%	17%	15%
House building techniques								
Initial building techniques	fully present	fully present	fully present	fully present	slightly diminishing	slightly diminishing	diminishing	diminishing
Modular building with integrated energy management	nonexistent				upcoming	upcoming	expanding	expanding
Organization of building new houses								
Stand alone designers, suppliers and constructors	mainly	mainly	mainly	mainly	mainly	slightly diminishing	diminishing	diminishing
Networks of researchers and builders	nonexistent					upcoming informal networks	expanding informal networks	upcoming formal networks
Knowledge base								
Knowledge on initial technology	present	present	slightly diminishing	slightly diminishing	slightly diminishing	diminishing	diminishing	diminishing
Knowledge of innovative technology and cooperation	nonexistent		limited expansion	limited expansion	limited expansion	expansion	expansion	expansion

Fig. 2. *Change Process Notation Form* representing the transformation of the system of newly built houses in the Netherlands (1996–2004).

translate the narrative description of it into a set of sequential state vectors.

Firstly, we describe the dimensions of the initial state vector of the changing system in column 1 of an Excel table, clustered per aspect of the change process. From the change story we distinguish the following aspects: 'Standardization', 'Heating Technology', 'Insulation Technology', 'Ventilation Technology', 'Housebuilding Techniques', 'Organization of building new houses', and 'Knowledge Base'. Secondly, we derive from the change story and the underlying research data the parameters of the initial state vector, describing the rate of application of each dimension at the start of the change process, and record them in column 2 of the Change Process Notation Form (CPNF).

Having specified the initial state vector and its parameters, we now translate the change process, as described by the change story and the underlying research data, into a set of sequential state vectors, which may change in their parameters or in their dimensions (see Fig. 2).

In the aspect 'Heating Technology', the initial technology consists of a gas condensing boiler, which is improved by changing the parameters of the yet existing components, resulting in ordinary change. The introduction, however, of a heat pump driven by a sterling motor is a change of the heating technology into a new dimension, and thus is an innovation.

In the aspect 'Insulation technology', rock wool is the initial technology. This aspect expands ino a new dimension, by the introduction of rigid plastic foams. Increase of the thickness of the plates is a change in a parameter, and thus ordinary change.

In the aspect 'Ventilation Technology', the initial technology consists of natural inlet and mechanical outlet. Optimization of the fans of the ventilator, is a change in the parameters of the technology and thus ordinary change, in contrast to the addition of a compensation system for wind pressure or the application of heat exchange between outlet and inlet, which are expansions of the state vector aspect into new dimensions, and thus innovations.

In the course of tightening the EPC, the aspect 'House building techniques', expands into a new dimension by the introduction of modular building with modules that incorporate integrated energy management systems.

The organization of the building of houses is characterized by individualistic, stand-alone design, supply and construction firms. Tightening the EPC led to the emergence of informal networks, which under the pressure of further tightening of the EPC started to change into more formal constructions of cooperation, with which the aspect 'Organization of building new houses' expands into a new dimension.

In the course of tightening the EPC, the knowledge base for the application of the initial technology, building techniques and organization, expanded into new dimensions by the addition of new knowledge on, for instance, solar heating, geothermic information of the deep grounds of cities, modular building design and construction, or the legal possibilities for building network organizations.

4.1.3. *Evaluation*

The case of the tightening of the energy efficiency requirements for newly built houses illustrates that change processes usually proceed in steps. Although such steps are often called 'incremental innovations', our socio-mathematical definition of innovation reveals that not every 'incremental innovation' is an innovation (whereby the state vector expands into a new dimension), but is often an adaptation, modification or optimization of one or more parameters of the state vector of the system, resulting in ordinary change. In addition, the case illustrates that innovation often starts in technology, but induces step by step innovation in other (soft) aspects, whereby the entire systems changes into new dimensions: 'systemic innovation'. Systemic innovation thus unfolds step by step and thus does not stand opposite of incremental innovation.

In the periods that the EPC-level was not tightened, the architects and construction companies lacked incentives to change their houses into new dimensions (apparently a costly and demanding task), but rather consolidated and optimized their houses by changing only the parameters of these in ordinary change, for instance by applying ventilation systems with slightly better fans, by using a heating boiler with higher efficiency, or by thickening the insulation of roofs. These adaptations and modifications even led to deleting costly innovations that were introduced initially.

The narrative description of the effects of tightening the prescribed energy efficiency level of newly built houses, thus can be transformed into a sequential set of state vectors described in the Change Process Notation Form shown in Fig. 2. The form shows both numerical and non-numerical parameters. The latter can be transformed into numerical parameters using, for instance, a five-point scale (Kelle, 1995; Langley, 1999). After this transformation, the '*speed*' or '*flow*' of state vector element S_{ji} at $t = t_i$ can be described by $\Delta S_{ji}/\Delta t_i = (S_{ji} - S_{ji\text{-}1})/(t_i - t_{i\text{-}1})$ and its acceleration by $\Delta^2 S_{ji}/\Delta t_i^2$, which is related to the rate of energy – the '*flux*' – that passes the boundaries of the changing system (Benenson et al., 2002). The size of n determines the accuracy of the description: the larger n, the smaller the distance between subsequent state vector positions and the more accurately the movement, flow and flux of the state vector through system space is specified. If n is as small as 2 or 3, the longitudinal description of the change process turns into a cross-sectional description, which hinders the study of the dynamics of the change process (Rajagopalan and Spreitzer, 1997; Kunisch et al., 2017).

4.2. *The metamorphosis of a customer support department*

4.2.1. *Change story*

The management of the customer support department of a big software company wants timely and well-structured information on the problem-solving activities by the experts of the department, instead of the dated and inapplicable information filed in the outdated computer system presently used (Orlikowski, 1996). Over several cycles of programming, testing and adaptation, a new information system based on state-of-the-art data base management technology is developed. The implementation of the new system, however, fails. The experts appear unwilling to change their habit of scribbling some data on paper during the day and filing it in the computer system at the end of the day or later. The managers therefore decide to change the system fundamentally: not the experts but the computer will record the time when a problem or action is filed, and files will be locked to prevent subsequent editing. Now, real-time information is obtained, giving the management a completely new view of the activities of their employees, and a process of function differentiation and structuring of working relations starts. The content of the new functions and structures gets shape in a process of searching and learning, drawing on the informal clustering of working relations that emerges among the experts. After some time, it appears that the expert knowledge stored in the new information system is valuable to the other units of the company, and the dissemination and selling of knowledge becomes a new business activity, inducing changes in other units of the company. Since the new information system offers the experts a real-time view of the activities of their colleagues, gradually new patterns of interaction between them get shape. After three years, the department has undergone a metamorphosis.

4.2.2. *Translation of the change story into the movement of a state vector*

From the change story of the metamorphosis of the customer support department, we identify four main aspects of the organization that were changing: its technology, knowledge, organizational structure, and business processes. We break down each aspect into a number of characteristic properties – 'dimensions' – and note them in column-1 of the Change Process Notation Form (CPNF) as pictured in Fig. 3. In column-2 we note for each dimension the qualitative or quantitative value of the state vector at the start $t = t_0$ of the change process when the outdated computer system is still in use. We distinguish the following subsequent moments of time: $t = t_1$ when a new computer system based on expert

State vector aspects	State vector dimensions	Movement of the state vector through time				
		t=t0	t=t1	t=t2	t=t3	t=t4
Technology						
	Data storing capacity	limited	moderate	good	high	very high
	data management	poor	moderate	good	excellent	excellent
	Expert controlled filing	highly retrospective	retrospective	largely abandoned	abandoned	abandoned
	Computer controlled filing	nonexistent		real-time, prescribed	real-time, formalized	real-time, formalized
Knowledge						
	Mentally stored help expertise	fragmented	fragmented	related	connected	highly connected
	Computerized help expertise	poor	limited	moderate	good	excellent
	Real-time control information	nonexistent		existent	expanded	further expanded
Organizational structure						
	Working relations	ad hoc	ad hoc	informally clustered	slightly formalized	formalized
	Hierarchy of functions	nonexistent			function differentiation	hierarchical functions
Business processes						
	Solving problems (probl./expert/day*)	3	3	4	5	6
	Dissemination of knowledge	nonexistent				existent

Fig. 3. *Change Process Notation Form* of the metamorphosis of a software company's customer support department (Orlikowski, 1996), represented by a moving state vector within and beyond its initial system space.

controlled filing becomes operational; $t = t_2$ when computer controlled filing is implemented and the management obtains a real-time view of the activities of their employees; $t = t_3$ when formalized functions and structured working relations become operational; and $t = t_4$ when the dissemination and selling of knowledge get shape, and a formal structure of functions and working relations is implemented. Filling in the columns of the CPNF for these moments of time, we find that the state of the system at $t = t_1$ can be described by a variation of the parameters of the initial state vector. At $t = t_2$, however, the change of the technology aspect of the organizational system can no longer be represented by only a variation of the corresponding parameters of the initial state vector, and expansion of the technology and the knowledge aspect into a new dimension – the presence of real-time computer controlled filing, respectively the presence of real-time control information – is necessary to describe the observed change adequately. At $t = t_3$, expansion of the organizational structure aspect into a new dimension – the presence of formalized functions – is necessary, and at $t = t_4$ expansion of the business process aspect into a new dimension – the selling of knowledge – is required to describe the progression of the change process adequately. The set of state vectors $\{S_i \mid i = 0, 1, 2, 3, 4\}$, as noted in the CPNF structures the longitudinal observations of the changing system, and translates the change story of the customer support into the movement of a state vector. Between t_0 and t_1, the state vector moves within the system space spanned by the dimensions of the initial state vector – the 'initial system space'; after $t = t_1$, it starts moving beyond it.

4.2.3. Evaluation

Our socio-mathematical definition of innovation functions as a lens that helps to reveal not only the effects of the introduction of the computerized filing system on the technological aspect of the software company but also the induced changes on its knowledge, organizational structure and business processes. Observation of the induced changes requires 'a long breath', which often does not fit within a few years of PhD or postdoc research.

4.3. The decentralization of the youth care in The Netherlands (2012–2015)

4.3.1. Change story

In January 2015, the Youth Act came into effect in the Netherlands, which decentralized specialized youth care from the level of the provinces to the level of partnerships of municipalities (Bosscher, 2014; Van Gerven, 2019; Grevinga and Van Hattem, 2021). The aim was to provide youth care in closer coherence with other care processes within a municipality, which would increase effectiveness and efficiency. The management of the decentralization process, which started in 2012, was assigned by the Ministry of Health, Welfare and Sport (Ministerie van Volksgezondheid, Welzijn en Sport; VWS) to the so called Transition Committee (TC), which included representatives of the Ministry of VWS, the Association of Dutch Municipalities (Vereniging van Nederlandse Gemeenten; VNG), and youth care experts from practice and science. In 2012, the TC instructed the municipalities to establish regional partnerships and to develop a plan for the decentralization of the youth care from the provinces to their regional partnership. The TC provided financial resources for this. All municipalities took part in a regional partnership, and each partnership produced a sketchy vision of the intended future and how to achieve it. These sketchy plans were shared. Subsequently, most partnerships approached the change process as a lot of ordinary change and started to elaborate the sketchy vision in detailed designs and plans for the establishment of various types of youth care as to their organizational, juridical and financial aspects, their inter relations and the relations with other processes in the social domain. These detailed designs and plans, however, drowned in uncertainty and complexity. A small number of regions, in contrast, had started to actually move towards their sketchy vision of the future in pilots, and were gaining practical experience with how decentralized youth care could actually be achieved. The TC stimulated the sharing of these results and the knowledge from good practices was actively disseminated during frequent national meetings. New characteristic properties of decentralized youth care were developed in practice, in fast moving cycles of planning, acting and learning, with regard to cooperation, purchasing procedures, legal anchoring, and quality assurance. Existing purchasing of youth care by the provinces, organization and financing were transferred step by step in an increasing number of broadening pilots to the regional partnerships. The transformation process was monitored by the TC with a public monitor revealing the progress of each regional partnership and by frequent dissemination of good practices. In the course of the decentralization process, the business processes of the municipalities expanded into new dimensions, as to the planning, purchasing, supply and financing of youth care and the knowledge base to do so. Pilots were broadened and transformed into structural changes and finally into the complete transfer of the planning, purchase and supply of youth care to the regional partnerships and the municipalities by January 2015, when the Youth Act came into effect. During 2015, the knowledge base for the decentralized youth care at the level of the regions was expanded and consolidated; the transfer of knowledge from the level of the provinces was completed; and the integration of youth care with other processes in the social domain began to get shape in pilots in many municipalities.[1]

4.3.2. *Translation of the change story into the movement of a state vector*

See Fig. 4, without further explanation.

4.3.3. *Evaluation*

Firstly, case 3 illustrates that our socio-mathematical definition of innovation is not only applicable in technology and business environments but also in public administration.

Secondly, the case also illustrates that innovation can easily be misjudged as a lot of ordinary change. Even after acknowledging that innovation is not a lot of ordinary change, the making of detailed designs and plans stays to be an attractive activity in change projects, while starting actual change without certainty on the position of the goal to achieve and the path to follow is suspect and opposed to the trusted ways of working of policy makers, project workers, managers and executives. Therefore, it is desirable that starting actual change does not concern the entire system, but is limited to pilots that can be easily be adjusted and not only result in (second-order) learning in short time, but also deliver a profit of some kind in short time, for instance the solving of a problem or the reduction of costs.

Thirdly, the case shows that after entering unknown systemspace, a long period of time may be needed to develop the new dimensions, in many fast moving cycles of planning, acting and learning. This makes innovation challenging for researchers, policy makers, innovation managers and executives, who all usually must deliver results within a short time frame.

5. Discussion

The concept of innovation is defined without reaching consensus, but in any case it concerns something new or the process of achieving such a thing. Since 'new' is a subjective qualification, the concept of innovation is weakly defined, and the difference between an innovation and not-an-innovation ('ordinary change') stays unclear.

The aim of our research is to present a more accurate, general definition that addresses the most relevant element of any definition of innovation: newness, and distinguishes innovation from ordinary change.

From our review of definitions of innovation, we have identified 7 approaches to specify 'new' more accurately, but found that they do not produce a general, accurate distinction between innovation and ordinary change. Our review confirmed that a general, accurate definition of innovation that distinguishes innovation from ordinary change is missing yet. As a consequence, innovation and ordinary change may be viewed as part of a continuum of change, in which innovation is just a lot of ordinary change. This vision however is contradicted by the finding of innovation researchers of a dichotomy of change. Using systems theory as a general modeling technique, we have revealed the presence of two fundamentally different types of systems change: the change of the parameters of a system, versus the expansions of its dimensions. The first type we have identified as ordinary or first-order change and the second type as innovation or second-order change. We have explained how our mathematical definition of innovation, combined with social processes of argumentation and discussion, can be operationalized methodically, and demonstrated this in three historical cases. We will now discuss the relevance of our socio-mathematical definition of innovation for theory and practice.

5.1. *The difference with current definitions of innovation*

Our socio-mathematical definition of innovation as the expansion of the dimensions of a system, does not build on the current definitions of innovation. Instead, it applies new concepts as 'system', 'parameters' and 'dimensions'. It raises the distinction between innovation and ordinary change from the level of discussing the word 'new', to the level of discussing the dimensions of a changing system and deciding whether yet dimensions change in their parameters or new dimensions must be added. Indeed, disagreement may persist, but the disagreement can be specified more accurately in terms of parameters and dimensions, than the disagreement on what is 'new'.

5.2. *A lens to observe systems change more accurately*

Our socio-mathematical definition of innovation functions as a lens that helps to observe changing systems more accurately, and to distinguish innovation from ordinary change. It is applicable on a macro level, as demonstrated in case 1 and 3; on a meso level, as demonstrated in case 2; and on a micro level, for instance by revealing the development of new dimensions in the aspects 'shopping', 'cooking skills', and 'values' of a family, after adoption of a vegetarian life style by one of the children.

Often, the application of the concept of innovation is restricted to new technology or products. Our socio-mathematical definition generalizes innovation to all aspects of a system, both the hard and soft aspects, as demonstrated in the 3 cases: for instance technology, processes, knowledge, network organization, juridical procedures, planning, integration, and quality control.

In addition, our socio-mathematical definition reveals the alternations between ordinary change and innovation, and also reveals that innovation in one aspect of a system may induce innovation of other aspects, as demonstrated in our cases, and confirmed by other researchers (Burns and Stalker, 1961; Kanter, 1983; Kline, 1985; DeJong, 1994; Orlikowski, 1996; Orlikowski and Hofman, 1997; Lewin and Volberda, 1999; Van de Ven et al., 1999; Caves, 2000; He and Baruch, 2009; Scarbrough et al., 2015). Innovation thus is a multi-dimensional phenomenon (Damanpour and Schneider, 2006; Rosenkopf and

[1] The description of the transformation process was provided by G.V.A. Mulder, transition manager during 2012–2015 for the region IJmond, comprising the cities Velsen, Beverwijk and Heemskerk.

<table>
<tr><th>State vector aspects
State vector dimensions</th><th colspan="5">Movement of the state vector through time</th></tr>
<tr><td></td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td></tr>
<tr><td>Centralized Youth Care by the Provinces</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Planning by the provinces</td><td rowspan="6">fully present</td><td rowspan="6">in a few pilots partly transferred</td><td rowspan="6">in many pilots partly transferred</td><td rowspan="6">in many municipalities partly transferred</td><td rowspan="4">in all municipalities transferred</td></tr>
<tr><td>Purchase and quality control by the provinces</td></tr>
<tr><td>Supply by the provinces</td></tr>
<tr><td>Financing at the level of the provinces</td></tr>
<tr><td>Juridical procedures at the level of the provinces</td><td>stopped</td></tr>
<tr><td>Knowledge base at the provinces on centralized Youth Care</td><td>partly transferred</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Decentralized Youth Care by regional cooperating cities</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Planning by the regional cooperating municipalities</td><td rowspan="6">nonexistent</td><td rowspan="6">in a few pilots partly present</td><td rowspan="6">in many pilots partly present</td><td rowspan="6">in many municipalities partly present</td><td rowspan="4">in all municipalities present</td></tr>
<tr><td>Purchase and quality control by the regional cooperating the municipalities</td></tr>
<tr><td>Supply by the municipalities</td></tr>
<tr><td>Financing at the level of the cooperating municipalities</td></tr>
<tr><td>Juridical procedures at the level of the municipalities</td><td>in all municipalities partly present</td></tr>
<tr><td>Decentralized knowledge bases for decentralized youth care</td><td>in all municipalities partly present</td></tr>
<tr><td>Integration of Youth Care with other process in the social domain of municipalities</td><td colspan="3">nonexistent</td><td>in a few pilots partly present</td><td>in many pilots partly present</td></tr>
</table>

Fig. 4. *Change Process Notation Form* of the decentralization of youth care in the Netherlands in the period 2012–2015, represented by a moving state vector, beyond its initial system space.

McGrath, 2011).

5.3. The different dynamics of ordinary change and innovation

The study of the dynamics of innovation and knowledge is a major research area (Teece et al., 1997; Eisenhardt and Martin, 2000; Vögel and Güttel, 2013). Our socio-mathematical definition of innovation helps to understand the different dynamics of innovation in comparison with the dynamics of ordinary change.

In ordinary change, the state vector of an (organizational) system moves within its initial system space. The position of an intended goal within the initial system space can be specified in detail before the change process start, even if the goal is far away like a '*dot at the horizon*', because knowledge on the dimensions of initial system space and how they interrelate is present or can be obtained by extrapolating the present knowledge, or by investigating the initial system space in more detail. Subsequently, the path through the initial system space to attain the intended goal can be planned in the most efficient way and be specified in detail before the change process starts. Uncertainty can be eliminated by thorough research beforehand, which makes experiential learning during the change process unnecessary. As a consequence, planning, acting and learning can be separated. Only after finishing the change process, evaluation and learning is recommended for the benefit of future change processes, resulting in the adjustment and expansion of the knowledge base on the initial system space. Execution of a process of ordinary change requires skilled researchers and planners, and managers that are able to accurately execute plans and stick to time tables. Managers of ordinary change should direct the energy and human dynamics of their team to the predefined goal, path and planned actions. The vast literature of planned change confirms these characteristics (Porter, 1985; Hamermesh, 1986; Chakravarthy and Lorange, 1991; Mintzberg, 1994; Tenner and DeToro, 1996; Beer and Nohria, 2000; Cleland and Ireland, 2002; Allen et al., 2007; Ryan et al., 2008; Bisel and Barge, 2010; Mitchell, 2013; Rosenbaum et al., 2018).

In innovative change, the state vector moves beyond the initial system space and expands into new dimensions. The knowledge base on the properties of the new dimensions and their interactions, and the interrelations with the yet existing dimensions of the initial system space, is largely missing. As a consequence, the position of the presumed goal beyond the initial system space cannot be specified in detail before the change process starts. The presumed goal is an ideal picture, a dream, or a '*dot behind the horizon*', or may emerge, for instance by tightening a performance standard. Uncertainty on the presumed goal and path cannot be reduced by thorough research and planning beforehand. The true position of the goal and a path towards it can only be discovered by entering unknown system space. Fast moving cycles of planning, acting and experiential learning are needed to reduce uncertainty and to develop the knowledge base on the expanded system space. Experiential learning is required, not only as to the path to follow but also as to the true position of the goal (second-order learning). Execution of a process of innovative change requires a team of flexible, agile, driven change agents with the ability to live with uncertainty, to improvise and to learn from practical experiences. Managers of innovation need to be able to respond continuously to uncertainty, new discoveries, new insights and unexpected circumstances and the interaction with the team members and the human dynamics involved. The vast innovation literature confirms these characteristics (Kanter, 1983; Kline, 1985; Coopey et al., 1997; Cummings and Worley, 2001; De Meyer et al., 2002; Mumford and Licuanan, 2004; Damanpour and Schneider, 2006; Cinite et al., 2009; Antunes and Pinheiro, 2020).

Ordinary change and innovation thus differ fundamentally in their dynamics of planning, acting and learning, in their management of knowledge, uncertainties and human dynamics (see Table 2). Both theory and the practice of innovation need to reckon with these dynamical differences.

5.4. Innovation management versus quality management

The distinction between ordinary change and innovation has been made in quality management literature as well, using different terms. Jouslin De Vries (2006) was the first to make the distinction between four phases of quality management: conformity, continuous improvement, breakthrough, and reaching the essential. Van Kemenade and Hardjono (2019) see these phases as four paradigms that exclude each other. From its description, 'breakthrough' is similar to our concept of innovation, whereas 'improvement' is similar to ordinary change. Innovation/breakthrough deviate from the traditional focus of quality management: control and (continuous) improvement. The main textbooks in quality management ignore innovation entirely (Beckford, 2016; Dale et al., 2007; Oakland, 2014) or describe how quality management may contribute to the design process in innovation management, implicitly separating the two. In quality management, improvements are the result of systematic approaches such as Plan-Do-Check-Act, for which several tools have been developed. The fact that such approaches and tools can be used confirms that the improvements are ordinary changes. In contrast, innovation is 'different from the one to which one was accustomed' (Jouslin de Noray, 2004, p. 9). Our socio-mathematical definition of innovation puts this in perspective: innovation adds a dimension to what can be achieved with quality improvements. Therefore, innovation management differs from (and builds on) quality management.

Table 2
Differences between ordinary change and innovation as to the dynamics of planning, acting and learning, uncertainties, knowledge management and human dynamics.

	Ordinary change	Innovation
Socio-mathematical definition	change of the parameters of a system	Expansion of the dimensions of a system
Intended goal	within the initial system space can be specified in detail before the change process starts	beyond the initial system space cannot be specified in detail as it is beyond the horizon; finding its true position requires second-order learning
Planning, acting and learning	can be separated	must proceed in short cyclic alternation
Knowledge	all necessary knowledge can be gained before the change process starts	knowledge from beyond the initial system space lacks and must be gained by experiential learning; this requires movement beyond the initial system space into uncertainty
Uncertainties	uncertainties are reduced or eliminated by accurate research and planning beforehand	uncertainties are reduced by making short cycles of planning, acting and learning
Competencies of the project team	able to accurately execute prescribed tasks	able to live with uncertainties, to learn from experience and to overcome unforeseen problems
Competencies of the managers	able to accurately and timely execute plans	able to live with uncertainties, and overcome unforeseen problems, and to inspire and support the team

5.5. More accuracy in explaining the innovation standardization paradox

Standardization may be accused of hindering innovation, as it freezes aspects of changing systems (David and Steinmueller, 1994; Tassey, 2000; Swann, 2005). Nevertheless, standardization also may stimulate innovation (Choi et al., 2011; Hawkins et al., 2017; Teece, 2018; Blind et al., 2017; Navarro Gonzalez, 2022). Our mathematical definition of innovation helps to clarify this paradox and reveals in more detail the complex interaction between standardization and innovation.

Firstly, freezing aspects of changing systems by standardization results in a beneficial reduction of complexity and uncertainty, but may hinder the fast-moving cycles of planning, acting and experiential learning that are required to expand the state vector of a changing system into one or more new dimensions. This hindering can be avoided if standardization is combined with built-in flexibility and adaptability, as the case of the standardization management of the energy efficiency of new houses in the Netherlands demonstrates (De Vries and Verhagen, 2016). On the one hand a performance standard for the energy efficiency (EPC) was set by government, which was tightened step by step, forcing the building companies to replace modifications by innovations and resulting in a shake-out of non-innovative companies. On the other hand the hindering of innovation by frozen standards was avoided by keeping the procedure for the calculation of EPC adaptable to incorporate new systems for heating, insulation and ventilation via revisions of the standard. Moreover, for innovative technologies for which the calculation method was not fit, an alternative was available: calculation by an independent research organization. Such a combination of standardization combined with built-in flexibility and adaptability of the applied standard(s) seems, for instance, also required for the innovative reuse of building materials, as actual standards may prevent the reuse of building materials for purposes they initially were not meant for. Egyedi and Blind (2008) also describe this combination of standardization and flexibility. Van den Ende et al. (2012) relate the flexibility of applied standards to changes in the set of stakeholders involved in developing the standard. In the Dutch energy performance case, 46 different stakeholders were represented in the committee developing it.

Secondly, innovation not only comprises the hard, technical aspects of organizations and industries but also their more soft aspects, such as their structures of cooperation and their culture, as in the case of energy efficiency of newly built houses in the Netherlands. The construction industry was a domain of independent, 'loosely coupled' firms (Weick, 1976; Orton and Weick, 1990; Dorée and Holmen, 2004). Only when participating in a specific project, their activities needed to have a logical order and cooperation was required, making them 'tightly coupled' (Dubois and Gadde, 2002), whereby standardization supported effective execution of these tightly coupled project activities (Gidado, 1996). The step by step tightening of the performance standard EPC, however, made the tight coupling at the level of materials and technology insufficient and forced the independent, loosely coupled firms to expand cooperation beyond the project-level. Gradually new structures of cooperation in the form of network organizations of designers, suppliers and constructors emerged, which were step by step formalized. Also the culture of independency and every firm for itself, gradually changed into a new dimension of inter-firm cooperation. Such evolvement of new cooperative structures in successful innovation of the construction industry has been found by other researchers as well (Ettlie and Reza, 1992; Dorée and Holmen, 2004). Standardization thus may trigger innovation in the form of both technical, process-, organizational and knowledge dimensions.

Thirdly, innovation re quires expansion of the knowledge base of an organization into new dimensions (Cohen and Levinthal, 1990). Organizations that are successful in standardization are able to absorb knowledge (Wu and De Vries, 2022). They may dispose of systems, procedures and a staff for knowledge management and maintaining a knowledge base. This will help them to record, evaluate and apply experiential knowledge when moving beyond the initial system space, supporting innovation.

Future research into the innovation and standardization paradox may be directed to studying how standardization management can: (a) incorporate the flexibility and adaptability necessary to stimulate innovation; (b) support knowledge management and the second-order learning necessary for innovation; and (c) stimulate organizational innovation.

5.6. The management of strategic change

The usual definition of innovation as at least something new, or as the process of achieving such a thing, does not touch the mathematical and empirical finding of fundamental differences between innovation and ordinary change, and implicitly suggests that they only differ in degree. This misconception may not only occur in innovation projects but also in strategic change projects. Strategic change is usually defined as substantial change affecting major elements of an organization (e.g. Hamermesh, 1986; Chakravarthy and Lorange, 1991; Tenner and DeToro, 1996; Stern and Stalk, 1998; Morgan and Page, 2008; Boppel et al., 2013; Kunisch et al., 2017). Description of the intended substantial change by a set of sequential state vectors may usually reveal that in strategic change projects transition into new dimensions is pursued, and thus innovation. This is also the case in strategic eco and climate projects, to become energy neutral and sustainable (Roddis, 2018; DuBose, 2000).

Misconception of innovation or strategic change as a lot of ordinary change results in: (a) extensive desk-research to specify the presumed goal beyond the initial system space in detail, which is impossible; (b) time- and energy-consuming detailed programming of the path beyond the initial system space to be followed to reach the presumed goal, which is impossible too; (c) abstaining from actual steps into unknown system space before every uncertainty has been investigated, which obstructs the necessary (second-order) experiential learning; and (d) in the overlooking of the emerging energy and human dynamics when moving away from the initial system space into the second-order uncertainties beyond. All these factors impact negatively on the success of the innovation or strategic change process.

The majority of the strategic change programs fail (Beer et al., 1990; Bashein et al., 1994; DeJong, 1994; By, 2005), and indications for improvement are an absent. The failure is usually thought to be the result of inadequate policy-making and strategic management, existing organizational structures, power and politics, organizational cultures, individual uncertainties, and psychological resistance to change (Boonstra, 2004: 1). Derived from our socio-mathematical definition of innovation and ordinary change and their fundamental different dynamics of planning, acting, learning, knowledge management and human dynamics, we hypothesize that many strategic change programs pursue innovation (intended goal beyond the initial system space), but are mismanaged as substantial ordinary change (planning, acting, and learning are separated), being the fundamental cause of failure.

5.7. Mathematical foundation for a process orientation to organizations

In the last decades, there is an increasing interest to adopt a process orientation to organizations, focusing on continuous change, becoming, transformation, flow, and flux rather than substance, being, and temporal appearance (Van de Ven and Poole, 1995; Orlikowski, 1996; Brown and Eisenhardt, 1997; Dean et al., 1999; Weick and Quinn, 1999; Tsoukas and Chia, 2002; Schatzki, 2006; Langley and Tsoukas, 2010; Langley et al., 2013; Reay et al., 2019; Cloutier and Langley, 2020). Our mathematical representation of organizational change as the movement of a state vector within or beyond its initial system space, provides a mathematical foundation for this process orientation to organizations. In addition, it provides a meso-level view of the (continuous) change of organizations and a macro-level perspective of (national) systems of innovation (e.g. Erzurumlu et al., 2022), which stands opposite of a micro-level view, focusing on the acting of individuals and on micro-level events and circumstances (e.g. Scarbrough et al., 2015). This opens new avenues for research into the meso- and macro-level dynamics of (continuous) organizational change, and into process orientational concepts such as flow and flux, and opens new directions for the development of process oriented organization theory.

5.8. Innovation as a journey of discovery

Our socio-mathematical definition of innovation as the change of a system into new dimensions, is uncommon to policy makers, managers and executives. Nevertheless, this definition can be communicated effectively to them as ‘a movement or journey out of the box’ or ‘– beyond the horizon’. A powerful metaphor that helps them to intuitively understand the differences between innovation and ordinary change is the ‘journey of discovery’, which stands opposite of the ‘train journey’, as a metaphor for ordinary change. These journey metaphors provide an integral picture of the fundamental differences between ordinary change and innovation in the aspects: position of the (intended) goal, path of change, dynamics of planning acting and learning, knowledge management, uncertainties and competencies needed (DeJong and Mulder, 1999; DeJong et al., 2001). Based on the socio-mathematical definition of innovation, the journey of discovery metaphor helps to approach innovation and innovation management effectively.

6. Conclusions

The articulation of concepts is at the heart of scientific progress. This paper aimed at presenting a more accurate, general definition of innovation that distinguishes innovation from ordinary change. We defined innovation as the expansion of the dimensions of a system, in contrast to the change of its parameters (ordinary change). Our socio-mathematical definition of innovation is not derived from cases, but from a mathematical framework based on systems theory, combined with social processes of argumentation and discussion. It can be applied to any system without limitations and is easily applicable by change agents, (innovation) managers and policy makers.

Our socio-mathematical definition of innovation clarifies that innovation is a multi-dimensional phenomenon, which comprises both the ‘hard’ aspects of (organizational) systems, such as technology, materials, products, structure and business processes, and the ‘soft’ aspects, such as knowledge, culture and values. This combination of aspects, and the long periods of time that may be needed, as observed in the three presented cases, makes innovation challenging both for academic researchers, policy makers, change agents, managers and executives.

The usual definition of innovation as at least something new, does not reveal the fundamental differences between innovation and ordinary change, and may easily lead to the misconception that innovation is just a lot of ordinary change. Ordinary change and innovation, however, differ fundamentally in their dynamics of planning, acting and learning and in the management of knowledge, uncertainty and human dynamics. As a consequence, innovation cannot be managed as ordinary change – the latter is rather the field of quality management.

Strategic change projects aim at substantial change, which usually means change of an organization into new dimensions and thus innovation. Managing strategic change as a lot of ordinary change will likely lead to project failure. The articulation of the concept of innovation by a socio-mathematical definition thus not only benefits the research and theory of change and innovation, and the distinction between quality management and innovation management, but also the management of (strategic) change and innovation.

Finally, our socio-mathematical definition of innovation opens new avenues for future research into the dynamics of organizational change and innovation, the management of strategic change, and the innovation - standardization paradox.

CRediT authorship contribution statement

William M. DeJong: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Henk J. de Vries:** Writing – review & editing, Methodology, Formal analysis, Conceptualization.

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Data availability

No data was used for the research described in the article.

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