A review of diagramming in systems practice and how technologies have supported the teaching and learning of diagramming for systems thinking in practice

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Abstract

The educational process arguably involves a mediated discourse between teachers and learners to aid sense or meaning making for both parties. That mediation, particularly in distance teaching models, is often done through the use of educational resources, whereby teachers develop and/or select the educational resources which the learners then study or engage with through purposeful activities. Some issues or topics are so complicated or complex that words or numbers may be insufficient to represent the meanings contained within them and this is particularly relevant to systems studies which examine complex adaptive systems. Equally diagrams can break out of the linear and systematic nature of printed text to show non-linear and systemic features. This latter trait has been enhanced through the emergence in recent years of digital technologies whereby hypertext and other web applications now make it easier to create dynamic and/or interactive diagrams. And yet there has been little recent research into the influence of such technologies on the learning of systems diagramming skills at a distance. These issues are examined through a review of the literature and the reporting of previously unpublished surveys within The Open University on the value of diagrams to systems studies and the role of technology in influencing the study of diagramming in the teaching of systems thinking in practice. This review indicates that diagrams are seen as an important feature of systems studies and that digital technology can be effective in supporting the teaching and learning of systems diagramming skills at a distance. It also notes that new investigations are needed to examine whether more recent developments in digital technologies have made them more effective and/or efficient for teaching and using such skills in practice.

Keywords:

Diagramming, teaching, distance teaching, learning, technology, systems thinking, systems practice

Introduction

This paper reviews the literature on the use of diagrams in teaching and learning in general and in relation to system thinking in practice and looks back at some past, previously unpublished research at The Open University covering the latter. This research examined the perceived value of diagramming to systems studies and the role of technology in supporting the teaching and learning of diagrams at a distance, particularly in system studies (see Figure 1 for a snapshot of the issues covered). The main aims of this review are to identify how diagrams have featured in the teaching of system thinking in practice and in relation to system practice; whether technology can substitute for direct face to face teaching of diagramming; and to indicate what new research studies might be needed to better understand the role of technologies in both these activities.

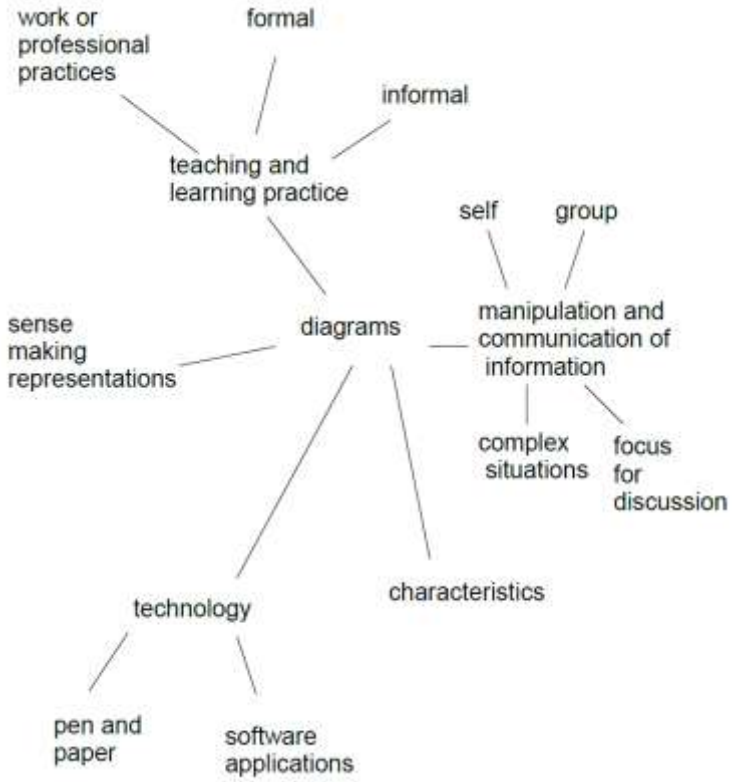

Figure 1 A spray diagram of the features of diagrams covered in this review paper

Both teaching and learning require the manipulation and communication of data and information. The manipulation involves the structuring of the data and information into meaningful patterns by teachers and/or learners that are understandable to both teacher and learner. The communication involves the way and form in which that structured data and information is conveyed from the teacher to the learner (and vice versa as the full educational process of teaching and learning involves repeated dialogue between them). In other words the educational process arguably involves a mediated discourse between teachers and learners to aid sense or meaning making for both parties (Lane, 2008) and in which the data and information involve combinations of words, numbers, symbols and diagrams of varying types in various possible media formats (e.g. printed words, photographic images, graphical charts, sound recordings, etc.).

While this simple description covers the essence of the educational process it does not reflect the complexity of broader educational systems in which the context, purpose and people involved in the teaching and learning can greatly differ. The context can vary from the formal classroom to the informal home setting, the purpose from demonstrating a particular skill to exploring a new concept and the people ranging from one teacher working with one learner to a complete workforce studying an e-learning package put together by a team of teachers and media specialists. It also includes the lifelong learning that people do for career and interest reasons thus linking it to working and living practices.

All representations can be seen as sense making models of messy situations or complex systems (Lane, 2002; Fathulla and Basden, 2007). Diagrams can be pictorial representations of our thinking that can help by attempting to capture as much of a situation as possible on one or more sheets of paper or computer

screens, showing both components and connections in different ways. Similarly, physical or mathematical models provide the means to test assumptions about, predict the behaviour of or understand the dynamics of a chosen system of interest. These models can guide our actions and learning as it is often difficult to express and comprehend complex systems in words alone, particularly where you are covering many discipline areas. They can be used for personal actions or learning or for collective action or learning where many participants contribute to their construction and interpretation, sharing their thinking or understanding about a situation.

The varying use of diagrams in teaching and learning

Diagrams have always featured to some extent in teaching and learning but they have not been used as much as either the spoken or written word. The widespread formalisation of teaching and learning within schools, colleges and universities occurred at a time when levels of literacy and access to books for reading and notebooks for writing in were very limited. Accordingly, much of teaching and learning embraced an oral form of communication which might be supplemented to a small degree by printed diagrams in scarce text books or on classroom walls or more ephemeral diagrams created by the teacher on blackboards. As both the media and publishing industries and media and publishing technologies have become more sophisticated then the use of diagrams in (distance) education (and in work settings) has greatly increased, but even so they tend to be dominated by certain forms of diagram that emphasises the representation of 'things' and 'processes' rather than representations of 'thoughts' and 'feelings' (Lane, 2002).

Diagrams are representations of reality as seen or perceived by the person or people creating them, mental constructs given a physical form to aid thinking, communication and action. There are a number of ways they can be categorised. Lane (2002) has distinguished between four types of representation that goes beyond their use in teaching and learning to also cover the professional use of diagrams, hence the discussion of their use in systems studies [1]:

1. Analogue representations, where the diagram looks similar to the object or objects it portrays. Such diagrams play little part in most systems studies but are widely used in much scientific and technological work.

2. Schematic representations, such as maps or plans, where the map or plan represents the essence of 'real world' objects or phenomena but do not look similar to them. Diagrams like these are not commonly used in systems studies but they are and can be extremely valuable where they are used for debating and negotiating land use and planning issues.

3. Symbolic representations. These are the charts and graphs created to portray relationships between numbers or quantities of things or processes. These diagrams are a mainstay of all scientific subjects including many systems studies, because they are central to the dynamic modelling of processes as much as the static representation of them.

4. Conceptual representations. These diagrams largely try to describe inter-relationships between ideas or processes that cannot be readily observed or depicted as 'things' but are put forward as a model for acceptance by others. It is conceptual diagrams that feature most strongly in systems work, even where the components are seen as fairly real.

In all these cases, and particularly conceptual diagrams, the creation of diagrams requires learning the nature and purpose of the diagram and practising its use and getting feedback from others both on the skill involved in following the 'rules of construction' of the diagram (the practice) as well as how the diagramming process aids learning about the topic of the diagram (the sense making). As a very interactive skill there is inevitably a bias towards thinking that the skill can best be learned in face to face settings, where practice and feedback on that practice can be immediate or where several people are collaborating on that diagram and can share reflections on practice. Teaching diagramming practice is therefore a particular challenge when teaching at a distance and the role that technology might play becomes important to understand better.

How technology influences diagramming practice

The creation and use of diagrams can depend upon the technologies used. Most diagrams that I draw are done with pen and paper and may require several attempts for me to be satisfied with but are ones

[1] This is not the only typology of diagrams and in their review of the literature Carney and Levin (2002) discuss the functions of pictorial illustrations in teaching texts as representational, organisational, interpretational and transformational.

which I may never share with another person. The reason for that is that the rigour of drawing a diagram, iterating through several versions and of clearly specifying the purposes and assumptions behind the diagram is enough to change my own thinking about a situation just as writing text helps organise and present ones thoughts to others. Of course just drawing a diagram to help my thinking is of little use in influencing learning if in an educational setting or systemic change when used professionally if that diagram is not shared with others or unless I am able to convey that changed thinking to others through non-diagrammatic means. This is where using software applications comes in to its own – not so much for creating and amending a diagram as to create a readable version for others and to overcome the drafting abilities of the author just using pen and paper. Since the 1980s there have been an increasing numbers of computer based graphics packages which have been followed in the past 10 years by similar web-based applications. While many graphics packages are there so as to be able to produce good static diagrams to include in documents or presentations, there is an ever growing set of sophisticated mapping software that enables dynamic diagrams or animations to be produced (sometimes in real time from open online data), and which can partly blur the distinctions between a diagram and a model. Web based tools also enables use of the hypermedia functionality to create diagrams that can be easily shared, amended and annotated synchronously or asynchronously (Okada et al, 2008). Finally, the use of such technologies can also mean that the diagrams, whether produced individually or collectively, can be more easily shared across time and space to help those involved to gain a shared understanding of a situation

Working with diagrams in practice

The use of diagrams in teaching and learning should also bear some relation to the use-in-practice of such diagrams within the subject or professional area they relate to. Systems thinking in practice is characterised by a broad range of theoretical concepts and a wide variety of practical tools, techniques and methods (Reynolds and Holwell, 2010). The discipline of systems thinking is also used within a wide range of other disciplines such as systems engineering, earth systems science, information systems and organisational behaviour. Being a discipline where both the describing of any complex situation (the sense making) and the prescribing of ways to affect changes to that complex situation (the decision making) are seen as important, there may be significant tensions between the thinking and the practice.

One of the central tenets of systems thinking is that understanding complex situations is helped by considering that situation as if it were a set of interconnected entities separated from its context or environment by a notional boundary. A significant feature of all these approaches is the capturing, sharing and reviewing of representations of these systems of interest, often as diagrams. However despite diagrams supposedly being an important feature in much of systems thinking and practice previous reviews have found that this is rarely evident in many academic or professional publications on systems studies (Lane and Morris, 2001). This tendency also appears in the literature of the use of diagrams in teaching and learning as noted by Carney and Levin (2002):

> *'As an aside that is especially apropos for present purposes, we note that (1) professional journal articles typically consist of densely worded technical text; (2) such text often can benefit from clarifying pictorial accompaniments; but (3) pictures, diagrams, and figures take up precious journal space, adding to cost of an already costly enterprise. Nevertheless, it is ironic that one often reads research articles focusing on the effects of text-accompanying illustrations without encountering even a single illustration of the illustration used in the research'.*

This raises the question of how significant diagrams are viewed amongst system practitioners and then what implications that has for teaching and learning of diagramming as a skill within systems practice.

This first issue was partly answered by the results of a previously unpublished scoping study that involved a postal survey of systems practitioners undertaken by the author in 2003. A short questionnaire was sent to 383 people associated with 2 practice based networks. The first network was the Open University Systems Society which was open to anyone that has been associated with the Open University as a student, member of staff or as a consultant. The second network was entitled Systems Practice for Managing Complexity, created as part of an EPSRC grant-funded project that aimed to explore the ways in which system practice was tackling the increasingly topical issue of complexity. With overlapping membership (27 people belonged to both), duplicate names were eliminated and the questionnaire variously sent by email or postal mail to the 383. A total of 59 responses were received, a response rate of 15%.

All the questions were open-ended requiring respondents to provide a suitable response from their own perspective and aimed at providing qualitative information as much as qualitative information. Being open-ended many questions were not answered by all respondents. The responses were then coded into broad categories.

The respondents varied in terms of their employment sectors (Table 1) and were also generally very experienced in doing systems studies with 66% (n=41) having undertaken 5 or more substantive studies and 93% (n=56) having spent 5 or more years involved in systems studies. Most often this was as a facilitator, change agent, researcher or consultant. Of the 59 respondents 29% declared to be 'self taught' while the remainder (71%) learned about systems ideas and methods at University when studying for a degree.

Table 1 The major employment sectors of the respondents (n=53)

Employment sector	*Percentage*
Academic teacher/researcher	28
Self employed consultant	26
Employee in public/not for profit sector	21
Employee in private sector	15
PhD student	9

It was found that the majority of respondents (73%, n=33) believed that diagrams are essential components of any system study with the others (27%) feeling that they are not essential but can be helpful depending on the context. Respondents generally agreed that that the key roles of diagrams in systems studies were simplifying complexity in a situation through sharing relationships and making assumptions explicit in an easier and quicker to read format (Table 2), although there are inevitable overlaps between these categories. Interestingly the former group more often declared themselves to be primarily 'visualisers' (in that they preferred to think about situations visually) than the latter group who tended to prefer mixing diagrams and prose. Overall, 46% (n=59) found it easier to think about situations visually, 8% preferred to use spoken or written words and 46% liked to use a combination of both. Twenty eight different types of diagrams were mentioned overall but those getting 10 or more mentions were rich pictures (53%, n=59), multiple cause/systems dynamics diagrams (39%), systems maps (27%), influence diagrams (25%) and flow diagrams (17%).

Table 2 The main reasons how using diagrams helped the respondent and other people involved in their systems studies (n=59)

Reason	*No. of responses*	*Percentage*
Provides clarity of thought or understanding	18	31
Shows relationships, boundaries and links	18	31
Showed whole situation	13	22
Helped communication	10	17
Quicker to produce and read	7	12
Sharing or exchanging knowledge and ideas	7	12
Helping with reflection and discussion	6	10
Making assumptions explicit	5	8
Sharing own thinking	2	4

The over-riding picture that this small survey of systems practitioners provided was that diagrams were generally an essential feature of systems thinking in practice, but possibly that while those diagrams were an important feature of the process they were not as important to be used in any outcome such as a publication. Such details are difficult to examine through such a survey and would have benefitted

from in-depth semi structured interviews with those survey participants, but lack of funding prevented investigations proceeding past this scoping study.

Another unexplored question from this scoping survey is whether this preference for diagrams was reflected in how the subject was learned by those practitioners? And equally, if that learning was through distance teaching, did the medium or technology used to encapsulate that teaching influence their learning? While a more in depth study of these practitioners may have helped with these questions, another survey did try to examine parts of this issue amongst University students studying a systems thinking in practice course.

Teaching with diagrams

The role of diagrams in teaching and/or instructional design has not been extensively researched or evidenced. Equally, many studies into the use of diagrams in education examine both the teaching mode and the learning experiences or achievements of learners at the same time (Seddon and Shubber, 1984; Winn, 1991; Carney and Levin, 2002; Doymus, 2007; Davenport et al. 2008). In this respect there is a distinction that can be made between diagrams that are mainly to be read, that is they are used in texts, presentations or animations (Jones and Scaife, 2000) as an instructional device but the students is not expected to create similar diagrams while learning or in assignments, and those that are to be read and written, where students will be expected to create similar diagrams (but not just simply re-create the ones they have read). In the latter case diagramming as a skill is an inherent and hopefully explicit learning outcome for the students and equally hopefully this is a skill that is not just for learning but one that is to be used in practice by graduates in the subsequent jobs they have.

Learning from diagrams

There have been many more studies looking at how diagrams might aid learning or be a better medium of instruction than text describing the same object or process. Lawless (1997) found that students on Open University Science courses regard illustrations as important and that 'interpretation' was rated the most important function for illustrations. They also rated diagrams as more effective than photographs for illustrations and were valued for assisting visualisation and understanding processes. Similarly, McCrudden et al (2007) found that *'causal diagrams improve comprehension by explicitly representing the implicit causal structure of the text in a visual format'* while Kealy and Webb (1995) investigated how maps more than diagrams associated with text add value to the learning of concepts.

While these studies looked at learning from pre-prepared diagrams other studies have shown how the construction of diagrams by students can be a tool for deeper understanding by those students (Ainsworth and Loizou, 2003; Afamasaga-Fuata'i, 2004) implying that 'writing' enhances the learning from diagrams as well as text more than just 'reading' of those same diagrams or text.

Another issue noted earlier is whether the mode of the learning experience can influence the value students put upon what they are learning given that they can access similar teaching or informational material in a number of face to face, textual or virtual forms. The influence of the mode of learning experience within a distance teaching setting of systems diagramming is seen in the previously unpublished results of another survey undertaken at The Open University in 2003, this time by Karen Shipp, Magnus Ramage and the author. This survey was of students taking a Level 2 open and distance learning module (2nd year equivalent in a full time higher education institution) presented at The Open University called T205 *Systems Thinking: Principles and Practice*. As would be expected this module both taught and assessed diagramming skills relevant to systems practice and diagrams were used as an explicit part of the teaching and learning strategy. This was the first module to extensively use technology to help support teaching of diagramming and the survey was aimed at seeing whether this new teaching approach was as effective as previous modes as part of teaching quality assurance and continuous improvement of the module.

All 513 students registered on the module in that year were mailed a survey form to complete by the University's Student Survey Team at the end of the scheduled time they were expected to have studied the third block of six blocks in the module, that is, half-way through their studies. The students were asked about their experience of learning systems diagramming across three dimensions:

- Five main diagram types that were being taught
    - Rich pictures
    - Spray diagrams
    - Systems maps

    - Multiple cause diagrams
    - Sign graphs
- Eight types of learning experience
    - Prior study
    - Reading discursive printed material about meaning and use
    - Reading a printed appendix summarising use and conventions of each diagram type
    - Seeing and hearing about the development of individual diagrams in Flash movies on the WebZone (a virtual learning environment)
    - Using a variety of more interactive Flash tutorials available on a CD-ROM
    - Participating in group work at face to face tutorials or summer schools
    - Reading their tutor's comments on their module assignments
    - Exploring and experimenting with diagrams on their own
- Four different learning outcomes
    - Learning about the use, meaning and conventions of each type of diagram
    - Learning to read and grasp the meaning of diagrams
    - Learning to draw simple diagrams of their own
    - Learning to use the diagram type to increase their understanding of a situation

We also asked how useful they felt each diagram type would be to them once they had completed the module, how much natural aptitude they felt they had for each diagram type, and how much they felt their understanding of each type developed as they studied more of the module.

There were 139 responses received, a response rate of 27%. When responses were averaged across all the diagram types listed fewer than 20% had previously studied diagramming explicitly. Nearly half had encountered spray diagrams and only 12% has encountered rich pictures. Of those students who did have prior experience of a diagram type nearly all of them found all types of learning experience associated with studying diagrams in T205 more valuable than their prior study of that diagram type. However there was considerable variation both in participation in the different types of learning experience and in the extent to which participating students found these experiences helpful (Table 3).

Table 3 The percentage of respondents (1) participating (averaged across all diagram types) in the different types of learning experience for diagramming and (2) who stated that the type of learning experience for diagramming offered in T205 was fairly or very valuable (n=513)

Learning experience mode	*Percentage participation*	*Percentage rating as fairly of very valuable*
Prior knowledge	19	71
Discursive print	93	85
Appendix	92	86
WebZone	84	89
CD-ROM	74	92
Group work	28	93
TMA[2] feedback	88	83
Own exploration	48	88

[2] TMA stands for Tutor Marked Assignments which form the summative continuous assessment of the module

There was a tendency for some of the more valuable types of learning experience to be overlooked by students:

- Fewer than a third of students participated in group work, while more than 905 of those who did participate in group work found it very or fairly helpful across all diagram types
- Only about half the students experimented with diagramming on their own, but, of those who did, almost 90% found it valuable

The pattern with the supplied learning materials show a small but consistent pattern across all diagram types for print media to be used more but valued less than electronic media (Table 3). In general, the more interactive the learning experience, the more valuable students found it, although again these differences were small albeit consistent across all diagram types.

This 'interactivity effect' increased as the learning outcomes became more demanding. For example, when learning about the meaning and conventions of a diagram type, there was little difference in value between printed and electronic media. But when learning to use the diagram type to increase the students' own understanding of a situation, this difference was more marked, with group work and individual exploration becoming increasingly important.

Another complicating issue was that while the questions were asked about the different learning types some students were inevitably using only one or two of them while others would many to variously support their learning of them as noted by this respondent: *'Whilst the WebZone was a preferred area of learning for me, I believe it was a combination of methods which drove the message home'*. However the existence of the various learning types does give flexibility to students when learning to become competent in using diagrams, as noted by this respondent: *'The combination of materials is very useful and clarifies things quite well. I have found systems maps particularly useful at work since learning how to draw them'*. This last comment was rarity though, in that when talking about how they might use diagramming beyond T205 most only talked about their continued use in their studies and not in their working lives, even though the majority of Open University students are in employment while they study the module.

As with the previous study this survey raises as many questions as it answers. While it says how students perceived their learning and use of diagramming it does not cover any objective assessment of how well this learning was put into future practice, either within the marked assignments in this module or future modules. Both in depth interviews and longitudinal studies would have been needed to explore this further.[3]

Conclusions

Diagrams and diagramming are features of many working and professional practices, especially systems thinking in practice. They are also a feature of teaching and learning practices both as a means of instruction and as a means of training learners in the use of diagrams that are features of many working and professional practices. This review has both examined the literature and presented previously unpublished results from two past surveys at The Open University that had investigated the use of diagrams in professional systems practice and how technology influenced the teaching and learning of systems diagramming at a distance. There are two main conclusions from these reviews.

First, diagramming has been seen as an essential part of the practice of systems thinking. However there is a relative lack of published studies on diagramming as part of systems practice (as opposed to using diagrams to exemplify aspects of a systems study); the teaching and learning of systems diagrams; and the linkages between learning diagramming skills and their use in professional practice. New investigations are required to determine whether these two trends remain the same given there has been many developments in the use of diagrams in general and in the use of new technologies in particular.

Second, students on a distance taught systems module preferred to learn diagramming in face to face situations as part of a group even though that was the least used mode. However, learning diagramming by themselves through a mix of technology mediated modes was not seen as substantially less valuable. Both print and web based teaching modes were the most popular in terms of use by the students. This indicated that the mediating technologies available at the time could successfully substitute for face to face learning of diagramming skills in the view of the learners themselves. However, the nature and capabilities of the technologies have developed since then to include videoconferencing or other virtual collaboration tools

[3] It should also be noted that the original data set has been lost and so does not allow for further statistical analysis beyond that which was done as part of teaching quality assurance.

which can replicate some of the features of a group based face to face teaching model. New studies are needed which both broaden and deepen our understanding of diagramming in systems practice and how technologies have supported the teaching and learning of diagramming for systems thinking in practice.

References

Ainsworth S, Loizou, A. Th. (2003) The effects of self-explaining when learning with text or diagrams, Cognitive Science, vol. 27, pp 669-681

Afamasaga-Fuata'i K (2004) Concept Maps and Vee Diagrams as Tools for Learning new Mathematics Topics, in Canas AJ, Novak JD, Gonzalez FM (eds.), Concept Maps: Theory, Methodology, Technology, Proceedings of the First International Conference on Concept Mapping, Pamplona, Spain, 6 pp.

Carney RN, Levin JR (2002) Pictorial Illustrations *Still* Improve Students' Learning from Text, Educational Psychology Review, Vol. 14, No. 1, pp 5-26

Davenport J, Yaron D, Klahr D, Koedinger K (2008) When do Diagrams Enhance Learning? A Framework of Designing Relevant Representations, Proceedings of 8th International Conference of the Learning Sciences, Utrecht, 8 pp, retrieved 30th January 2012 from http://oli.web.cmu.edu/openlearning/publications/145

Doymus K (2007) Effects of a Cooperative Learning Strategy on Teaching and Learning Phases of Matter and One-Component Phase Diagrams, Journal of Chemical Education, Vol. 84, No, 11. Pp 1857-1860

Fathulla K, Basden A (2007) Frameworks for understanding diagrams: Enriching the debate, Applied Semiotics, 19(7), pp 54-70, retrieved 9th January 2012 from http://french.chass.utoronto.ca/as-sa/ASSA-No19/index.html

Holwell S, Reynolds M (eds.) (2010) Systems Approaches to Managing Change: A Practical Guide, 309 pp, Springer, London ISBN 978-1-84882-808-7

Jones S, Scaife M (2000) Animated Diagrams: An Investigation into the Cognitive Effects of Using Animation to Illustrate Dynamic Processes, In Anderson, M., Cheng, P. and Haarslev, V., Diagrams 2000, LNAI 1889, pp 231-244, Springer-Verlag, Berlin

Kealy WA, Webb JM (1995) Contextual Influences of Maps and Diagrams on Learning, Contemporary Educational Psychology, Vol. 20, pp 340-358

Lane AB (2002) Systems Thinking and Practice: Diagramming, Open University, Milton Keynes, UK, 2nd Edition, 93 pp, ISBN 0 7492 4167 5

Lane A, Morris R (2001) Teaching diagramming at a distance: seeing the human wood through the technological trees, Systemic Practice and Action Research, 14(6): pp 715-734

Lane AB (2008) Who puts the Education into Open Educational Content? In Katz, RN (ed.), The Tower and the Cloud: Higher Education and Information Technology Revisited, EDUCAUSE, Boulder, Colorado, pp 158-168, ISSN 978-0-9672853-9-9, available at http://www.educause.edu/thetowerandthecloud/133998

Lawless C (1997) Illustrations and their functions in two Open University Science courses, Student Research Centre report No. 204, 23 pp, The Open University

McCrudden MT, Schraw G, Lehman S, Poliquin A (2007) The effects of causal diagrams on text learning, Contemporary Educational Psychology, Vol. 32, pp 367-388

Okada, A; Buckingham Shum, S and Sherborne, T Eds. (2008) Knowledge Cartography: Software tools and mapping techniques, Advanced Information and Knowledge Processing, 1. London, UK: Springer.

Seddon GM, Shubber KE (1984) The Effects of Presentation Mode and Colour in teaching the Visualisation of Rotation in Diagrams of Molecular Structures, Research in Science and Technological Education, Vol. 2, Issue 2, pp 167-176

Winn W (1991) Learning from Maps and Diagrams, Educational Psychology Review, Vol. 3, No. 3, pp 211-247