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IMPLICATIONS OF COMPLEXITY SCIENCE FOR THE STUDY OF BELIEF SYSTEMS

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This paper begins with a brief discussion of existing understandings of the nature of beliefs system, and of complexity science. The extent to which belief systems might be complex is then considered and possible implications of thinking of beliefs systems in this way are discussed with a particular focus on how insights gained from a complexity science perspective might inform attempts to influence the development of the beliefs of pre-service and in-service teachers of mathematics.

BELIEF SYSTEMS

In spite of the considerable interest in the study of teachers' beliefs there is still little consensus around the meaning of the term and, in particular, how beliefs are distinct from attitudes and knowledge. Here, beliefs are defined as anything that is regarded as true. They thus incorporate knowledge from a constructivist view that sees it as beliefs that attract relatively greater consensus as a result of being based on more of better information (Guba & Lincoln, 1989). Attitudes are regarded as evaluations of psychological entities and may result from groups of beliefs.

Green's (1971) description of beliefs systems involved three dimensions and has been useful in explaining the findings of many studies of teachers' beliefs (e.g., Cooney, 2001). Green (1971) described belief systems as structured such that some beliefs are primary and others are derivative. He arrived at this distinction as a result of observing that when asked their reason for believing a particular proposition, a person will often answer with another statement of belief, and that this process can be repeated until eventually a belief is reached for which no justification can be given. This last belief is a primary belief from which others in the chain are derived.

Green (1971) described more strongly held beliefs as more central, and those less strongly held as peripheral. The more central a belief, the more resistant it is to questioning and change. Pajares (1992) cited Rokeach (1968) as defining the idea of centrality in terms of the degree to which a belief is connected with others. The greater its connectedness, the greater its implications for other beliefs, and the more dearly it is held, and, hence, the less susceptible it is to change. Green (1971) also acknowledged that the relative centrality of beliefs varied with context and thus acknowledged the dynamic nature of belief systems.

The third dimension of belief systems that Green (1971) described is crucial to explaining how people can hold conflicting beliefs without any sense of conflict. He suggested that beliefs may be held in isolated clusters, thus preventing conflicting beliefs from being juxtaposed to reveal their inconsistency. Distinct clusters are likely to develop when beliefs arise in independent contexts (Green, 1971).

In addition, Green (1971) described an individual's beliefs as either evidentially or non-evidentially held. Beliefs in the latter category are held for reasons such as the authority of the source of the information, or because they support existing, centrally held beliefs. They are more likely than evidentially held beliefs to be held in isolated clusters, and are, by definition, impervious to change even in the light of contradictory evidence (Green 1971). Implicit in this is the crucial notion, that in order to change an individual's beliefs, one must challenge the bases of those beliefs.

COMPLEXITY SCIENCE

Davis and Simmt (2003) explained how the notion of complex systems arose from the recognition that traditional ways of studying the world were inadequate for certain phenomena. For example, Newtonian mechanics provides powerful descriptions of simple systems involving interactions between very small numbers of objects. Increasing the numbers of interacting entities results in systems that are complicated and to which probabilistic models have been successfully applied. Davis and Simmt (2003) explained that complex systems have been recognised as not just very complicated but are inherently different and demanding of quite different tools for their analysis. They typically involve collections of living and hence (at some level) autonomous agents whose interactions give rise to characteristics of the collective that are not attributable to the actions of any particular individuals in the collective. That is, complexity emerges from the interactions of autonomous agents and without any imposed leadership or authority. Complex systems have properties that transcend those of the individuals that give rise to the system. It thus makes sense to talk about complex systems in anthropomorphic terms (Davis & Simmt, 2003). Examples of complex systems include flocks of birds, and in the context of education, classes.

Complex systems are often nested within other complex systems. For example, cells, organs, individuals, social groups, society more broadly can all be considered to be complex systems which emerge from the interactions of agents which comprise entities of the previous level (Davis & Simmt, 2003). Davis (2004) described complex systems as self-organising, self-maintaining, self-renewing and structurally determined. The latter relates to the fact that a complex system's reaction is not wholly determined by the nature of the influence upon it but is also related to the history, or prior learning, of the system and hence its reaction to the same stimulus on different occasions is unpredictable. In this way complex systems embody their histories as they adapt to their environment. Miller, McDaniel, Crabtree and Stange (2001) described complex systems as engaged in sense-making and improvisation in response to changes in the environment. Key to this are multiple feedback loops and nonlinear interactions among agents which allow systems to self-organise and to adapt to unpredictable events (Miller et al., 2001).

Davis and colleagues (Davis, 2004; Davis & Simmt, 2003; Davis & Sumara, 2005) have suggested interdependent and necessary but not sufficient conditions for the emergence of complexity from the interactions of a collective. *Diversity* refers to

variations among the agents in a collective provide possibilities for novel responses. *Redundancy* refers to common ground among the agents of a system that is sufficient for them to interact meaningfully. *Enabling constraints* organise and focus activity while still allowing the diversity present in the collective to be expressed. *Decentralised control* emphasises that complexity cannot be planned nor its outcomes entirely predicted, rather complexity emerges from the shared endeavours of autonomous agents. *Neighbour interactions* refer to interactions between agents. In educational settings it refers most importantly to interactions between ideas.

These conditions have been used to analyse educational settings (e.g., Sinclair, 2004) and incorporate elements contained in similar sets of conditions derived from non-educational contexts (Miller et al., 2001; Seel, 2003). For example, Seel (2003) applied complexity theory to organisational change. He described organisations as ready for spontaneous, relatively easy change when there are optimum levels of: connectivity (analogous to neighbour interactions facilitated by sufficient redundancy); diversity; and amount of information being transferred (content of neighbour interactions); and appropriate boundaries and a lack of inhibitors (analogous to decentralised control and enabling constraints).

BELIEF SYSTEMS AS COMPLEX

If belief systems are complex then individual beliefs can be thought of as the agents that comprise them. In complex systems, agents are autonomous in the sense that each is capable of independent action. It does not imply consciousness on the part of agents. For example, individual cells have been considered as complex systems nested within other complex systems (organs) in relation to which the cells are agents. An individual's beliefs are in some sense separate in terms of their implications for attitudes and behaviours and yet, like agents in a complex system, they do not operate alone. That is, attitudes and actions are rarely the result of isolated single beliefs but of collections of relevant beliefs, the relative centrality and influence of which is dependent upon the context in which the individual is operating at the time. Conceptualised as positive or negative evaluations of psychological objects, attitudes can be regarded as emergent phenomena arising from belief systems.

Belief systems may also contain beliefs that can be described as emergent in that they arise from interactions of other beliefs. In her study of pre-service primary teachers Schuck (1999) found that many had firmly held beliefs about the importance of making mathematics enjoyable, but did not believe that their own mathematical knowledge was necessarily important to their ability to teach mathematics well. Indeed many actually believed the converse to be true (Schuck, 1999). She attributed this to experiences that had resulted in the teachers feeling insecure with regard to their own mathematical ability. The belief that mathematical ability is not requisite for effective mathematics teaching allowed them to maintain belief in themselves as potentially effective teachers (Schuck, 1999). Schuck's (1999) plausible suggestion amounts to a perhaps unconscious act on the part of pre-service teachers to isolate

their beliefs about mathematics from their beliefs about mathematics teaching in order to protect from challenge their perhaps most centrally held beliefs that relate to their own identities as teachers. It suggests that when two centrally held beliefs conflict, in this case the beliefs that, 'the teacher should make mathematics enjoyable' and that, 'mathematics is difficult and not enjoyable', teachers may construct other beliefs that enable them to resolve the conflict: in this instance, the belief that 'the teacher's mathematical knowledge is not related to their ability to teach it well'. The term construct implies a more active and conscious process than is likely to be at work here. Rather, the reconciling belief emerges as a response to a disruption to the individual's beliefs about themselves as prospective teachers.

Such a belief is held non-evidentially although teachers who hold such a belief are likely to focus on and believe any shred of evidence that supports it. The anecdotes that Schuck (1999) describes, involving the stereotype of the brilliant mathematician who cannot communicate, fit this category. Schuck's example illustrates how belief systems embody their histories. That is, the experiences which have contributed to structuring the individual's belief system influence the way in which that belief system responds to subsequent events, interpreting some as evidence of a belief that is now important to the individual's identity.

Belief systems are thus adaptive and hence learning, and, at least to the extent that interactions among beliefs and shifts in relative importance or centrality are unconscious, they seem to be self-organising. The concept of nestedness can also be applied. One might imagine sub-systems of beliefs with wider systems, for example, beliefs about oneself as a teacher nested within ones' beliefs about teaching.

It thus seems possible to conceptualise an individual's belief system as a complex system. If beliefs systems are complex and we accept Davis' (2004) necessary conditions for complex emergence, then these also must apply. Belief systems certainly contain diversity in terms of the subjects of beliefs and the range of beliefs in relation to individual entities. It would also seem that belief systems include redundancy in terms of the multiplicity of interconnections among beliefs. For example, derivative beliefs are not simply links in a chain originating in a primary belief, because each belief in that chain may also be similarly connected to others which in turn are connected to others or are the consequence of groups of beliefs rather than a single belief. For example, a teacher who believes that students should do regular homework might do so because of a belief in the importance of establishing regular study habits and also that homework provides opportunities for consolidation of class work. Each of these beliefs may also be derivative, perhaps being consequences of beliefs about his/her own experiences as a learner, though not necessarily the same ones. So while it may be possible to trace a chain from a derivative belief to a primary belief by repeatedly probing for the basis of each belief, the chain that results is just one of many that could be identified. Some beliefs in such networks are redundant in the sense that the derived beliefs would not necessarily collapse if one or perhaps many related beliefs no longer existed.

The link thus described between redundancy and connections among beliefs suggests that the relative centrality of beliefs is related to the degree of redundancy among their interconnections with other beliefs. Clustering of beliefs would serve to reduce redundancy by reducing the number of interconnections. A beliefs system in which clustering was taken to its logical limit would comprise individual isolated beliefs with no connections among them and could not in fact be described a system. At the other extreme a belief system without clusters would have all beliefs interconnected and redundancy would be maximised. Redundancy therefore facilitates neighbour interactions, in the sense of connections between beliefs.

Much of the dynamic behaviour of beliefs systems happens unconsciously and is not controlled by any central authority and thus appears to be characterised by decentralised control. Davis (2005) described the teacher in the complex system of a classroom as the consciousness of the collective in that the teacher's role is to make decisions about the focus and directions of the collective activity, in a way analogous to that in which the conscious mind directs an individual's attention. In relation to belief systems such attention directing activity places the conscious mind in the role of providing enabling constraints. In any given circumstance certain beliefs may be called upon and applied so that the activity of the belief system is not random but adaptive and characterised by learning.

IMPLICATIONS AND CONCLUSION

Researchers in the area of teacher beliefs have realised that there are not simple causal relationships between what teachers' believe and what they do but instead, beliefs and practice are related in subtle yet powerful ways. Complexity theory enables a view of belief systems as dynamic learning entities with properties that transcend individual beliefs. Such a view makes it quite sensible to regard actions as dependent upon beliefs systems in ways that cannot be understood by analysing the precise beliefs and interconnections between them. It suggests that precisely explaining the origin of teachers' actions is not just a complicated and difficult task but an impossible one. As well as diverting attention from lines of inquiry that may be futile, complexity theory emphasises the difficulty of influencing an individual's beliefs or, indeed, of an individual attempting to reconfigure his/her own beliefs. Such changes have system wide ramifications and are in fact changes to the system rather than to particular beliefs within it. However, complexity theory also suggests ways in which beliefs might change.

Applied to belief systems (and using Davis's terminology), Seel's (2003) ideas about organisational change suggest that increasing the diversity, redundancy, and neighbour interactions among beliefs might increase the likelihood of change. Change could thus be facilitated by providing new ideas either from interactions with peers and/or experts or materials (increased diversity); helping teachers to make links between beliefs that may be held in separate clusters by uncovering and challenging apparent contradictions among beliefs. Providing diversity at the level of a group of colleagues and/or sources of ideas, and providing provocative prompts to discussion

may be helpful. Balancing diversity and redundancy (in terms of shared experiences) and encouraging interaction between members of groups engaged in professional learning may thus be a stimulus to increasing diversity, redundancy and neighbour interactions of individual participant's belief systems. In effect planning professional learning experiences mindful of the conditions for complexity in relation to the system comprising the participants in the professional learning may also enhance to the extent to which these conditions are present in the beliefs systems of individuals.

Empirical studies of professional learning and the efficacy of programs have arrived at a degree of consensus around factors that maximise their effectiveness in terms of impacting teachers' practice (Hawley & Valli, 1999). These are consistent with the conditions for complexity to emerge from the collective of learners in this context. The idea of diversity applied to belief systems suggests the value of broad knowledge (i.e. beliefs) in terms of facilitating the emergence of complexity. When such systems are well integrated, and hence characterised by redundancy, activities that simulate the interaction of beliefs are likely to contribute to the emergence of new beliefs. This sounds very much like creativity or at least learning. This tentative exploration of the implications of complexity science for the study of belief systems suggests that the ideas warrant further consideration and development.

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