Using the Cognitive Dimensions framework for analysing cognitive interaction with animated diagrams

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Abstract:

This paper explores the use of the Cognitive Dimensions of Notation as an analytical framework for investigating the cognitive effectiveness of animated diagrams for learning about dynamic processes. The concept of cognitive dimensions was found to provide a sound theoretical grounding for investigating the effects of animation on cognition, informing a cognitive model of processing and in highlighting the different cognitive demands of diagrammatic animated representations. Identifying features particular to animation, enabled investigation of their specific effect on cognition, and their trade offs in terms of cognition, e.g. by providing one aspect that is beneficial to cognition may affect another dimension that is then detrimental to cognition. From findings of a series of studies a set of initial cognitive dimensions of animated representations are proposed, and the continued relevance for future cognitive research is discussed.

Introduction

Research in external representations suggests that each representation has certain properties that are inherent in the structure of the representation that may be beneficial (or not) to cognitive processing in domains such as problem solving or reasoning (e.g. Larkin & Simon, 1987; Zhang, 1997). However, it is not only the properties, but also the cognitive effects of the properties that are important for this research. The value of analysing properties of representations in terms of their cognitive benefits and disadvantages has been highlighted (e.g. Scaife & Rogers, 1996; Green, 1989). The term 'cognitive dimensions' (Green, 1989; 1991) was developed in the context of analysing systems and programming and a wide range of information artefacts. Certain features of a system, identified in relation to the user are characterized as cognitive dimensions because they have some relevance to the system or programme being cognitively beneficial or hindering. Similarly, animated diagrams may have specific properties that facilitate or hinder the cognition process. In understanding cognition in relation to animation, identifying some kind of dimensions of the diagrams that have a cognitive effect (be it beneficial or detrimental to learning) may help us to understand how the representation guides or influences reasoning or learning with that particular representation. Thus, the concept of cognitive dimensions is a useful way of investigating the effects of animation on cognition. If features or properties particular to the representation can be identified, then these aspects can be investigated in terms of their effect on cognition. These features too are likely to offer trade offs in terms of cognition, e.g. by providing one aspect that is beneficial to cognition may affect another dimension that is then detrimental to cognition, and inform the design of representations. Therefore, an effective paradigm for investigating animation, is to define the form of animation and identify cognitive and/or semantic properties or dimensions that are specific to animation, and explore ways in which they are beneficial or detrimental to processing information.

Using the cognitive dimensions framework

In addition, to identifying representational properties, Green (1991) expresses the need to understand the users' 'model' or knowledge structure in order to understand e.g., the visibility and parsability of a meaningful structure. Guided by the concept of cognitive dimensions a series of studies were designed to look at cognitive processing of animated representations by identifying particular properties of animation in conjunction with an appropriate model of learning (outlined below). This provides a clearer understanding of the interaction between representation and cognition, and points to particular features that can be described in terms of cognitive dimensions particular to animated representations.

Animation may be assumed to be cognitively beneficial due to the visually explicit depiction of dynamics, and the degree of computational offloading that this might offer. However, previous research has already identified some specific properties of animation that affect cognition (e.g. Kaiser et al., 1992; Stenning, 1998; Lowe, 1999). *(i) Multidimensionality* (amount of simultaneous information): Diagrams are often used to display large amounts of information in one representation. As a result of explicit depiction of dynamics, animated diagrams have an additional amount of

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perceptually available information, which could decrease computational offloading, explicit dynamic depiction making motional aspects of the information more salient and 'easy' to understand, and /or increase cognitive effort required to focus attention as a consequence of the large amount of different information displayed. *(ii) Transient media:* In animations the illusion of movement is brought about by a series of consecutive frames and fundamentally differs from that of static presentations in that information becomes transient, as opposed to persistent (Stenning 1998). Information passes by and is no longer available to the user, thus affecting memory load, and the ease at which a learner can re-access information. *(iii) Graphical change*: In animation a sequence of still images depicts change of some kind. Lowe (1999) identified particular aspects of graphical change according to form or position, movement from one location to another, and transformation referring to changes in size, shape, or orientation. To make sense of the change the learner needs to distinguish the particular meaning of each graphical change. Learner attention is also selectively distributed according to perceptual salience rather than thematic relevance (Lowe, 1999), therefore salience of graphical change may be dependent not only on the graphical component itself, but also on the frequency, speed, and magnitude of dynamic change.

Although learner tasks in given learning contexts may differ, and particular designs of animation may differ, certain aspects of the learning model can be identified, e.g., learners need to focus on salient pieces of information, interpret, and integrate them in order to construct knowledge. Cognitive processing of animated diagrams can be seen on four principal levels: a visual graphical level (where learners are required to perceive components of the diagram and different graphical changes that occur, and is therefore dependent on the salience of the components and their dynamics); an interpreting level (where learners are required to make accurate interpretations of the diagram, understanding the meaning not only what individual components represent, but also changes to those components and what this means in relation to the diagram and to one another); an integration level (which requires learners to integrate all the information together, making links between information on the diagram); and a conceptual level (requiring learners to build a coherent understanding).

On the basis of the representational properties and learning model described above, a series of studies using both qualitative and quantitative data looked at salience graphical change; interpretation of the graphical changes taking place; and integration of information across the animation as a whole, in terms of the kind of graphical change, transience and multidimensionality.

Cognitive dimensions of animated representations:

Findings from the studies point to certain important dimensions of animation for learner interaction, features that not only relate to the representation itself, but also to cognition. From this some initial 'cognitive dimensions of animation' are proposed: *visibility* refers to the degree to which the representation facilitates noticing of all graphical changes (translation, transformation, feature presence); *identifiability* refers to the degree to which the representation enables differentiation between different types of graphical change, i.e. facilitates the distinction between translation, transformation and feature presence; *trackability* refers to the degree to which the representation facilitates tracking of changes over time; *interpretability* refers to the degree to which the representation facilitates the placing of appropriate meaning on graphical changes; *parsability* refers to the degree to which the representation facilitates segregation of information into smaller coherent components, be they a dynamic change, or a domain relevant section of the diagram; *linkability* refers to the degree to which the representation makes explicit the links between appropriate sections of information.

The findings also suggest that cognitive demands differ according to the level of dynamic information load, transience, the type of graphical changes, and links between information sections. *(i) Visibility demands*: Processing graphical change consists of both noticing and identifying the kinds of graphical changes taking place. Noticing graphical change basically refers to an awareness of the learner that a dynamic change or event has taken place. The likelihood of the change being noticed is a function of the type of change, the dynamic information load within the animation (the more changes occurring the more difficult it is to notice accurately) and the transient nature of the representation, which potentially contributes to loss of information from the start to the end of a change. Identifying graphical change is essential for accurate interpretation of the representation, and may be affected by transience and dynamic information load. *(ii) Interpretative demands:* Accurate interpretation is necessary for a coherent understanding of the system or process depicted. The interpretation is dependent on the type of change that is perceived and identified, and on the amount of detail of the change that is observed, e.g., understanding may be incomplete if only part of a translation change is viewed. This research

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suggests that interpretive demands differ with the type of graphical change. *(iii) Assimilation demands*: Assimilating information and/or making links incorporates the linking of information across smaller relevant domain sections of the diagram, as well as linking the dynamic events with the static features of the representation, and is important to building a coherent model of the process being depicted.

These research findings point to particular aspects of animation primarily in terms of its visibility, interpretability, and linkability that are important for the learner. This can inform designers on particular ways in which this representational format may be designed to facilitate understanding of dynamics by being aware of the importance of the dynamic components and movements being 'cognitively available' to the learner, the effects of multidimensional dynamics and transience.

Conclusion:

This research shows the Cognitive Dimensions to be a valuable framework for investigating the cognitive effects of animation for learning, in identifying the trade offs in terms of cognition and for informing design of animated representation, for example, this research suggests that integration of information may be facilitated by provision of explicit links within the representation. This research also indicates the relevance of other cognitive dimensions to the design of animated representations that would benefit from further research. For example, studies suggest a similar phenomenon to the concept of 'hidden dependencies', when dynamic processes depicted through diagrammatic animation that are dependent on other tangential processes are not explicitly apparent (Jones, 1999). In such instances, relevant links of information are missing, making inferences and interpretation of what is happening complex and often erroneous.

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