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Animation and learning: selective processing of information in dynamic graphics

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Abstract

Animation can provide learners with explicit dynamic information that is either implicit or unavailable in static graphics. However, the inclusion of temporal change in a visual display introduces additional and qualitatively different information processing demands. For learners to be successful in building high-quality mental models from animated instruction, they must extract thematically relevant information from the animation and incorporate it into their knowledge structures. Animation group subjects used a dynamic depiction of weather map changes to help them predict the future pattern of meteorological markings on a given map and then made a further prediction for a different map without the aid of the animation. Predictions from these subjects were superior in some respects to those produced by control subjects but this superiority tended to be limited to aspects that had high perceptual salience in the animation. The findings indicate selective processing of the animation that involved perceptually driven dynamic effects analogous to the field-ground effects associated with the visuospatial characteristics of static graphics, and raise questions about the widely assumed intrinsic superiority of animations over static graphics as resources for learning.

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1. Introduction

In recent years there has been a growing trend across a range of media to use highly illustrated materials for instruction rather than relying on largely text-based presentations of information. With the newer technologies of instruction, this increas-

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ing reliance on pictures as a central part of instruction is not limited to static illustrations but also includes animations (see Rieber, 1994). Further, more and more educational materials seem to prefer graphics to be animated wherever possible. However, this growing preference for animations appears to be based on little more than intuition, and research evidence is beginning to challenge the widespread assumption that animations are intrinsically superior to static graphics (Narayanan & Hegarty, 2000). Evidence is also accumulating that the instructional effects of animations may not always be beneficial (e.g. Schnotz, Böckheler, & Grzondziel, 1999; Schnotz & Grzondziel, 1996). Possible reasons for this lack of benefit include (a) the imposition on learners of excessive information processing demands ('overwhelming') and (b) a reduction in the extent to which learners engage in valuable processing activities ('underwhelming'). With respect to the first of these possibilities, it seems reasonable to suppose that the mere presentation of dynamic aspects does not of itself necessarily benefit learning, particularly if those dynamics are rather involved. Indeed, animations that present very specialised dynamic subject matter having a high degree of visual complexity may actually have negative consequences for learners who are novices in the depicted domain, because they are so demanding for them to process. There is already evidence with respect to sophisticated spatial tasks that beginners need less spatially complex forms of instruction (e.g. Kirby & Boulter, 1999). The investigation reported in this paper focuses upon underlying requirements for learning with complex animation: the extraction of information from such a display and its incorporation into the learner's knowledge structure.

1.1. Controlling cognitive load

There has been considerable interest recently in how to present illustrated information to learners in ways that avoid cognitive overload (Sweller & Chandler, 1994). Investigations with both conventional print materials and the newer forms of presentation such as multimedia have examined the effects of various spatial and temporal arrangements on learning outcomes (e.g., Mayer, 1994, 1997; Mayer & Anderson, 1991). Typically, the concern has been with how pictorial and verbal information can be coordinated so that a presentation facilitates rather than impedes their effective integration by the learner. An important theoretical consideration underlying much of this work is the issue of minimising split-attention effects, in which attention to one type of presentation component may result in information being missed in a different, accompanying presentation component (Mayer & Moreno, 1998). This notion also appears to be useful when considering how the nature of dynamic graphics could affect learning from animations.

The essential instructional characteristic that distinguishes dynamic from static graphics is their capacity to depict temporal change directly. A consideration of the perceptual and cognitive implications of this direct depiction of change suggests that with some animations, learners may face higher levels of cognitive load than would be expected for static alternatives (Lowe, 1999a). Animations in general typically incorporate three main types of change in their component graphic entities:

- Form changes (*'Transformations'*) that involve alterations to graphic entities with respect to properties such as size, shape, colour and texture;
- Position changes (*'Translations'*) that involve the movement of whole entities from one location to another and can be perceived with respect to the border of the animation or other material within the animated display;
- Inclusion changes (*'Transitions'*) that involve the appearance or disappearance of entities (either fully or partly). This can occur in various ways such as entities edging in and out of the display at its borders, or entities being added or removed in other parts of the display.

There is a possibility that an *intra*-representation split-attention effect, analogous to the *inter*-representation effect described for picture–text combinations, may actually occur *within* the pictorial material of an animation itself. Consider an animation that depicts a complex referent via numerous pictorial components, each one engaged in its own regime of dynamic change. In this high-demand situation, a type of split-attention effect would seem possible between the different pictorial components, so that full attention to one part of the display would result in neglect of information in other regions. Such exclusive direction of attention would probably also prejudice learners' capacities to build the connections between various parts of the display that are necessary for relating the individual fragments of information into a coherent, meaningful whole (cf. Mayer & Anderson, 1992).

1.2. Animation and mental models

The animation that is the focus of the research reported here was developed with the aim of helping beginning students of meteorology improve their interpretation of static weather maps, so that these maps would be more useful to them as tools for learning about their domain of study (Lowe, 1995). Previous investigations revealed a range of problems these students had in making effective use of weather maps, many of which could be attributed to their lacking certain aspects of the domain-specific knowledge that are central to the way meteorological professionals 'read' these specialised depictions (Lowe, 1993, 1994a, 1996). A particularly critical knowledge deficiency appeared to involve basic meteorological dynamics. Being able to make plausible predictions and inferences from a given weather map is an important part of using weather maps as a way to learn about meteorology. A theoretical explanation of such capacities in terms of mental models assumes that they are the result of 'running' a suitable model forwards or backwards to generate a later or an earlier state of the subject matter (Johnson-Laird, 1983). However, generation of a meteorologically appropriate prediction or inference from a weather map would rely on the individual being able to construct a mental model of sufficient quality from the given information. Such a model would have to include not only appropriate tokens to represent the meteorological entities depicted on the map, but also an effective representation of the dynamics of those entities. In particular, it would have to contain relevant, comprehensive, and accurate information about how the markings comprising a weather map change over time.

Previous investigations of students' capacities to make predictions from given static weather maps suggested that the mental models they generated were based upon very rudimentary, undifferentiated, and flawed conceptions of meteorological dynamics (Lowe, 1999b). In particular, changes of position were applied to weather map markings incorrectly and in a highly over-generalised manner that treated all meteorological features and regions of the weather map in much the same fashion. When these domain novices generated a prediction from a given map, they tended to move all meteorological features from west to east en masse irrespective of the type of feature concerned. Further, the predictions indicated a resistance on the part of these subjects to make changes to the form of meteorological markings; when form changes were made, they appeared to be the result of a preoccupation with low-level graphics-based pragmatic issues and the application of everyday informal knowledge about the weather rather than a concern with higher-level meteorological considerations (Lowe, 1994b). In reality, the dynamic behaviour of different types of meteorological features is highly individualistic and is reflected in different alterations over time in the size, shape and orientation of the markings that depict those features. In order to generate a mental model of sufficiently high quality for dealing with this complexity, an individual would need a knowledge base that adequately represents these broad dynamic characteristics. The purpose of the interactive weather map animation that is the focus of the present investigation was to help students develop this type of knowledge base by explicitly portraying the required dynamic information and allowing them to explore the dynamic relationships involved. However, the success of such an approach is contingent upon students being able to both extract this information from the animation in an effective manner and properly incorporate it into their knowledge structures for subsequent use in building higher-quality mental models.

1.3. *Nature of weather map animation*

Consideration of the character of the weather map animation used in the investigation reported here highlights the processing demands faced by subjects participating in this study. The animated display consists of an array of markings and symbols that change in a coordinated manner as the animation proceeds. The most prevalent types of change occurring in this animation are those in the position and form of the markings and symbols (translations and transformations). However, there is considerable diversity across the set of graphic elements comprising the display in the nature and extent of these changes. With respect to changes in position (*extrinsic* change), characteristic motions of graphic elements range from almost static to relatively rapid (but the speed of individual elements can also vary from time to time, depending on the particular meteorological context). With respect to changes in form (*intrinsic* change), there are different degrees of flexibility in the way that various types of elements internally reconfigure over time. The elements representing some aspects of the meteorological situation are continually altering their size, shape and orientation whereas others remain relatively unchanged. From a meteorological perspective, there is no simple connection between these various changes in the graphic

representation of the depicted situation and the implications for the weather conditions. In other words, large and obvious changes in form or position are not necessarily of particular meteorological significance, whereas much more subtle changes may be of great significance. This means that the ‘raw’ perceptual character of the dynamics is not of itself a reliable or comprehensive guide to thematic relevance.

1.4. Extracting information from animation

A previous study explored the types of information that were extracted from a weather map animation by subjects (working in pairs) who had no specialist knowledge about meteorology (Lowe, 1999a). Simplification and cuing facilities targeting selected fundamental meteorological features were included in this animation with the intention of enhancing learning. Subjects’ written records indicated that they tended to extract both visuospatial and dynamic information on the basis of perceptual salience rather than thematic relevance. Extraction of information from the animation appeared to depend on the level of dynamism of the display components. Graphic entities that exhibited pronounced changes (particularly in position) during the course of the animation tended to be noted more frequently than less dynamic aspects of the presentation. For those entities that were the focus of attention, there was little evidence in subjects’ records of the complex interrelationships involved in their spatial and temporal structuring. These findings were accounted for in terms of subjects’ lack of domain-specific knowledge and consequent adoption of a domain-general approach for controlling cognitive load, in order to cope with the high level of demands imposed by the complexity of the animated material involved. However, the field study context of that investigation imposed constraints on several aspects of the data collection.

The main output generated from the previous study was *written* description of how various aspects of weather map patterns change over time. It is possible that this form of subject response somewhat limited the scope of information recorded as having been extracted from the animation. Perhaps a more comprehensive and appropriate reflection of the information subjects extracted would be obtained by requiring them to respond in a way that more closely matched the form of information presented in the animation (i.e. eliciting drawn rather than written responses). In the previous study, subjects’ reliance on written rather than drawn records may have been because verbal expression of such information is a more convenient way for capturing generalisations about the behaviour of meteorological features that are embodied in the animation. It may also simply have been a matter of preference. However, the transformation into verbal format of information originally presented in graphic format has the potential to introduce mediating effects that could constrain data collection. For example, visuospatial changes that are readily perceptible but awkward to describe in words may be omitted from subjects’ records. Further, verbal descriptions may concentrate on ‘events’ (more active aspects of the display where something obvious is happening), rather than on less foregrounded aspects of the display that effectively constitute a context for the action. This would be analogous to the way that the backgrounds in animated cartoons produced for entertainment

are subservient to the main action. In giving a verbal description of such a cartoon, we are unlikely spontaneously to give much emphasis to details of the action's context, unless for some reason it is especially salient.

The data collection in the previous study was also confined to the *products* of subjects' exploration of the animation and did not incorporate any *process* measures. In addition, the investigation did not require subjects to make predictions after studying the animation (which could have provided a basis for considering possible relationships between the information extracted and mental model quality). Further, the task completed by subjects involved them in compiling information from the animation that they considered would be *generally* useful for making predictions. This was a rather decontextualised activity in which subjects had to anticipate their likely needs for the making of a prediction, a task that the subjects involved were unlikely to have attempted before. Instead of interrogating the animation with the demands of a familiar task in mind, subjects had to extract information in anticipation of a hypothetical situation.

In the present study, a more controlled investigation environment was employed with the intention of addressing the limitations described above. On this occasion, subjects worked individually with a version of the animation that contained no simplification or cuing. Subjects' exploration of the animation was directed towards a quite specific and immediate learning task involving drawing a prediction of how a given weather map changed over time. The requirements of this learning task corresponded closely with those of a later application task (also a drawn prediction) designed to evaluate the effect of the animation on the quality of subjects' mental models. Data in the form of the maps produced during the learning and application phases of the investigation were supplemented with records of subjects' drawing actions during both phases.

The issues that are the focus of the present research are closely related to those from the previous study. However, this research also explored the degree to which the extraction of information from the animation during learning is reflected in the performance of a later application task that is assumed to provide an indication of the quality of the mental model developed (i.e. the extent to which it incorporates features of meteorological relevance and the accuracy with which those features are represented). The research addresses the following specific questions regarding the way that meteorological novices learn from the weather map animation:

- (a) What characteristics of displayed information are most influential in determining how readily it is extracted from the animation?
- (b) Is the type of information extracted from the animation appropriate for constructing a high-quality mental model?
- (c) How well is information from the animation retained and incorporated into knowledge structures as a resource for mental model construction?

2. Method

Subjects in the animated training group were 12 undergraduate students from the Faculty of Education at Curtin University with no special knowledge in meteorology who participated for partial course credit. A control group who received no training were a further 12 subjects drawn from the same population. Allocation to groups was by random selection.

Subjects in the animation group undertook two successive weather map-related tasks: a learning task and then an application task. For both of these tasks subjects were provided with a weather map (an ‘original’) and requested to draw on a separate blank map the pattern of meteorological markings they predicted would occur 24 hours later than those shown on the original map. The two different maps used in these successive tasks will be identified as originals ‘A’ and ‘B’, respectively. During the learning task only, subjects used a computer-based interactive animated weather map sequence to support their prediction drawing. Upon completion of the learning task, each subject in the animation group undertook the application task. For that task, subjects were given original ‘B’ and asked to apply what they had learned from the learning task in drawing a 24 hour prediction based on that map. While completing both tasks, subjects’ drawing actions were recorded on video.

In summary, the stages in the animation group procedure were as follows:

1. *Learning task*: Original ‘A’ used with the animation to draw prediction ‘A’.
2. *Application task*: Original ‘B’ used without the animation to draw prediction ‘B’.

Although they depicted similar seasonal phenomena, neither of the original maps formed part of this animation (having been selected from maps originating in years other than the period depicted). Instructions to the subjects emphasised that their purpose was to use the learning task to prepare for the subsequent application task in which they would be asked to draw another prediction from a different original weather map, but on that occasion without the support from the animation. The two original maps used in the study were both A4 sized Australian summer weather maps that shared the same typical seasonal structure overall but differed in various ways as to their local particulars. For example, original map ‘A’ contained a cyclone in the ocean to the north east, a feature not present in original map ‘B’.

The animation that supported subjects during the learning task showed how the pattern of meteorological markings on a typical sequence of Australian summer weather maps changed over a seven-day period. It was designed as an instructional simulation that provided subjects with very extensive direct control over the rate at which its component information was displayed and its display direction. Subjects were instructed to use information available in the animation to help them complete prediction ‘A’. They were shown how to interact with the animation to run it forwards and backwards at different speeds, either to view continuous change in the meteorological pattern or to examine frames in a more detailed step-wise fashion. Because their ultimate task was to predict changes expected to occur over a 24-hour period, subjects were given explicit instruction in how to run the animation forward

or backward by exactly 24 hours (for any portion of the total seven-day sequence). Before beginning the learning task, subjects practised with the animation until they were fluent in the required operations.

The control subjects were presented with original 'A' without the animation and asked to draw on a blank map the pattern of meteorological markings they would expect to appear 24 hours later than those shown on the original map.

After completion of their prediction tasks, both groups of subjects completed a further task in which they were given original map 'A' and asked to rate the relative extent to which they expected changes to occur over a 24-hour period in (a) the position and (b) the form of all meteorological markings on the map (1 = little or no change; 5 = very great change).

3. Data analysis

A fundamental intention of the data analysis was to determine from the learning phase responses the bases upon which the animation group subjects extracted information from the animation about how a weather map changes over time. Of particular interest was how well they were able to capture information that differentiated amongst the various meteorological features with respect to their changes in position and form. A related issue is that of what aspects of the information extracted during interaction with the animation became incorporated into knowledge structures, such that they could be called upon in building a mental model that better addresses the dynamic nature of meteorological systems. For this reason, comparisons of performance on the learning task and application task are required.

Although in a rudimentary sense weather maps are comprised of individual graphic markings, the specific meaning of each marking in this context depends on the meteorological feature of which it forms a part. If data analysis were to be confined to no more than a detailed marking-by-marking comparison on a purely graphic basis, this would neglect structural aspects of fundamental meteorological significance such as the broader patterning of markings. For this reason, rather than only dealing with markings on an individual basis, the analysis of subjects' predictions was based upon a set of meteorologically significant macro features (as determined from a consultant professional meteorologist's 'model answers'). In most cases, each of these features was comprised of several markings. The production order for a specific feature was recorded by noting the position in the overall drawing sequence of the first-drawn component marking of that feature. For example, with a high pressure cell, this could be any one of the following: (a) the main cell isobar, (b) the 'X' marking its centre, or (c) the 'H' labelling it as a high-pressure region.

Observations of animation subjects during the learning task showed that their general approach to using the animation for making predictions involved the following broad processes for each marking or group of markings:

- Inspect the animated display;
- Notice a specific marking or marking group;

- Locate a corresponding marking or group on the original map;
- Analyse the behaviour of the noticed marking or group over time;
- Refer to animation and original while drawing a predicted version of the marking or group.

The order in which meteorological markings were drawn in the learning task was taken as an indication of the priority they were given during the process of extracting information from the animation. By this assumption, markings produced earlier in the drawing sequence indicated the types of information in the animation that attracted selective attention before those produced later. A possible caveat with this interpretation is that subjects' drawing orders may also have been modulated by their judgements about how demanding it would be to generate a satisfactory prediction for each marking. However, observations of subjects' actions during the learning task suggested this was unlikely.

Measurements of the changes in position and form of features were made on the basis of a sub-set selected from the total group of meteorological markings present on the original maps. The selection of these markings was based upon their capacity to act as indices for meteorologically important weather map features while providing sufficient points of comparison across the collected data. Indicators of the position and form of selected markings from the predictions drawn during the learning and application phases were based on properties of a bounding box constructed to enclose each marking (Fig. 1). An indication of a feature's overall change in position was obtained by comparing the coordinates of the centre of its bounding box in the original and prediction maps; an indication of its change in form was obtained from the lengths of sides of the bounding box.

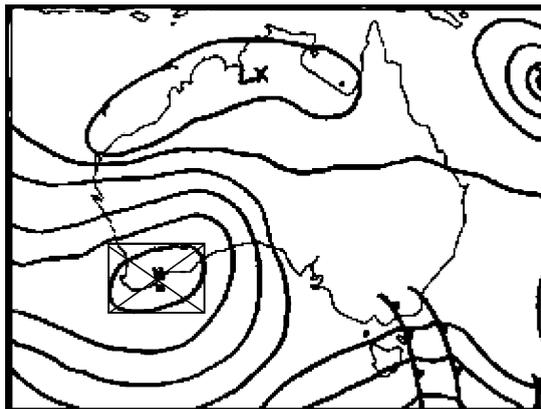


Fig. 1. Example of animation group prediction for map 'A' showing use of bounding box (aligned to map borders) as basis for measurement

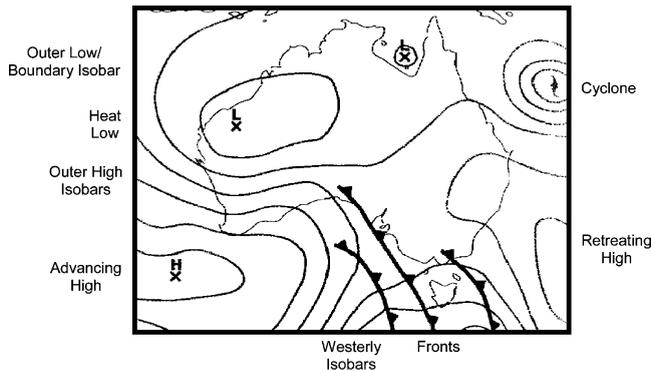


Fig. 2. Meteorological features on original map 'A'.

4. Results

4.1. Drawing sequence

Animation group subjects' drawing of the predicted pattern of meteorological markings involved discontinuous production of graphic elements. The overall effect was the generation of chains of subgroups of markings segmented via pauses (see also Lowe, 1993). Fig. 2 identifies meteorological features that correspond to these subgroups.

The learning task drawing sequence is summarised in Table 1, which shows mean drawing orders for the subgroups and the associated ranks. The early-drawn features tend to differ in two broad ways from those drawn later. The first of these differences concerns the fundamental visuospatial characteristics that these features possess, irrespective of their dynamic qualities. The second difference concerns the nature and extent of their change over time. The sequence in Table 1 reflects a tendency for the types of features with visuospatial characteristics that make them perceptually

Table 1
Learning task drawing sequence

Feature	Overall rank	Mean drawing order
Cyclone	1	5.8 (6.1)
Fronts	2	7.4 (7.1)
Heat Low	3	8.3 (5.5)
Advancing High	4	11.3 (5.4)
Westerly (Frontal) Isobars	5	15.9 (5.3)
Outer High Isobars	6	16.0 (5.3)
Outer Low/Boundary Isobars	7	17.3 (4.5)
Retreating High	8	17.6 (7.1)

Standard deviations in parentheses.

more coherent and compelling to be produced earlier than those that are less well defined. However, there is in fact no necessary relationship between the perceptual properties of these features and their meteorological importance. Indeed, it is often the case that relatively inconspicuous aspects of a meteorological pattern are highly significant indicators of the likely weather conditions in a specific region. For example, markings such as the visually unremarkable isobars that ‘fill in’ the area between other more perceptually salient features of a map typically provide professional meteorologists with key insights into present and future conditions.

Fig. 3 shows that the first four features drawn tended to be those that in the animation either appeared as closed figures (Cyclone, Heat Low and Advancing High) or had a highly distinctive appearance (Fronts). In addition, these early-drawn features had a distinctive dynamic character that contrasted with the ‘background texture’ provided by the map’s other markings. Thus the Advancing High and Fronts are features that move rapidly across the display area while maintaining a high degree of visual coherence. In contrast, the Heat Low stays relatively stationary overall but nevertheless exhibits pronounced dynamic contrast with its surroundings because it undergoes considerable internal change (in size and shape). Compared with the perceptually compelling changes in position or form of these first three early-drawn features, the Cyclone remains almost unchanged. However, this confers it with a different type of dynamic contrast in which it stands out as a static and structurally stable feature against an overall background texture of change in the rest of the map.

Fig. 4 shows the features drawn later in the learning sequence. With the exception of the Retreating High, these remaining features are isobars that occupy the space between or around the early-drawn features shown in Fig. 3. The early-drawn features could therefore be considered as a core for the arrangement of most of the markings added subsequently. The Frontal, Outer High and Outer Low/Boundary Isobars shown in Fig. 4 do not constitute discrete visual ‘objects’ in the animation but rather act more like a dynamic background texture that appears to adjust to changes in the more perceptually compelling features. The Retreating High is a feature that in the

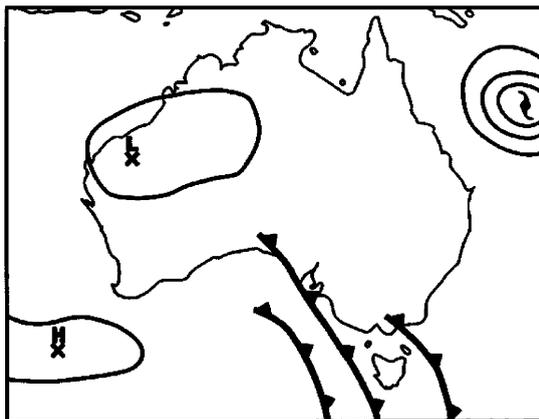


Fig. 3. Early-drawn features.

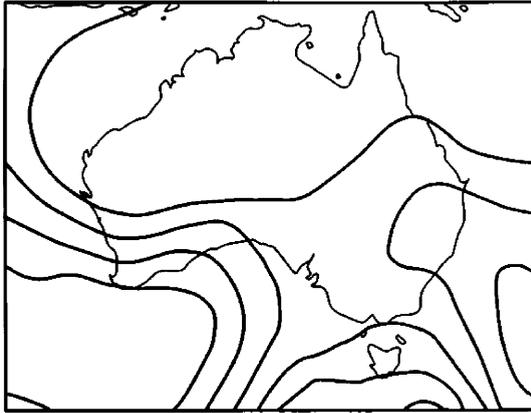


Fig. 4. Later-drawn features.

animation is relatively ‘short-lived’ in terms of its activity on the screen (compared with the other features that are far more persistent). Despite their relative neglect, these later-drawn aspects contain vital dynamic meteorological information which, although perceptually subtle, can be no less important than that associated with early-drawn aspects. Together, these less conspicuous features cover a major proportion of the Australian region and are essential in forecasting the area’s weather.

In summary, relatively persistent features that contrast markedly with the visual context of the overall pattern of markings tended to be produced earlier in the learning sequence. This contrast can involve both visuospatial and dynamic characteristics of the features concerned.

4.2. *Position and form changes*

For the purpose of comparing changes made from originals ‘A’ and ‘B’ to their respective predictions, six index markings common to both these maps were selected (Advancing High Outer Isobar, Advancing High Inner Isobar, Westerly Isobar, Trailing Cold Front, Retreating High, and Heat Low). The basis for selecting these markings was that they are indicative of major meteorological features comprising the original weather maps. Tables 2 and 3 present illustrative examples of the types of changes that subjects made in the original position and form of these index markings. The position changes are illustrated by alterations in the mean locations of the centres of marking bounding boxes between the original and its corresponding prediction. These location changes are reported with respect to the X and Y axes of the map (i.e. west–east and south–north).

Table 2 shows the mean centre changes for the animated group (predictions for originals ‘A’ and ‘B’) and the control group (prediction for original ‘A’ only). For position change in the X direction, Mann–Whitney tests showed that there were significant differences between the animation and control groups for the Heat Low and Cyclone. For their prediction from original ‘A’, control subjects tended to move

Table 2
Position changes

Index marking	Mean centre change (cm)					
	Map A			Map B		
	Animated prediction		Control prediction		Animated prediction	
	x (+ve to east)	y (+ve to north)	x	y	x	y
Advancing High: Outer Isobar	2.3 (2.5)	−0.7 (1.2)	1.9 (1.3)	0.4 (0.9)*	3.9 (4.3)	−1.9 (1.3)
Advancing High: Inner Isobar	6.3 (2.9)	1.3 (1.0)	4.8 (1.7)	1.4 (0.9)	7.1 (4.9)	0.5 (0.8)
Westerly (Frontal) Isobar	1.8 (2.9)	−0.4 (0.7)*	3.0 (0.7)	0.7 (0.9)*	3.2 (5.7)	−0.4 (0.9)
Trailing Cold Front	5.6 (2.3)	−0.9 (0.7)*	5.4 (1.7)	1.1 (1.1)*	5.9 (1.3)	−1.3 (0.8)
Retreating High	1.7 (0.9)	−0.4 (1.1)*	1.1 (1.0)	2.2 (1.2)*	3.4 (0.6)	0.8 (3.8)
Heat Low	3.0 (1.1)*	1.4 (0.9)	4.7 (1.0)*	1.2 (0.9)	3.6 (2.7)	−0.5 (1.1)
(Cyclone)	0.0 (0.7)*	−0.4 (0.7)	−1.4 (1.5)*	0.1 (1.2)	N/A	N/A

Standard deviations in parentheses.

* indicates significant difference.

Table 3
Form changes (W/H ratios)

Index marking	Map A			Map B	
	Original	Animated prediction	Control prediction	Original	Animated prediction
Advancing High: Outer Isobar	1.1	1.9 (1.0)	1.5 (0.3)	1.1	1.8 (0.6)
Advancing High: Inner Isobar	2.1	2.0 (0.8)	1.8 (0.4)	2.3	1.9 (0.5)
Westerly (Frontal) Isobar	2.7	3.5 (1.7)	2.1 (1.0)	0.4	3.5 (0.9)
Trailing Cold Front	0.7	0.5 (0.2)	0.5 (0.3)	0.5	0.6 (0.2)
Retreating High	0.7	0.6 (0.2)	0.7 (0.2)	0.4	0.5 (0.2)
Heat Low	1.6	1.9 (0.4)	1.9 (0.3)	1.9	2.0 (0.4)
(Cyclone)	0.8	0.7 (0.2)	0.9 (0.3)	N/A	N/A

Standard deviations in parentheses.

the Heat Low towards the east as part of a somewhat indiscriminate eastward shift they imposed upon most meteorological markings. As with their treatment of other components of the meteorological pattern, the controls tended to make changes for the Heat Low that were largely extrinsic with little intrinsic change being made to the Heat Low itself. In contrast, those in the animation group singled out the Heat

Low for different treatment. They tended not to translate the Heat Low as a whole towards the east in concert with other features but rather preserved its general location while modifying it intrinsically by stretching it out across the north of Australia. This is indicated by the difference between the more substantial mean change in position of the eastern side of the Heat Low's bounding box compared with that of its western side ($M_{\text{east}} = 3.8$, $SD = 2.3$; $M_{\text{west}} = 1.7$, $SD = 1.3$). With the Cyclone, the overall tendency was for the control group to move this feature westwards (toward the coast) in their prediction while, for the animation group, its position remained essentially unchanged. For both the Heat Low and the Cyclone, the animation group's prediction responses corresponded with the (meteorologically appropriate) dynamics depicted in the animated weather map material. However, the controls' responses are more consistent with explanations such as the application of simplistic, over-generalised dynamic rules (e.g. 'Australian weather patterns move from west to east' in the case of the Heat Low) or reliance on isolated knowledge fragments about meteorologically newsworthy events (e.g. 'Cyclones off the coast of Australia can swing inland to cause great damage'). In reality (and as depicted in the animation), the situation is far more complex and varied. For example, although features in the southern half of the map generally move from west to east, this is not true for northern features. In particular, Heat Lows typically persist over the hot northern part of the land mass which generates them; as time passes, they merely change in size and shape but remain within the confines of the Australian continent. In the case of Cyclones, patterns of movement are highly varied and unpredictable. Although they sometimes move inland, they frequently (a) remain stationary for extended periods, (b) move out to sea, or (c) simply weaken into a normal low pressure cell then fade away.

For both subject groups, the changes in position along the X axis were much more pronounced than along the Y axis. This appropriately reflects the zonal tendency for daily movement of meteorological features in the Australian region to occur mostly along the west–east axis of the map. However, there were significant differences between the groups in Y axis changes for the majority of index markings. Table 2 shows that, in a number of cases, there was even a tendency for those in the control and animation groups to move these markings in opposite directions (controls shifting them towards the north and the animation group shifting them towards the south). Once again, the changes of position made by the animation group better reflected the meteorologically correct movements depicted in the animation.

Comparison of changes in position along the X and Y axes in the predictions made by the animation group for originals 'A' and 'B' needs to be approached with considerable caution because of the differences in details of the meteorological patterns on these maps. The results for map 'B' appear to indicate that when applying what they had learned (i.e. drawing predictions without the aid of the animation), the animation group tended to exaggerate changes in position along the X axis overall ($M_{\text{A}} = 3.6$, $SD = 2.8$; $M_{\text{B}} = 4.6$, $SD = 3.9$) but differentiate less between features. For example, the differences in mean X axis position changes between all successive pairs of index markings shown in Table 2 are greater for map 'A' than for the corresponding map 'B' values. This raises the possibility that the dynamics extracted

from the animation during the previous task were not properly retained and incorporated as part of their knowledge structures. However, interpretation of these results must also include the possibility that they could have arisen from differences in the two map patterns.

Form changes in subjects' responses are illustrated by alterations in the proportions of the markings' bounding boxes. Table 3 gives the width-to-height ratios of the original markings and those for the subjects' predictions. While numerous clear differences were found between the animation and control groups with respect to changes in the positions of markings between original and prediction, this was not the case for changes in form. These direct measurements of the drawings also detected almost no difference between the animation group's form changes for predictions 'A' and 'B'. At first sight, this may seem to indicate that the animation was less successful in helping subjects internalise this aspect of weather map dynamics. A possible explanation under these circumstances would be that subjects' attention is preferentially drawn to the overall extrinsic change in a dynamic entity (translation) rather than its more subtle intrinsic change (transformation). If this were the case, we might expect that the animation group would be more successful at detecting the intrinsic changes that occur with less mobile structures such as the Heat Low, but this is not reflected in the results. However, it is also possible that width-to-height ratio is too crude a measure for detecting the relevant changes in form. The results obtained from the form change expectation ratings discussed in the next section provide some indirect support for this possibility.

4.3. Position and form ratings

Figs. 5 and 6 show the variation in mean ratings of the changes in position and form expected for individual meteorological markings after a 24-hour period (each point represents an individual meteorological marking).

The markings included in these graphs have been restricted to those that most directly represent the pattern of pressure and temperature across the map (i.e. isobars

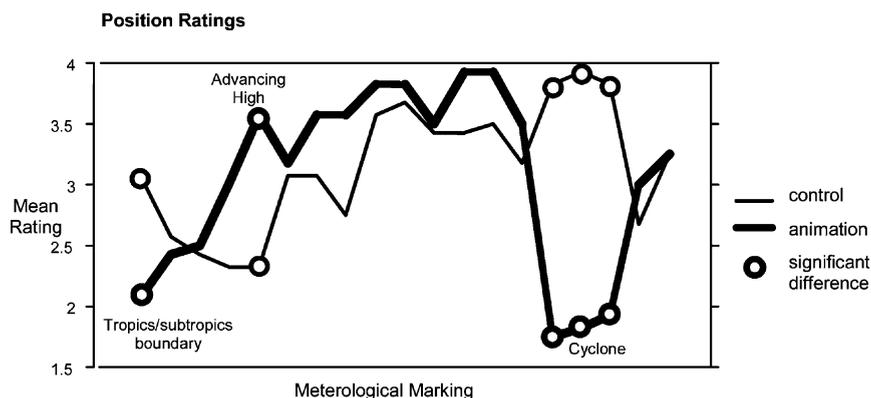


Fig. 5. Position ratings (for individual meteorological markings working anticlockwise around the map).

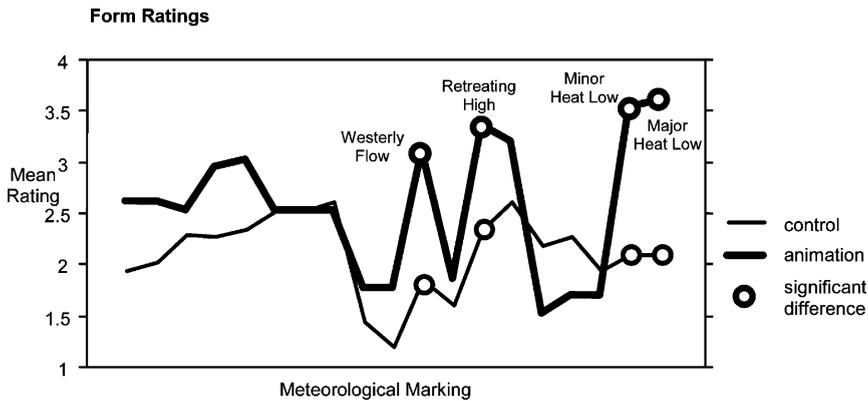


Fig. 6. Form ratings.

and fronts rather than alphabetic symbols etc. that indicate aspects such as central pressures or the identity of a feature). For both position and form, the control group's graphs have flatter profiles overall. This is a result of their ratings showing less distinction between the markings than was made by the animation group. The graphs indicate that the animation group generally tended to give higher change expectation ratings for both position and form. Mann–Whitney testing for position change expectations showed that in the case of the Advancing High, this difference was significant. However, there were a number of cases where this situation was reversed (notably the markings comprising the Cyclone and the Boundary Isobar running between the northern and southern halves of the map). The animation group's ratings for the expected position changes of the Cyclone and the Boundary Isobar were significantly lower than those from the control group. This result for the Cyclone is consistent with the result reported above in which the animation group changed the position of the Cyclone significantly less than the control group when making their prediction for map 'A', and directly reflects specific dynamic information provided in the animation. Considering the previous results for position change between original 'A' and its corresponding prediction, it is perhaps surprising that the animation group's change expectation rating for the Heat Low was not also significantly lower. This may be because the position change expectation ratings were not broken down into X and Y components, or because the extensive change in the Heat Low's form masked separate identification of its overall change in position. However, the animation group's significantly higher results for the Heat Low form change expectation rating does suggest that they incorporated this dynamic information from the animation into their knowledge structures. This is despite the fact that no such indication was obtained from the proportion measurements based on width-to-height ratios discussed earlier (lending support to the suggestion that the form change measure used was insufficiently sensitive). The animation group's form change expectations for the Westerly Flow and Retreating High were also significantly higher than those given by the control group. These features, like the others for which significant differences in change expectations were found, are key component elements for

major meteorological features around which the dynamics of a weather map are structured.

5. Discussion and conclusion

The overall findings from the present study are generally consistent with those from the previous investigation (Lowe, 1999a), in that meteorological novices' extraction of information from the weather map animation appeared to be largely driven by perceptual characteristics of the display. As a consequence, pictorial components with low perceptual salience tended to be neglected, irrespective of their thematic (meteorological) importance. An intra-representation effect was indicated for visuospatial and dynamic aspects of the display. Subjects tended to extract information about components with visuospatial characteristics such as structural coherence and distinctive appearance more readily than they extracted information about components lacking in these qualities. The extent to which components of the animation exhibited dynamic change also appears to have been a major influence on the extraction of information. However, it is not only about graphic entities undergoing extensive change in position that information was preferentially extracted. Rather, information tended to be noticed when there was substantial dynamic *contrast* with the visual context. Findings from the present study suggest that components of the animation can attract attention either because they (a) change substantially *more* than their surroundings, or (b) change substantially *less* than their surroundings. Further, it seems that both form change and position change can play a role in preferentially attracting attention when they contrast sufficiently with the context.

Although useful information was extracted from the animation, its potential for helping learners construct higher-quality mental models is probably limited because of its narrow scope. For the perceptually more conspicuous aspects of the display, subjects in the animation group were certainly able to extract relevant dynamic information likely to help them both correct the types of gross inaccuracies that novices tend to have in their mental representation of weather map dynamics and develop a more differentiated knowledge structure about the dynamic characteristics of the various types of weather map features. However, there are many aspects of weather map dynamics that are of major meteorological importance and yet are perceptually far more subtle than those that subjects readily extracted from this animation. Previous research on the way meteorological novices mentally represent weather maps indicates that these subtleties of the dynamics are largely absent from their knowledge structures. In the present study, the animation did not appear to be effective in making subjects any more sensitive to these less obvious dynamics aspects, despite the fact that they were explicitly depicted in the animation and a high degree of user interaction was provided for. In addition, even if subjects can *extract* some potentially useful information from the animation, this does not necessarily mean that that it will be properly *retained* and *incorporated* into their knowledge structures. It seems likely that for animations in which users are given no control over the presentation, the types of negative consequences for learning of the intra-representation selective attention effect indicated in this study would be even more pronounced.

Retention of information extracted during the animation learning task with respect to both position and form changes was indicated. However, the general trend for position changes to become exaggerated while at the same time differentiation between individual features becomes degraded suggests that the information retained underwent some distortion. Retention seemed more likely for those aspects of the display that were extracted from the animation relatively easily, so that information incorporated into knowledge structures is also likely to be incomplete, fragmentary and of limited value in building high-quality mental models of weather map dynamics. A similar effect has been reported with text processing. Readers who do not know what information is important in a text document can respond to surface structural aspects of the text and so produce a somewhat idiosyncratic set of connections among its elements (Coté, Goldman, & Saul, 1998).

Processing of the animation in this study was consistent with perception having divided the set of presented information on the basis of its dynamic characteristics into a 'field' that received most selective attention and a 'ground' that served a secondary contextual role (analogous to the field-ground distinction made for a static image on the basis of its visuospatial characteristics). Extraction and retention of information from the animation appeared to be largely driven by this perceptually based hierarchical subdivision of the animation's content, with dynamic as well as visuospatial characteristics influencing perceptual salience. Although the 'field' part of this display did contain much dynamic information vital for building a high-quality mental model, other more subtle but equally critical dynamic aspects were present in the relatively neglected 'ground'. There would be important implications for the designers of educational animations if further research in other content domains established that this pattern of processing applies to complex animations in general. For example, animations designed for learners who are relatively unfamiliar with the depicted subject matter would need to take account of this *dynamic* field-ground effect by incorporating design features that addressed cases where perceptual salience did not correspond with thematic relevance.

Evidence from previous research (Lowe, 1999a) raises the possibility that visuospatial and dynamic factors function synergistically. In that investigation, domain novices sought to impose inappropriate simple everyday cause-effect interpretations on to the information displayed in a weather map animation by allocating features in the display to 'subject' and 'object' roles. A synergistic effect may underlie the present results, whereby the addition of movement heightens the perceptibility of visuospatial characteristics of features that are already relatively distinctive in a static display (for example, in a superficial sense a cold front moving rapidly from west to east misleadingly appears to push other markings across the display area). Such a predisposition to search for cause-effect relations that seem to make the material more 'meaningful' may be another low-level driver that fundamentally influences the way animations are interpreted, especially by those who lack expertise in the depicted domain. This possibility that misconceptions can actually be induced when learners work with instructional animation warrants exploration in future research.

The animation used in this study did not contain added cues intended to focus learners' attention on particular aspects of the display. Without an extensive domain-

specific knowledge base to provide a more meteorologically appropriate approach to the extraction of information, learners who are novices in this area must process the animation in a largely bottom-up manner. Nevertheless, animations are frequently favoured across a wide variety of domains as a means of introducing difficult subject matter to learners who have little experience in the domain concerned. However, the findings of this study suggest that merely providing an accurate animated depiction of the to-be-learned material may not of itself be sufficient to produce the coherent and comprehensive knowledge structures required for learners to build high-quality mental models of dynamic content (even when the animation provides for interaction and extensive user control). This suggestion runs directly counter to much current educational practice, where the use of animation appears to be based upon a simplistic assumption that animation is intrinsically superior to static presentation. The findings of this study support the view that if animations simply display processes without providing further instructional enrichment, their educational potential may be compromised. On the basis of these findings, the potential of animation as a tool for learning is unlikely to be fully realised unless the design of these presentations gives proper attention to supporting learners' extraction of domain-relevant information and its incorporation into existing knowledge structures. The fundamental issue of conflict between thematic relevance and perceptual salience is not of course unique to animations. It is already well known for static pictures where it is addressed by using various visuospatial techniques to modulate perceptual salience. However, with animations there is the additional effect of dynamic characteristics on relative perceptibility. It seems likely that the high degree of freedom learners were given to explore this weather map animation had some negative consequences for learning. The problem appeared to stem from the lack of any explicit information about the relative meteorological importance of various aspects of the animation. On this analysis, it is possible to speculate that learners could be helped by animations designed to provide a more directive learning environment incorporating specific visual and temporal guidance (such as graphic cues and pre-set interrogation pathways). Further research is needed to determine the extent to which these findings can be generalised and how the characteristics of animations might be manipulated in order to modulate the way in which learners' selective attention is distributed between features of the display that differ greatly in their intrinsic perceptibility.

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