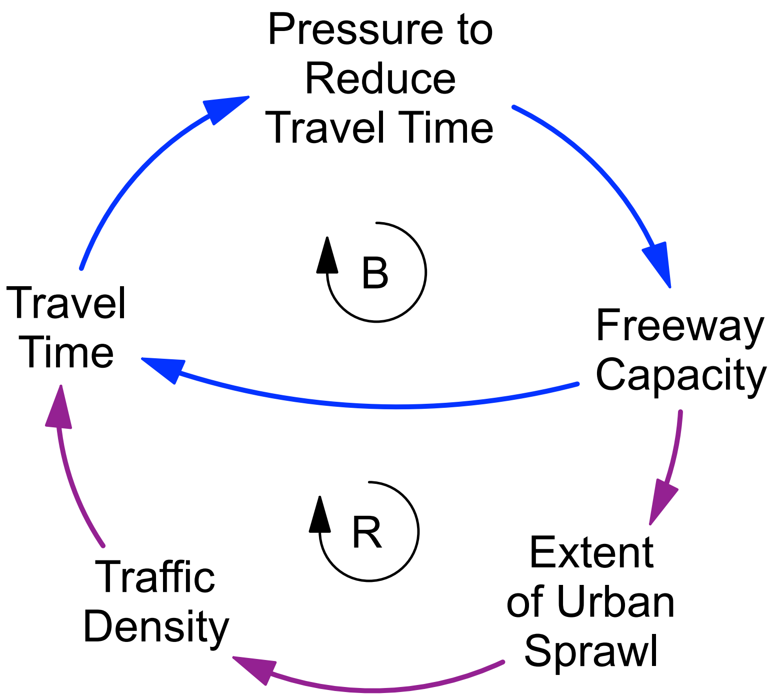
CONSTRUCTING INFLUENCE DIAGRAMS & CAUSAL LOOP DIAGRAMS



Katrina Proust & Barry Newell

Fenner School of Environment & Society
The Australian National University
Canberra

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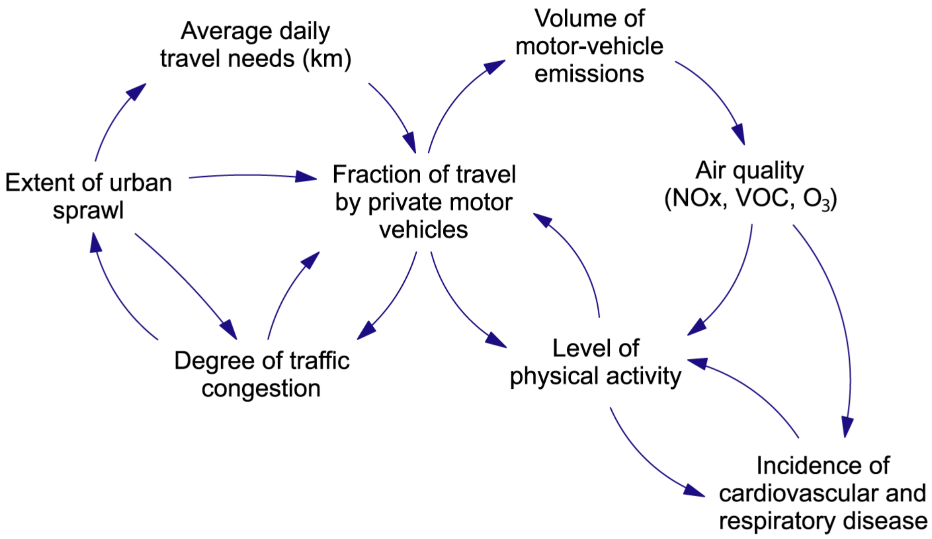
In general usage the term *influence diagram* covers several kinds of mind map. In this document we use the term to refer to a specific type of diagram that is designed to capture people's perceptions of cause and effect—that is, people's explanations of *why* things change over time. In this type of influence diagram (which we call an ID) there are words and phrases that represent the levels of key variables of a system, and arrows that represent processes or mechanisms whereby a change in the level of one variable affects the level of another variable. The construction of IDs requires an approach that is somewhat more disciplined than the usual mind-mapping exercise, while still allowing flexible expression of ideas.

The ID below illustrates some of the impacts of a community's use of private motor vehicles. This diagram is designed to show the feedback loops by which the selected variables interact with each other.



The process of constructing an ID can help clarify and reveal your thinking about problem situations: What are the key variables? How are they connected to each other? How do these connections influence the behaviour of the system (i.e., the way that it changes over time)? How does the problem situation fit into a wider context?

The basic ideas spelt out briefly in this document are intended as an introduction to the art and science of causal-diagram construction. For a thorough discussion see Sterman (2000) Chapter 5.

The ID shown on the front cover represents a feedback structure that can cause policy resistance. This is a commonly occurring structure, often called the *Fixes that Fail* archetype, that operates when management efforts are directed towards reducing the symptoms of an underlying problem, rather than focused on solving the problem itself (Meadows 2009: 112). While the actions taken may reduce the symptom in the short-term, in the longer term they exacerbate the underlying problem. As the problem increases, so the symptom returns with greater intensity.

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Vensim® was used to draw the diagrams presented in this document, see http://www.ventanasystems.com/

Constructing Influence Diagrams

1. Variables

In order to tackle a problem situation we need to understand the basic behaviour (dynamics) of the system of interest. How does the state of the system change over time in response to internal and external forces? To talk about how a system changes over time, we must consider changes in essential properties or aspects of the system. Such changeable properties are called *state variables*.

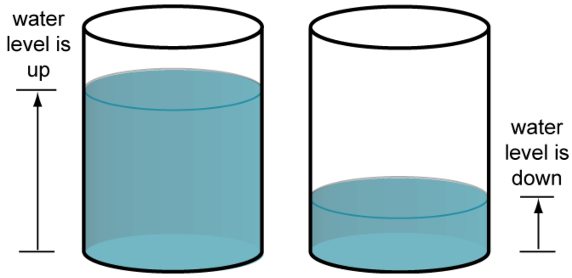


Figure 1. The water level in a glass is a measure of the 'state' of the glass. The variable 'water level' is called a state variable.

A variable has two attributes: a name and a 'level' (quantity, amount, size, magnitude, value). Consider the amount of water in a glass (Figure 1). As the glass is filled or emptied the water level changes. The glass has many attributes, such as its cleanliness, whether or not it is chipped, its material composition, its weight, and so on. How much water it contains at the moment is just one of its attributes. Taken together these attributes determine the state of the glass at each point in time. Some of its attributes (such as its material composition) are constant over time, and some change over time. When we are dealing with the *behaviour* of something we need to look at only those attributes that change and are important to us. That is, we need to focus our attention on just those changing attributes that are relevant to the issue or problem situation of concern. When we are concerned with getting enough water to drink, then we can consider the water level in the glass as an indicator, or measure, of the state of the glass at each point in time.

In a complex system there are many variables, and we can (in principle) describe the state of the whole system by reporting the levels of all of these variables. Of course, in any specific case this might be impossible—either because of the large number of variables involved, or because it is not possible to determine their levels, or both.

2. Naming Variables

Variables should be named using nouns or noun phrases. It is important that the name given to a variable makes it clear that the thing or characteristic referred to is capable of change. This can be done by ensuring that the name includes words that relate to level, quantity, or size. For example, a variable called *Population* would be taken by most people to be capable of increase or decrease. On the other hand, a variable called *Community attitudes* cannot easily be thought of in terms of quantity. Community attitudes do change, but it does not make sense to talk of them increasing or decreasing (see §4). In the case of a variable like *Community attitudes* it is necessary to use *surrogate variables* (such as, for example, *Level of trust in community*) that are focused on the particular community attitudes that are relevant to the issue or problem of concern.

Some variables are clearly measurable. Other variables are not usually thought about in quantitative terms, but the changes in such variables can still be discussed in terms of *more* or *less*. One way to build an effective name for a variable is to begin with a phrase that signals quantity – *amount, number, extent, area, size, level, degree of* . . . and so on (see examples below).

Some variable names in common use refer to things that are usually reported using numbers – *Population, Cost, Distance*. It is easy to think quantitatively about such concepts. Other variable names refer to less tangible things, e.g., *Happiness*. While such intangible variables are not usually measured and reported in numerical terms, they can still be thought about as increasing or decreasing. You can become more or less happy. So the same rules apply to the process of naming intangibles. Always use phrases that can be thought about in terms of quantity.

3. Selecting Variables

Each person sees a problem situation differently. The way that a person frames the situation will determine the variables that he or she selects to describe the system of interest. Let us consider examples of variables that may be relevant in a study of the management of a coastal area. Several variables that are clearly measurable, and typical units used in their measurement, are included in the following table:

Name of Variable	**Typical Units**
Area of seagrass beds	square metres
Extent of unsealed roads	kilometres
Lake depth	metres
Number of oyster leases	number of leases
Population	number of people
Rainfall in upper catchment	millimetres / annum
Size of catchment	hectares
Size of fish catch	tonnes

Other variables are not so easily quantified, but can be thought about as being measured in a more generalised way—perhaps on a scale from low to high. On such a scale a variable can, at any one time, be assesses as being low, high, or something in between. Similarly, the levels of such variables might be indicated on an arbitrary scale that runs from 0 to 1, or from 0 to 100. You may not know how to measure *Degree of commitment*, but you can always imagine rating it on a scale from zero to ten, or determining whether a community's degree of commitment is high, medium, or low. Examples include:

Name of Variable
Degree of community co-operation
Demand for municipal services
Perceptions of risk from sea-level rise
Perceived risk of pollution
Strength of local economy
Threat of fire
Level of enthusiasm

4. Clarity of Expression

If we want to use IDs as the basis of a common visual language with which to explore changes in a system (Newell and Proust 2018; Newell 2012), then we need to be very careful in our choice of the words and phrases that we use (Sterman 2000):

- Use clear language to describe variables in a neutral way that does not have any positive or negative connotations. In particular, do not use negative labels—use *Amount of rain*, not *Lack of rain; Ability,* not *Inability*. This avoids getting tied up in double negatives: *a decrease in the lack of rain*.

- Use a name that allows for variation, and does not tie the level of the variable to an end point of its range. For example, use *Level of Social Capital –* not *Low Social Capital* or *High Social Capital* (Figure 2). If you start the name of a variable with a word like 'high' or 'low' then you lock the variable into a particular state—it is no longer variable.

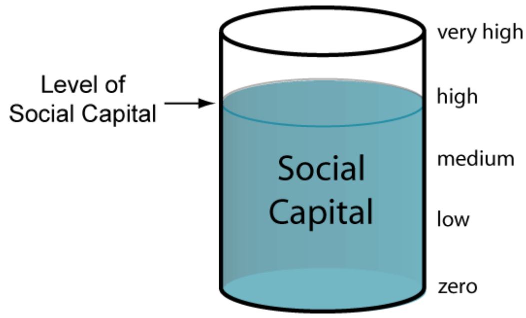


Figure 2. In this diagram 'Social Capital' is the variable of interest, and the name chosen to represent the state of this variable is 'Level of Social Capital'. The scale on the right-hand side shows that, in the usage illustrated, Level of Social Capital can vary from 'zero' to 'very high'.

- Avoid verb-based phrases, such as *Travelling to town*. Instead use:

  Distance travelled to town (measurable in kilometres)
  Travel-time to town (measurable in hours)

- Sometimes words and phrases used in diagrams are too general to be useful variables. For example, people sometimes draw causal structures like the following:

  History → *Community attitudes* [1]

  While it is clear that a community's attitudes are dependent on the community's history, such variables need to be represented by well-defined surrogates that capture the attributes at the heart of the issue. This will make the drawing more useful as a means of communication and assessment. Perhaps the intention of the above structure was to express the idea that:

  Extent of past conflict → *Level of trust in community* [2]

  Version [2] of the causal statement is clearly more informative than Version [1].

- Sometimes variables need to be 'aggregated' or 'disaggregated'. *Aggregation* involves identifying related variables and expressing them as a single variable that captures their overall effect—aggregation is sometimes necessary when causal structure has been expressed in excessive detail using too many variables. Aggregating these variables can make the important structures more visible. Examples are given in the following table:

Set of Related Variables Needing Aggregation	**Example of Aggregated Variable**
Rainfall, Humidity, Temperature, Wind speed	Suitability of Climate
Level of pollution, Area of public green space, Air quality, Extent of tree canopy	Healthiness of urban environment

Disaggregation involves replacing a single variable with several variables that together more clearly explain the context and suggested causation. In some cases a variable needs to be disaggregated because it expresses a concept that is too high-level or too abstract to be quantified. Examples are given in the following table:

Original Variable	Possible Components of Disaggregated Form
Desire for change in an issue of interest	Number of news reports Number of public meetings Level of activity on social media
Effectiveness of land-use policies	Extent of forest regrowth Richness and abundance of sensitive species Area of invasive weeds
Level of urban development	Area of land cleared for new subdivisions Number of building applications before Council Number of new businesses registered
Water quality	Concentration of pathogens Concentration of suspended sediments pH
Worldviews	Level of concern for environment Level of belief in anthropogenic climate change

5. Links and Loops

In an ID of the type described here, the arrows represent the *verbs* of the causal story. They indicate the flow of influence between the variables. This flow represents the effect of the processes or mechanisms whereby a change in the level of one variable affects the level of other variables. The following mantra can help you remember this idea: *The actions are in the arrows*.

The variables of a simple causal chain can be classified as follows:

Driving variable → *Affected variable*

This diagram tells the following story: A change in the level of the driving variable will eventually cause a change in the level of the affected variable (all else being equal).

Be alert to situations where there are causal loops. Consider the following example:

CH_4 released from permafrost → *CH_4 in atmosphere* → *Global temperatures*

This causal chain can be expressed as a causal loop (Figure 3).

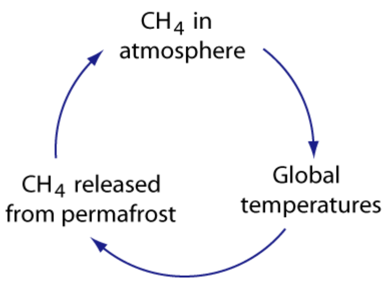


Figure 3. A causal loop. This diagram expresses the causal hypothesis that an increase in global temperatures can lead to melting of the permafrost, with the consequent release of methane (CH_4) into the atmosphere. Methane is a powerful greenhouse gas, so an increase in the methane content of the atmosphere leads to more global warming, increased global warming drives more methane from the permafrost, and so on around the loop. This is a reinforcing (amplifying, runaway) feedback effect.

6. Steps in Constructing an Influence Diagram

When you construct an ID it helps to begin with a *focus variable*. This variable should be selected to represent what you believe to be a key aspect of the issue or problem situation of concern. Then follow the steps outlined in the table on page 7. This approach is based on a suggestion by Vennix (1996: 120).

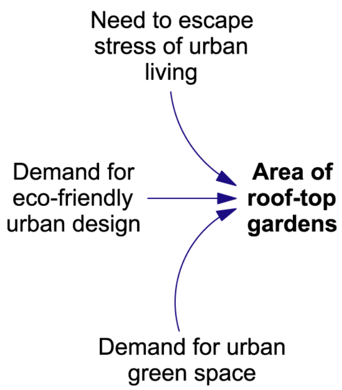
CONSTRUCTING AN INFLUENCE DIAGRAM

Step 1 - Think about the problem situation, list some variables, do some rough sketches of links.

Area of roof-top gardens

Step 2

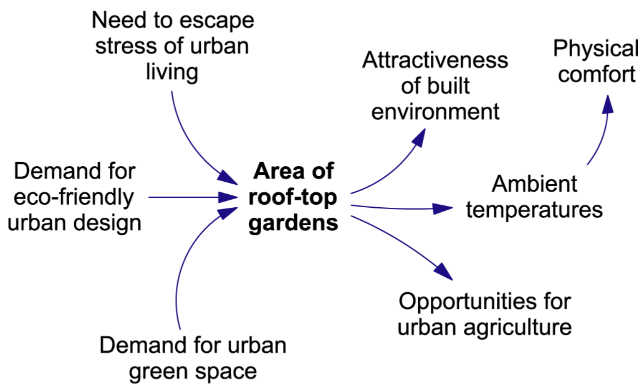
Identify a *focus variable* X whose level you believe plays a key role in the system-of-interest or problem situation.



Step 3

Add *driver* variables. Changes in the level (size, magnitude, value) of any of these variables can affect the level of X. Draw arrows to indicate your statement that the driver variables can influence (have an effect on) X.

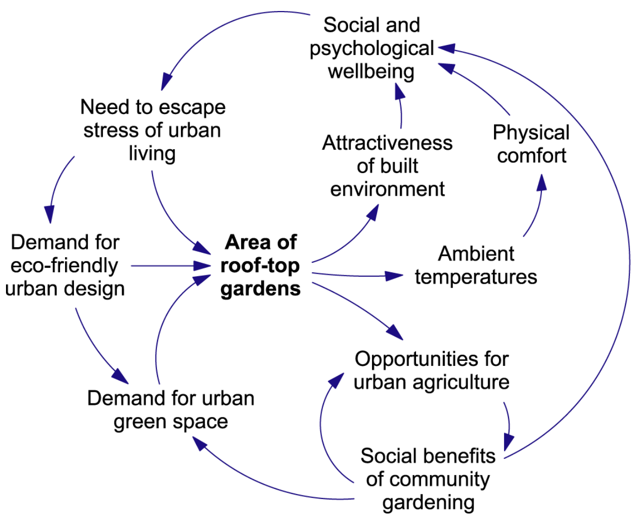
Try to keep the number of driver variables small, about 3 or 4. This will help you to select the most important variables.



Step 4

Add *affected* variables. These are variables whose levels can be affected by changes in the level of X. Draw arrows to indicate your statement that the affected variables can be influenced by X.

Keep the number of affected variables small, about 3 or 4.



Step 5

Draw additional influence links to describe possible feedback loops.

Add a few variables, if needed, to help build the feedback loops and capture your view of the dominant cause-effect structure. But keep the total number of variables as small as possible (≤ 10).

When feedback loops are constructed the distinction between *driver* variables and *affected* variables becomes meaningless. Changes in the level of any variable in a feedback loop are both cause and effect.

Causal Loop Diagrams and Feedback

Causal loop diagrams (CLDs) are important tools for describing the structure of a feedback system (Sterman 2000:137). While CLDs cannot be used to infer the dynamics of a system, they provide a powerful way to capture and communicate mental models and other hypotheses about the causes of observed behaviour.

CLDs are essentially the same as IDs, and require the same care in the naming of variables. The difference is that CLDs have *polarities* assigned to their arrows (Figure 4).

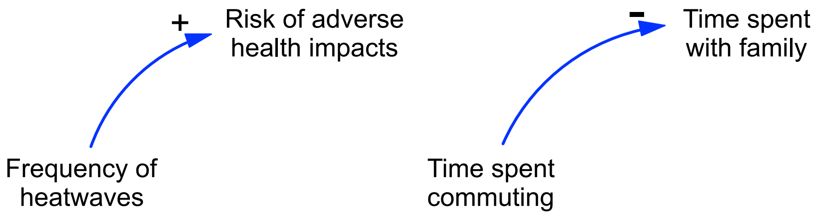


Figure 4. Causal-link polarities. In the diagram on the left the causal link has a *positive polarity* assigned. This is indicated by the *plus* (+) sign near the head of the arrow. In the diagram on the right the causal link has a *negative polarity* assigned. This is indicated by the *minus* (-) sign near the head of the arrow.

The assignment of a positive polarity (+) indicates that an *increase*/decrease in the level of the variable at the tail of the arrow (Frequency of heatwaves in the example shown in Figure 4) will eventually cause the level of the variable at the head of the arrow (Risk of adverse health impacts in Figure 4) to *rise above*/fall below the value that it otherwise would have had, all else being equal. That is, a change in the *same direction*.

The assignment of a negative polarity (-) indicates that an *increase*/decrease in the level of the variable at the tail of the arrow (Time spent commuting) will eventually cause the level of the variable at the head of the arrow (Time spent with family) to *fall below*/rise above the value that it otherwise would have had, all else being equal. That is, a change in the *opposite direction*.

The safest way to assign polarities to causal links is by following the Polarity Assignment Rule:

> When assigning polarities, treat each causal link separately and ask what will happen to the level of the affected variable if the level of the driving variable is increased.

In system dynamics usage, the term feedback refers to situations where there are causal loops. Causal loop diagrams are needed when feedback structures are to be identified and classified. As shown in Figure 5, there are only two types of basic feedback structure—reinforcing feedback and balancing feedback:

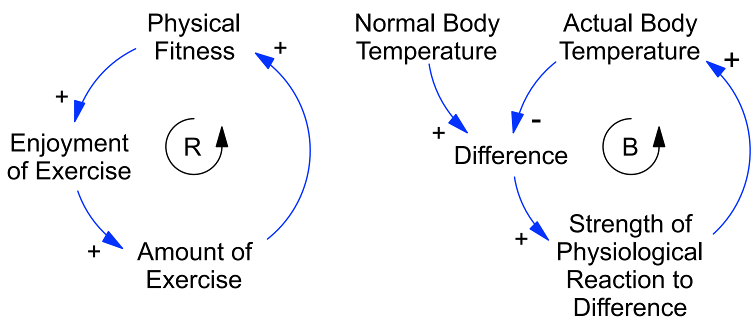


Figure 5. Two types of feedback. The diagram on the left illustrates reinforcing feedback (indicated by R). The diagram on the right illustrates balancing feedback (B)—the polarities shown are for the case where body temperature is *less* than normal.

Reinforcing feedback drives runaway effects. Exponential growth of populations is a good example. Balancing feedback works to hold conditions steady. Thermostats, homeostasis, and some forms of policy resistance are a good examples. In technical contexts reinforcing feedback is usually called positive feedback, and balancing feedback is usually called negative feedback. Note that the term ‘positive’ does not necessarily mean ‘good’, and the term ‘negative’ does not necessarily mean ‘bad’:

	Positive feedback is	Negative feedback is
When we want change	Helpful	Unhelpful
When we do not want change	Unhelpful	Helpful

The feedback structures that need to be studied in real-world situations can be complex. They consist of many competing reinforcing and balancing feedback loops. An example is shown in Figure 6. This CLD has been constructed by assigning polarities to the links in the roof-top garden diagram developed on page 7.

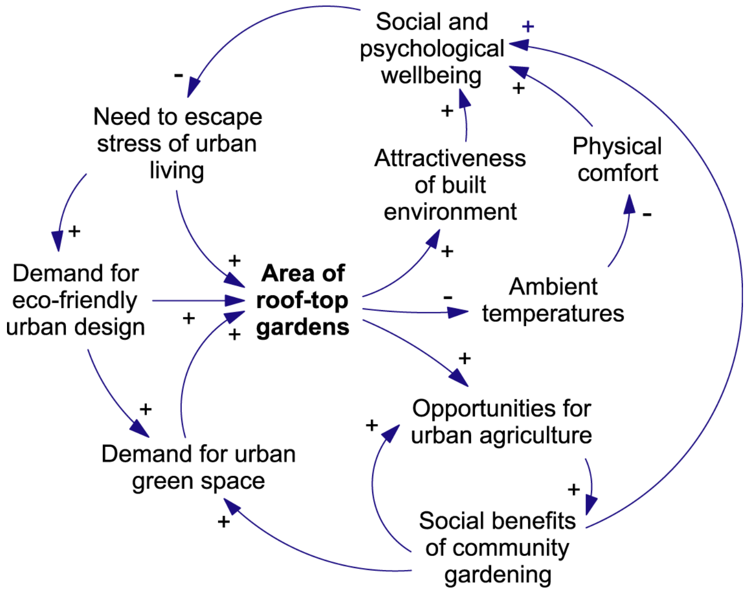


Figure 6. An example of a CLD that can guide a study of some of the feedback forces that affect the establishment of urban roof-top gardens. How many loops can you find in this diagram? Can you find a balancing loop? A reinforcing loop?

Further Reading

Dyball, R. and Newell, B., 2020, *Understanding Human Ecology: A systems approach to sustainability*, London: Earthscan/Routledge. Second Edition

Meadows, D.H., 2009, *Thinking in Systems: A Primer*, London: Earthscan.

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Newell, B. and Proust, K., 2018, Escaping the Complexity Dilemma, in A. König (Ed) *Sustainability Science: Key Issues*, London: Earthscan/Routledge, Chapter 5.

Sterman, J.D., 2000, *Business Dynamics: Systems Thinking and Modeling for a Complex World*, Boston: Irwin McGraw-Hill.

Vennix, J.A.M., 1996, *Group Model Building: Facilitating Team Learning Using System Dynamics* (Chichester: Wiley).