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Academic Paper

The Use of Non-Linear Dynamics to Help Facilitate Understanding of Learning and Development Within Groups

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Abstract

Complexity theory, including non-linear dynamics, provides a powerful approach to understanding and analysing complex interactions as seen when group members learn and develop. However, complexity theory does not feature heavily in the coaching literature, depriving coaches of this tool. This paper discusses the implications of non-linear dynamics on our understanding of group development and illustrate this with a toy model of anger in a group of three. While formal mathematical modelling of group behaviour is probably not achievable, the insights can help coaches understand how best to intervene to maximise their impact and bring benefit to their clients.

Keywords

complexity theory, non-linear dynamics, group dynamics, learning

Article history

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Introduction

Much learning happens in groups, which may be families, a work team, a social group, a classroom or an organisation. The learning may be about performance of a task, or about how that group can develop (e.g., work more cohesively) or the group may have been set up for the explicit purpose of learning (e.g., in a classroom). It therefore follows that most skills, knowledge, values and reasoning are developed as an activity of interdependent people (Stacey, 2003). In addition, the success of a group is dependent on the individuals in that group learning and developing. High performing teams can be considered ‘learning organisations’ (Senge, 1990), though it is necessary to remember that organisations cannot learn, it is the people in the organisation that do that (Stacey, 2003).

If a group is a learning organisation, and if learning happens because of the interactions within the group (Uzzi & Lancaster, 2003), then it would be useful to think about learning groups as collections of the relationships and interactions between individuals, rather than collections of individuals. These interactions and relationships are naturally dynamic and change over time. The role of a coach can be to help people learn and develop within a group. Therefore, a coach has to be capable of understanding and analysing the interactions and relationships that happen within a group, and what effect changing those interactions has. One tool to approach this task is to use complexity and systems theories.

Complexity and systems theories

In the natural sciences a series of theories emerged in the 1980s that helped analyse complex and dynamic interactions in a system. These approaches include systems theory, dynamic networks, chaos theory, non-linear dynamics and self-organisation (Gleick, 1988; Kauffman, 1993; Lewin, 1993; Watts, 1990). There is considerable overlap in these approaches, which share a common philosophy, and the terms are often used interchangeably without consistent definition (Horgan, 1995; Manson, 2001). The term systemic has also been used in coaching, often in an idiosyncratic manner (Lawrence, 2019).

The common underpinning of all these approaches is that a reductionist approach to science, while powerful, is not sufficient to understand complex systems. Simple, order-generating rules in dynamic non-linear systems can result, through a process of self-organisation, in complex structures emerging. These approaches have been transferred to understanding organisational behaviour, though the work is often shorn of its mathematical basis (Burnes, 2005; Mitleton-Kelly, 2003; Snowden & Boone, 2007; Stacey, 2007). Systems and complexity thinking are used in team coaching both to understand teams and to design interventions (Lawrence, 2019, 2021; Thornton, 2016).

The sections below outline some key concepts in complexity and team theory, indicating how these could be applied to how people learn and develop in groups.

Systems

This approach understands that systems are formed as the result of interaction between agents, in groups these will be individuals (in natural sciences they may be molecules or cells). It is important to consider the boundaries of the system under consideration. The system that is a ‘learning group’ may not just be the work team, but also the wider stakeholders and colleagues that members of the team interact with, as the team members will learn through these interactions (Thornton, 2016; Uzzi & Lancaster, 2003).

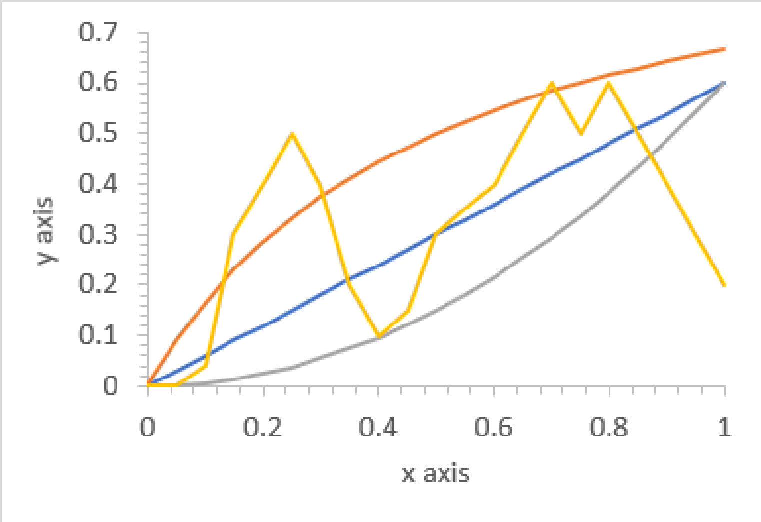
The boundary between systems of organisations and groups is not only difficult to define, but there is two-way communication between interacting systems that co-evolve with each other. This can be contrasted to the adaption of a system to an environment that is essentially unaffected by changes in the system (Mitleton-Kelly, 2003). In the context of learning, this means everyone in the group may be affected by the development of others (Stacey, 2003).

It is also important to consider whether the system is closed or open. Material (including information and energy) does not enter or leave a closed system which will, taken as whole, be at equilibrium. An open system receives or gives out material and so is not at equilibrium (Von Bertalanffy, 1950). Most social organisations will be far from equilibrium and will be open systems (and indeed we can make the argument that these are the most creative systems (Meyer, Gaba, & Colwell, 2005)).

Non-linear interactions

A key concept is that most interactions that occur are non-linear. Linear interactions are when the output scales in a linear manner with the input (in mathematical terms $y=ax$). In non-linear interactions the dependency of the output on the input is more complicated (Figure 1). The interactions between people is normally non-linear; if a person annoys me then, at first, I will not respond. If they continue, then I will become angry. The steepness of the 'dose response curve' may vary and I may suddenly 'lose it' (steep) or slowly escalate my anger (shallow). My anger will plateau at a maximum. While it is 'obvious' that most human interactions are nonlinear (including in learning (Chow, 2013)), we often analyse situations as if they are linear (Meyer et al., 2005).

Figure 1. Linear and non-linear interactions.



The x axis shows the input, the y the output. The blue line is a linear interaction (y=ax). The orange and grey line are non-linear interactions described by simple equations. The yellow line shows a complex non-linear interaction.

Feedback

A feature of complex systems is that they typically contain feedback loops (Manson, 2001). These are essential to understanding the behaviour of the system. Feedback can be positive or negative. For example, positive feedback within a group can reinforce individuals' thinking, emotions and prejudices (leading to group think). Negative feedback can modulate and control behaviour (e.g. Mitleton-Kelly, 2003, 2006).

Both forms of feedback are important in the learning and development of individuals in a group. Negative feedback normally maintains stability in system, while positive feedback allows amplification of small changes to form novel structures (Mitleton-Kelly, 2003). Negative feedback can be effective in a predictable situation to reinforce and adjust learning and development. Positive feedback may result in new patterns of behaviour or thinking if the group is far from equilibrium. However, positive feedback can lock in behaviours and hinder development, especially in mature established groups (Mitleton-Kelly, 2003). For example, the *lingua franca* of academic discourse is English. This need not be the case, it took a World War to displace German as a leading language of science (Gordin, 2015). However, positive feedback, the result of publishing, conferences, and collaboration, locks us into a monoglot system, impacting learning.

Dynamical

Complex systems are often found far from equilibrium and are dynamic with the constituent elements, and the interactions between them, continually changing (Mitleton-Kelly, 2003; Stacey, 2007). Learning and development, by definition, involves change and so is a dynamic process. As education does not operate at equilibrium it is necessary to put in resource (energy, information and time) for it to occur.

Emergent

In complex systems order is often created out of the interactions. As a system starts then, out of simple rules it is possible for order to be created. With minimal instruction or external intervention, groups will develop their own rules and behaviours. These will be different between groups set up under very similar conditions, because of differences in the individuals and starting conditions. Hence, learning groups normally self-organise to form their own identity (Wenger, 1998).

Wider context

Any open system exists in a wider context. A work team will exist in the context of a nested set of systems that may include departments, the company and the wider ecosystem that the company inhabits (Lawrence, 2021; Thornton, 2016; Whittington, 2020). The team itself may be made up of smaller teams. These different systems will also exhibit non-linear dynamical behaviour, that will affect what they do. Individuals in the team will also be part of other systems, which will have an impact on them, and the boundaries between systems may be unclear.

Application to learning in a group

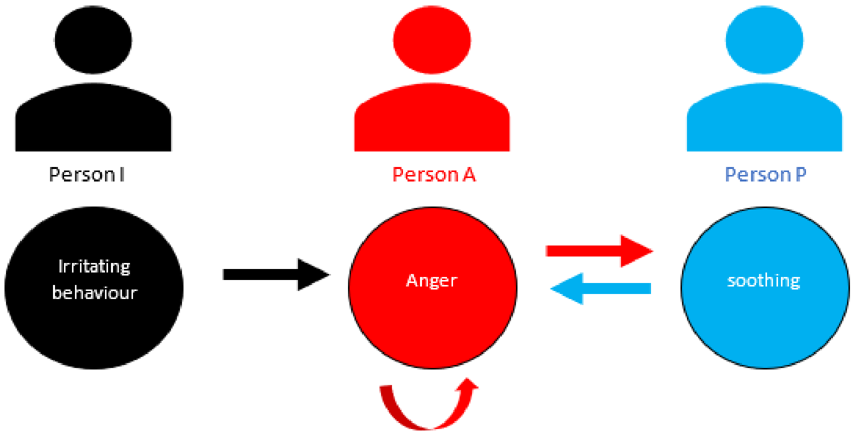
The potential application of complexity and systems approaches to facilitate an understanding of group dynamics, and how that impacts on learning and development, is enormous (Stacey, 2007). As will be discussed below, it can help to understand what can otherwise be seen as counter-intuitive outcomes and suggest alternative approaches to modulating the dynamics to support learning and development.

One approach to doing this is to develop mathematical models to explore the implications of non-linear interactions in groups. Models are useful tools to do this, however they are not reality. They work because they abstract and simplify, and so allow understanding and manipulation (we can ‘play’ with a model in a way that we cannot ‘play’ with reality).

Methodology

The methodological approach used in this paper is to use mathematical modelling to explore group dynamics in a coaching context. This model used is a toy model that does not analyse data sets. Toy models are deliberately simplistic and are not meant to be an accurate description of reality, but something to ‘play’ with to get insight. This model is based on a biological system, repurposed for this paper (Chan, Stark, & George, 1999). We will consider a group of three people. There is anger in the group that is reducing their effectiveness. The aim of modelling is to understand the group behaviour, in terms of the interactions between people, and to develop strategies that enable the team to learn to interact in a more productive manner.

Figure 2. Toy model of anger in a group.



This simple model shows the three people in the group, Person I who has irritating behaviour. This acts on Person A to increase their anger, which feeds back on itself and stimulates Person P's soothing behaviour that reduces Person's A anger.

The first stage is to understand the interactions. In a coaching scenario we might use a constellation approach to map these (Burchardt, 2015; Whittington, 2020). This paper discusses a hypothetical scenario in which Person I's behaviour is irritating Person A, who as a result gets angry. This anger feeds on itself and so there is a positive feedback increasing A's anger. Person P is a peacemaker, and they react to the anger expressed by A by placating them (soothing behaviour). This can be represented in a diagram as in Figure 2.

It is possible to model these interactions using ordinary differential equations. These equations describe how a value changes over time. This can be described by an equation

$$\frac{d[y]}{dt} = f(x) \qquad (1)$$

This describes how the concentration (square brackets) of *y* varies over time (*t*) as a function of *x*.

In this model there are three variables: the irritating behaviour, anger and the soothing behaviour. It is possible to write differential equations to show how these change over time as a function of the other variables and parameters.

In general, the interactions are modelled using Hill-Langmuir equations.

$$y = \frac{x^n}{x^n + K^n} \qquad (2)$$

Where *n* is the Hill coefficient, *x* the variable and K the value of *x* that gives 50% maximal of *y* (often called threshold, though this can cause confusion because the term is commonly thought to represent a minimal level of response). This equation plots a 'standard' dose response curve. Increasing *n* increases the slope of the curve at the 50% value, so as $n \to \infty$ the curve describes a step function.

The development of anger and soothing can be described by coupled ordinary differential equations that describe the rate of change of anger and soothing against time.

$$\frac{d[\text{anger}]}{dt} = v_1 \frac{[\text{anger}]^n + \epsilon_1^n}{[\text{anger}]^n + \alpha^n} \frac{\beta}{[\text{soothing}] + \beta} - d_1[\text{anger}] \quad (3)$$

$$\frac{d[\text{soothing}]}{dt} = k_2 + v_2 \frac{[\text{anger}] + \epsilon_2}{[\text{anger}] + \gamma} - d_2[\text{soothing}] \quad (4)$$

And the level of v_1 is determined by the level of irritating behaviour

$$v_1 = \text{f}([\text{irritating behaviour}]) \quad (5)$$

Equation (3) describing the rate of change of anger has three terms. The first represents the induction of anger by irritating behaviour and the positive feedback loop that drives anger. The second is the inhibition of anger by soothing and the third is the natural dissipation of anger (as A calms over time). Equation (4) describing the rate of change of soothing has two major terms: the induction of soothing by anger and its natural dissipation.

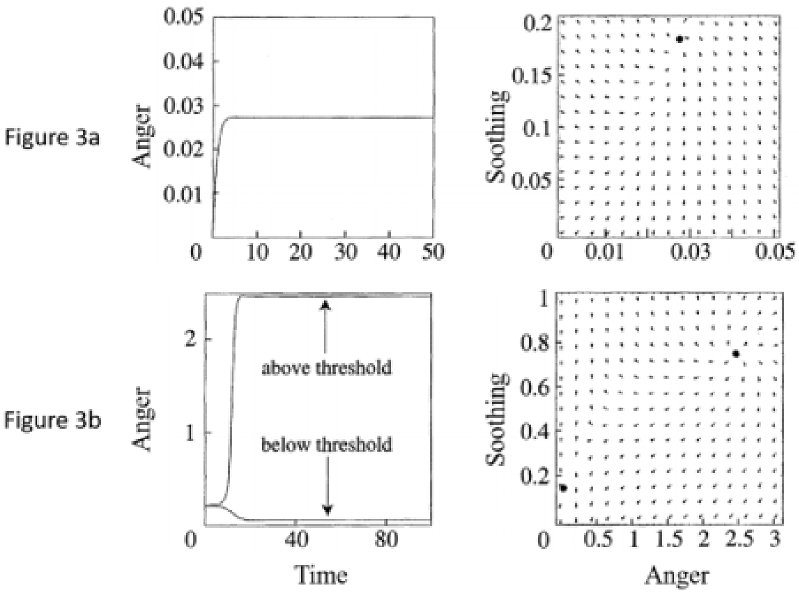
Definitions: [anger], [soothing] and [irritating behaviour] are the concentration (equivalent to intensity) of those behaviours, v_1 is the maximal rate at which A can be angry, v_2 is the maximal rate of soothing, k_2 a background rate for soothing, d_1 is the rate at which anger dissipates naturally, d_2 the rate at which soothing dissipates naturally, n Hill coefficient, α is the threshold (equivalent to K in the Hill-Langmuir equation) for positive feedback loop for anger, β is the threshold for soothing negative feedback, γ is the threshold for the induction of soothing by anger, ϵ_1 a baseline production of anger ($\epsilon_1 << \alpha$), ϵ_2 the baseline for the induction of soothing by anger ($\epsilon_2 << \gamma$). A full analysis of equations that are equivalent can be found in (Chan et al., 1999) from which all the graphs are obtained.

Analysis of the equations can be used to derive phase portrait vector fields (shown on the right in figures) and time series (shown on left). The phase portrait vector fields show ‘sinks’ (points of equilibrium to which the system will evolve), solid loops which show steady cycles through the system, dashed loops which are unstable cycles. The intensity of anger is on the *x* axis and of soothing on the *y*. The arrows show the direction the system will evolve. So, if we start at any particular concentration of anger and soothing (*x* and *y* coordinates) we can follow the arrows to show how the system evolves until it ends in a steady state (either in a sink or on a stable cycle). The left-hand graphs show the evolution over time from a starting point with a low level of anger and soothing.

Results

Phase portraits with vector fields that can be used to understand the behaviour of the system. Figure 3a (right hand side) shows a simple case with the amount of soothing behaviour (from P) on the *y* axis and the amount of anger (from A) on the *x* axis. In these analyses the amount of irritating behaviour is held constant. The single point shows the equilibrium of the system, and the small arrows represent the direction of change. The time series on the left shows how the system changes over time to reach equilibrium (a rise in anger until it reaches a plateau).

Figure 3. Time course and vector field for toy model.



The right-hand figures show a vector field. The state of the system can be described at any time by the levels of anger and soothing. The system evolves (following the arrows) until it reaches an equilibrium (dots). In (a) there is one equilibrium, in (b) two. The left-hand figures show time courses of anger evolving over time. In (b) there are two pathways, which start from similar but non-identical positions with one above the threshold for high anger, the other below it. This figure is modified from (Chan et al., 1999).

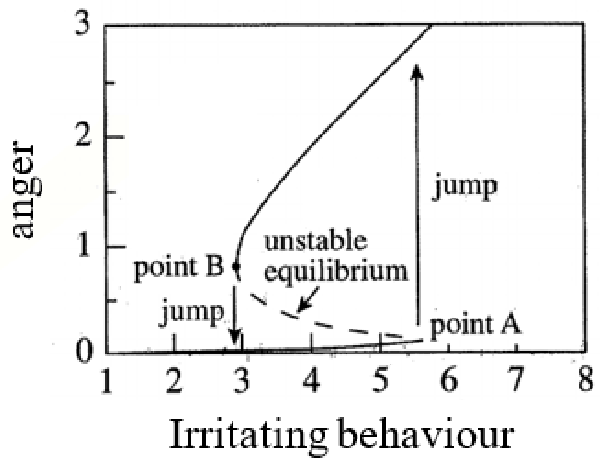
Figure 3b shows a more complex system (depending on value of other variables, see below) with two equilibrium points, one with a lot of anger and the other with a low level of anger (two dots on the vector field shown on the right-hand side). Each of these equilibria have their own basin of attraction. The time series on the left illustrates that how the system develops depends on the initial starting point; the two lines show the evolution of the system from two very similar, but different, starting points. In one case the group ends up in the ‘angry zone’, and in the other they are calm.

This system shows several interesting properties. First, the outcome (to be, or not to be, angry) is dependent on the starting point and that small difference in the starting conditions can result in massive differences in outcome. This is a form of the ‘butterfly’ effect in which a butterfly flapping its wings in Brazil sets off a tornado in Texas (Lorenz, 1972). This is recognised in education where an intervention at a critical moment can either massively help or hinder an individual’s learning (Godwin-Jones, 2018).

The second property is that the behaviour of the system depends on its history. Whether the group evolves to high anger or low anger depends on the starting point, and the starting point is historically determined.

It is interesting to look at this as a function of irritating behaviour (Figure 4). The amount of anger in the system is plotted on the *y* axis, and the irritating behaviour on the *x*. When there is little irritating behaviour, anger is low. As the irritating behaviour increases then the system is as described in Fig 3a, with a single equilibrium point, and the anger level rises slowly, but remains low. As the irritating behaviour increases (around 3) then the system bifurcates (as in Figure 3b) and develops two equilibrium points (technically three, but one is unstable and can be ignored for practical purposes). However, as the history of the system is to be in low anger mode, as we increase the irritating behaviour the anger will stay in the lower of the equilibrium points. This would continue until the irritating behaviour reaches around 5.5 when the system reverts to a single equilibrium point. Now, if the irritating behaviour increases by a very small amount, there will be a threshold behaviour with the system jumping from low to high anger.

Figure 4. The relationship between anger and irritating behaviour.



The equilibrium levels of anger, as a function of irritating behaviour, are shown. As described in the text there are two threshold points, (A) as irritating behaviour increases and (B) as it decreases. This results in both threshold behaviour and hysteresis. This figure is modified from (Chan et al., 1999).

If we consider the group in their high anger mode. If we decrease irritating behaviour then the system re-enters the zone with two equilibria, but now it will stay in the high anger point (albeit reducing anger slightly) as it is in the basin of attraction for that point. It is only when the irritating behaviour levels drop sufficiently (to around 3), when the equilibrium point disappears, that the group will reach a second threshold and 'jump down', reducing their anger to a low point.

The system exhibits both threshold behaviour and hysteresis (when the state of a system is dependent on its history) (Morris, 2012). Hysteresis is often seen in systems that switch, for example a central heating thermostat turns on at a lower temperature than it turns off, to prevent the system 'chattering' around the threshold.

Most of us would recognise the existence of thresholds in our behaviour; the small increment in irritating behaviour that causes us to lose our temper. Sudden transitions have also been noted in learning (Chow, 2013). The phenomena of hysteresis and dependency on initial conditions is also commonplace (small prior events can make us prone to lose our temper, and once lost it is difficult to calm down). This has been the subject of research, for example the perception of emotion in others is influenced by the trajectory of the emotions (happy to sad or *vice versa*) and recent exposure to emotional cues (Verdade, Castelhano, Sousa, & Castelo-Branco, 2020).

Discussion

There are some general lessons to be drawn from this toy model. The first is that relatively complex behaviour emerges from simple systems. Indeed, as shown in the Supplementary Data section below, this system exhibits other behaviours including stable cycles, in which the anger rises and falls, and excitable behaviour in which small perturbations result in spikes of anger.

This complex behaviour arising from a simplistic system warns that it is not enough to describe the relationships in a group in terms of the wiring diagram, or to think of interactions in linear terms (Meyer et al., 2005). The qualities of the interactions between people are important. This is addressed in coaching approaches such as constellations where the embodied nature of the analysis, realised by the placing and choice of items (Whittington, 2020) or the use of physical activities such as group sculpture (Fatien Diochon, Otter, Stokes, & Van Hove, 2019), can help explore the richness of the interactions.

It also opens the mind to consider different interventions. In a linear model where Person I irritates Person A then the temptation is to focus on removing the causative agent – the irritating behaviour. However, the response of the group members is dependent on all the interactions. If the group is to learn to deal with anger, then it would be useful to consider the feedback loops and the slope of the response curves. It might help to think about what other feedback pathways might be introduced to help the group adapt and develop their behaviour. Hysteresis means that modulating these pathways may be the only way for the group to move away from a high anger state, once they are locked into that (if threshold B in Figure 4 is at a very low or negative level of irritating behaviour then it may not be possible to get below it by reducing irritating behaviour. Even if Person I stops all irritating behaviour, then Person A may continue to be angry).

This approach suggests several factors can influence learning in an organisation or group. Removal of ‘stabilisers’ (negative feedback loops) and an acceptance of self-organisation (encouraging autonomy) can foster innovation (Mitleton-Kelly, 2006). It highlights the importance of interdependence and the nature of the interactions between individuals (in both quantity and quality). It has been shown in teams in the service sector that high quality relationships (both between team members, with their managers and with eternal people) are associated with improved learning and enhanced performance (Brueller & Carmeli, 2011). In this study high quality relationships included both positive structural features (e.g., connectivity) and subjective experiences (e.g., positive regard) and are associated with psychological safety. At the heart of this is an understanding that the knowledge of an organisation (and by extension a group) is created though the changing patterns of relationship between individuals (Stacey, 2000).

Strategies that encourage the group to be ‘far from equilibrium’ and to explore the local ‘landscape of possibilities’ (Kauffman, 1993), will also help development of innovative thinking. In the context of developing sporting skills, this has been done by manipulating constraints on key tasks to move the learning into a ‘meta-stable’ part of the landscape, encouraging the students to adapt and be innovative (Chow, Davids, Hristovski, Araújo, & Passos, 2011).

The use of complexity and systems approaches ends up looking at groups through a particular lens, which can be useful. However, we get a better appreciation of the system if we use multiple lenses. If we only used this lens, we would lose insights from cognitive and behavioural psychological approaches (amongst others). There are also different approaches to thinking systemically that have been described for team coaching (Lawrence, 2021).

There must be caution about transferring approaches developed in data rich natural sciences into understanding groups. Nonlinear dynamics is incredibly powerful in analysing big data sets, for example predicting weather with an accuracy undreamed of 20 years ago (Alley, Emanuel, & Zhang, 2019). However, when we look at our understanding of a group the amount of data is limited, in quantity and quality. This approach is perhaps best thought of as probing a “metaphorical device for creating new insights rather than a mathematical approach to understanding and managing” (Burnes, 2005). This may be why an influential textbook describing this complexity in strategic management does not to have a single equation, in spite of the mathematical foundation of the subject (Stacey, 2007).

This leads to a danger of misappropriating concepts. Without understanding the fundamental basis of a theory, it can be applied inappropriately. A pseudo-scientific approach can confer apparent respectability and status to an idea that is either without merit or whose merits are better argued from a different standpoint (Goldacre, 2009). This area is complex, there is a fine boundary between using scientific approaches as a form of poetry, to illustrate and communicate a concept, and using the same approach to provide spurious support to a theory.

It should be noted that this example is translated from a biological model of transplantation (Chan et al., 1999). Such mapping may be problematic, as there may be fundamental differences between social and scientific domains (Lawrence, 2021; Mitleton-Kelly, 2003). This modelling is offered as an insight into what might be done.

A final note of caution is that some have argued that complexity theory is not applicable when the system contains conscious agents (Sherblom, 2017). Complexity theory is deterministic in its philosophy (though some have argued that complexity and systems theories allow a more spiritual understanding to infiltrate science (Capra, 1982)), and it could be argued that it therefore cannot accommodate free will. The philosophical debate as to the extent of free will is outside the remit of this paper, but, even if humans do not behave in a deterministic manner, much of social and economic science operates on the basis that we can analyse behaviour, at least at the population level, as though it was deterministic. Non-linear dynamics can be analysed using stochastic modelling of individual agents (Chan, George, & Stark, 2001; Chan, Stark, & George, 2004), and it would be interesting to consider if the introduction of chance allows modelling of free will at the population level. However, this limitation must be considered.

Recommendations for Practice

The use of mathematical models may seem somewhat esoteric in the context of coaching. This paper is not advocating that coaches will want, or find it useful, to produce mathematical models of the groups that their clients are in. However, as discussed above, toy models like the one presented here are useful to provide insight and understanding. Unlike more complex mathematical models (such as those used for predicting weather), toy models should be thought of supplying foresight and insight rather than a forecast; a picture of what could be rather than a prediction of what will happen.

This section will not summarise all the understanding that can be taken from using non-linear dynamic modelling approaches for learning and development (see discussion above), but will explore just three implications for practice of the model presented here (Table 1). The practitioner needs to decide if and how these insights should be best used in the service of their client and themselves.

Table 1: Implications for Practice

Complex behaviours can emerge from simple group interactions
The nature of interactions is important
What maintains behaviours may be as important as what causes them

Complex behaviours can emerge from simple group interactions

This model of anger in a group presented here shows threshold behaviours (where a small change in circumstances results in a sudden change in anger). It exhibits hysteresis, in which the output (anger) depends on the history of what has already happened (when a person has lost their temper, then they find it difficult to calm down). It can also show other behaviours, such as cyclical or flare ups. However, the model is very simple, indeed easily criticised for being too simplistic (there are just three people with four interactions considered). This shows that in non-linear dynamical systems (which would include all human groups!) unexpected and complicated behaviours can arise from what appear to be a simple set of interactions. This suggests (using the principle of Occam's razor) it is not necessary to posit complicated causes to explain such outcomes.

This can also be helpful when considering interventions to help people develop (an intervention near a threshold can have a massive effect, while elsewhere it will have none). The possibility of hysteresis means that the history of the group can also impact on the learning of individuals within it, once we have crossed a threshold then it can be difficult to return to a previous state. That is often the case in learning; once we have crossed a threshold into a new state it is difficult to turn back. A coach may wish to consider how to use this (for example by encouraging appropriate feedback circuits) to help their clients 'lock in' their learning and development to make it durable.

In coaching there will be different ways of gauging when an intervention will be effective. Consideration of the model presented here would suggest that in the early stages it could be helpful to reduce either the irritating behaviour or its impact on Person A. However, once the threshold is crossed it would be more beneficial to look at other ways of modulating behaviour (for example, reducing the positive feedback). As discussed above, insights from models should not be seen as forecasts and will not replace the need for the coach to listen and attend to their client, judging when an intervention may be effective. A coach may look for evidence that that they are close to a threshold (as in motivational interviewing attention to the change talk of the client alerts the coach that they may be ready for change (Miller & Rollnick, 2013)). Alternatively, as suggested by Gestalt approaches, the coach may try an experiment to see if the client is ready for change (Leary-Joyce, 2014).

The nature of interactions is important

Interactions between people will always be non-linear. The nature of such interactions, as well as their existence, will be important. Thus, when considering the learning and behaviour that happens in a group it is necessary to move beyond the 'wiring diagram' and consider the form of the interaction (mathematically, the equation describing how the output varies as a function of the input, as graphically shown in Fig 1). It may be helpful to explore not just whether Person I irritates Person A, but whether the effect of the irritating behaviour increases slowly or rapidly. In some circumstances it may be more effective (or realistic) to modulate the nature of the interactions (change the parameters of the equation) than to remove them totally.

An example of this can be seen in self-reflection. One form of this interaction is rumination, that shares common features but also has different qualities to intellectual self-reflection (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). This may reflect differences in the equations describing the interactions. Interestingly. clients with a predisposition to dysphoric thought processes may be more likely to have strong and easily triggered ruminative self-reflective feedback loops which may be engaged and activated by problem focussed coaching approaches. These individuals respond better to solutions focussed approaches (Grant & Gerrard, 2020). Consideration of the nature of an interaction (in this case rumination) therefore should influence the coaching approach used.

What maintains behaviours may be as important as what causes them

The way a person responds in a group may be initiated by a particular stimulus, but may be maintained by feedback loops (either from others in the group or from themselves). The behaviour may well exhibit hysteresis, and so be dependent on the history of the interactions. The coach may wish to consider how to use this to help the development of their client by considering the feedback loops and how to modulate them, rather than concentrating on the putative causative agent. In addition, as described above, a coach may seek to help their clients lock in their learning or development by developing feedback loops.

This has parallels with cognitive behaviour therapy or coaching, which seeks to understand and overcome what locks people into particular states, rather than concentrate on past events that may have initiated the response (Palmer & Williams, 2013). The coach may also need to consider the interaction between their intervention and any feedback loops that an individual may have.

Transactional analysis also describes how feedback loops can lock in behaviours. A person may respond to a 'Parent to Child' interaction in a manner that reinforces it (Stewart & Joines, 2012). A coach will help clients understand, and break, these feedback loops.

Other applications

This approach has implications for research and for the education of coaches. While accurate modelling of groups interactions is unlikely to be useful, the development of toy models can be used to calibrate thinking and provide hypotheses that can then be tested 'in the field' (Yates, Chan, Callard, George, & Stark, 2001). It could be useful to explore what locks people into certain behaviour patterns and then explore what sort of intervention might be useful in helping them move to a different state. This has parallels with modelling of the immune system, which has been used to generate ideas for new therapeutic interventions (Callard, George, & Stark, 1999).

In terms of education and training of coaches, it might be argued that many of the insights outlined above are also given by other approaches. For example, the systemic constellation approach to coaching considers the nature of interactions as well as the 'wiring diagram' (Whittington, 2020), and cognitive behavioural coaching seeks to modulate the thoughts that people have in response to events, which determine how they feel and behave (Palmer & Williams, 2013). Indeed, while they would not have used the language of feedback loops, Stoic philosophers recognised that our reaction to what other people do can harm us more than the direct effect of what they do (Aurelius, 2006; Holiday & Hanselman, 2020). However, the use of complexity and systems theory can provide a unifying framework to many aspects of our understanding of behavioural change. It may also be an approach that is more accessible and intuitive to practitioners who come from a natural science, systems or mathematical background.

Conclusion

The use of complexity theory as applied to groups is a powerful tool that can help coaches (and their clients) understand the dynamics of the groups that they operate in. While it is unlikely that it will be possible to use the mathematical tools used by natural sciences, because of the inevitable lack of good quality data, the insights of this approach can be useful in understanding how to help the group develop. For example, an understanding of the role of feedback loops, the existence of thresholds and hysteresis, and the contingent nature of group behaviour can be used to develop an understanding of how individuals in the group learn and develop. What many find counterintuitive is that complex behaviour can emerge from simple (even simplistic) systems. A coach can use this to help their clients understand how to develop and learn in a group, and how to modulate the interactions in the group to best effect.

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Supplementary Data

Five behaviours

The results section concentrated on a few of the behaviours that the system exhibits. Full analysis of the model shows that there are 5 behaviours that can be seen. These are described below and shown in Figure S1 using the same approach as shown in Figure 3 (the data from Figure 3 is reproduced in S1 a) and b) to facilitate comparison).

Behaviour 1

There is a single equilibrium point. The system will evolve over time to reach that point.

Behaviour 2

There are two equilibrium points. The system will evolve over time to reach one of those two points. Crudely they may be characterised as 'high anger' or 'low anger'. Which one depends on the starting conditions. In the time series two possible evolutions are shown from two starting points that are nearly identical (but are not), one below the threshold for the high level of anger and the another above it.

Behaviour 3

When the variables lead to behaviour 3 there is no sink point. Rather there is a stable cycle and so the system would evolve from the starting point until it enters the cycle. This would be manifest by periodic rises and falls in anger.

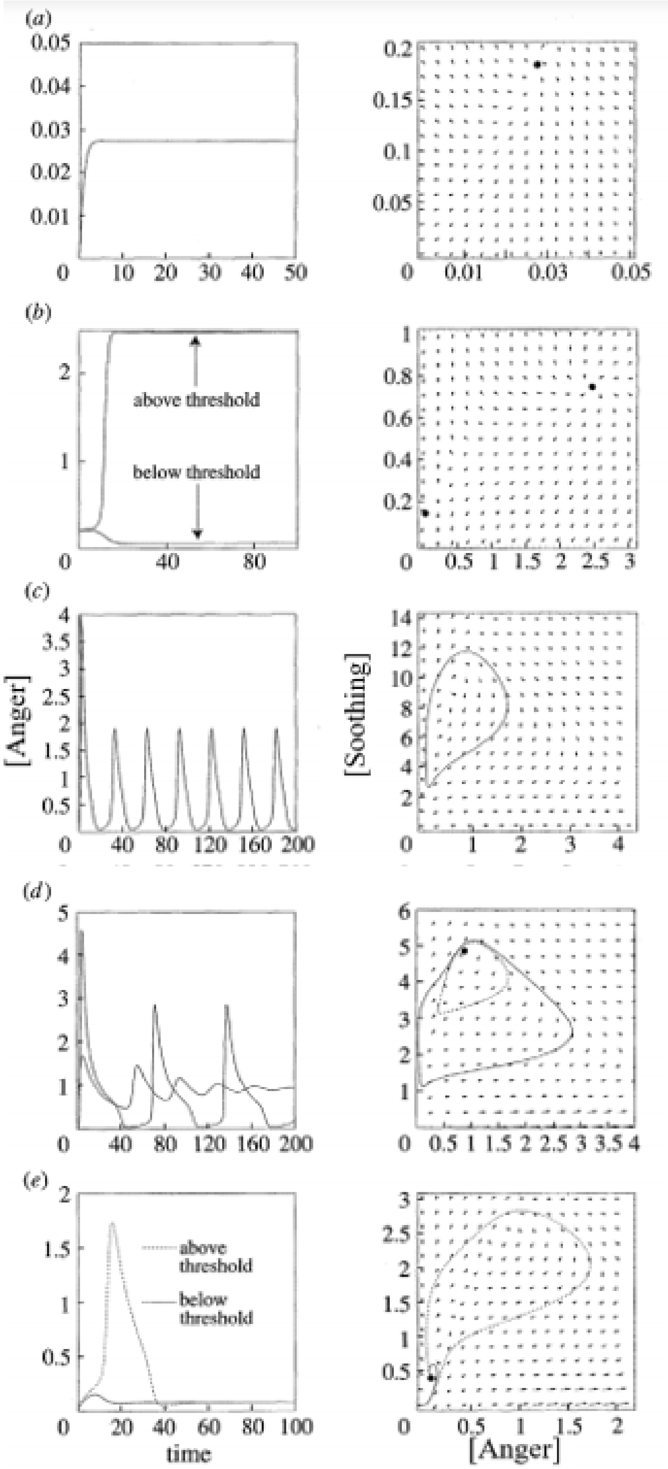
Behaviour 4

This is a peculiar state in which there is one sink and a cycle. Theoretically, depending on the starting point, the system could end up in a stable point or a cycle of anger. This is probably not an important behaviour.

Behaviour 5

This system shows an excitable behaviour in which there is a single sink. However, because of way the system is that there would be what can be termed large excursions from the stable point if the system is disturbed. So, if there is a small change in behaviour, the system will fall straight back to the sink. But if there is a change just above threshold then the system will return to the sink point only after it has undergone a large excursion through phase space. This would be manifest in the group by small changes in the system being absorbed, but a large change results in a spike of anger (and soothing) that then returns to the sink. This is shown in the time series as a perturbation above and below the threshold for this behaviour.

Figure S1, 5 behaviours of the toy model



The right-hand figures show a vector field. The state of the system can be described at any time by the levels of anger and soothing. The system then evolves (following the arrows) until it reaches an equilibrium (dots) or cycles (circular lines). The left-hand figures show time courses of anger evolving over time. The 5 behaviours described in the text are shown respectively in (a) to (e). Figure adapted from (Chan et al., 1999).