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Interrogation of a dynamic visualization during learning

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Abstract

Because animations can depict situational dynamics explicitly, they have the potential to help learners build coherent, high-quality mental models of complex change processes. Further, *interactive* animations provide opportunities for learners to deal with available information selectively and so avoid excessive processing demands. However, to be instructionally effective, the selected subsets of information must have high domain and task relevance. Approaches used by domain novices to interrogate an interactive animation of a complex dynamic system as they prepared for a subsequent prediction task were explored. Subjects searched the animation in order to learn generalizations upon which to base their predictions. Spatial and temporal strategies employed tended to be narrowly focused upon individual graphic features or localized groups while broader relational aspects required for coherence were neglected. The findings suggest that in order to build satisfactory mental representations from interactive animations, learners may require specific guidance regarding search strategies and targets.
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Dynamic visualizations are increasingly common in educational materials across a range of subject disciplines and levels of study. Animation is a type of dynamic visualization that is becoming particularly prevalent in multimedia learning environments such as those currently proliferating on the Internet. However, this explosion in the use of animation is occurring well in advance of adequate research-based accounts of how people cognitively process and learn from such resources (see Scaife & Rogers, 1996). As a result, instructional designers lack principled guidance as to what characteristics should be included in animations to maximise their educational effectiveness. Until quite recently, design advice tended

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to be very general in nature (e.g. Milheim, 1993). While this is beginning to change as a result of recent empirical work (e.g. Mayer & Moreno, 2002), a far greater understanding of the processes that learners use when studying animated information is needed as a foundation for principled design. This article reports an exploratory investigation of how learners interrogated an interactive animated display in order to extract information required to complete a prediction task. The investigation explored relationships among the characteristics of the animated content, the strategies learners used to interrogate the animation, and their success in predicting key changes in the content over time.

1. Text versus pictures versus animations

Comparisons of the information processing requirements of text and diagrams have been used to explain why pictorial representations can have advantages over text for presenting certain types of information to learners (Larkin & Simon, 1987; Winn, Li, & Schill, 1991). One such advantage is that diagrams can present important aspects of the information in a visually explicit fashion that is simply not possible with text due to fundamental differences in the representational systems involved (see Bétrancourt, Bisseret, & Faure, 2001). It appears that the explicitness of diagrammatic representation can facilitate comprehension of the subject matter because it obviates the need for learners to perform the burdensome mental manipulations of information that would be required to comprehend a text-based presentation of the same content. In essence, this additional and wasteful cognitive processing is necessary when there is a poor match between the nature of textual representation and key characteristics of the subject matter being represented. A good match between the representational medium and characteristics of the phenomenon being represented is considered instructionally desirable (e.g. Dijkstra, 1997).

The comparisons of text and diagrams referred to here typically concern the way their different *visuospatial* characteristics impact on information processing tasks such as search and the detection of relationships. It is possible to take this theme (of the benefits of presenting content explicitly) one step further and make a similar argument to support claims that animations are superior to static depictions as aids to learning. In addition to visuospatial characteristics, this further step requires *dynamic* characteristics to be taken into account when considering the consequences for information processing. At best, static depictions can present implicit representations only of dynamic content. They therefore require learners to infer the situational dynamics. This can be seen as imposing a processing burden somewhat analogous to that involved in determining visuospatial properties of a situation from a purely textual representation. In contrast, animations have the advantage of being able to present the situational dynamics explicitly and appropriately so that the majority of learners' processing capacity could be devoted to comprehending the content directly.

However the review by Tversky, Morrison, and Bétrancourt (2002) suggests caution in assuming the superiority of animated over static presentations because the depictions being compared may not present equivalent sets of information about the subject matter. In cases where animation has been found superior to static depiction, the benefits may not in fact be primarily due to differences in the cognitive or computational properties of the two forms of representation (Cheng, Lowe, & Scaife, 2001).

2. Educational potential of animations

Even in cases where animations and static depictions are comparable in terms of their content information, it does not necessarily follow that the cognitive and/or computational properties of animations would give them an edge over static depictions. Despite the superficial plausibility of arguments for the superiority of animations based on explicitness, various counter-arguments have been advanced on the basis of other aspects of the information processing likely to be involved (e.g. Lowe, 1999). In traditional animation, the material is presented in a pre-determined manner that plays from start to finish without the possibility of viewer control over aspects such as the length of the animated sequence viewed, its pace, and its direction. However, learners could be disadvantaged if their comprehension processes cannot keep pace with the speed at which an animation presents its information (Hegarty, Narayanan, & Freitas, 2002). With older analog presentation technologies such as films and videotapes, it was normally either impractical or at the very least inconvenient for the individual viewer to 'interrogate' the information in a flexible way.

In contrast to the pre-determined animation delivery regime of the recent past, computer technology now allows animation to offer a high degree of learner control. Interactive animation that can be freely interrogated by learners may help to reduce the likelihood of information processing problems. However, it is important to consider how this interactive potential can be put to best educational use (Aldrich, Scaife, & Rogers, 1998). Learners must be able to take advantage of the available interactivity. This is as much a matter of exploration strategy as it is of the fundamental perceptual and cognitive processing of the information viewed. Learners need to locate temporal segments containing thematically relevant changes then interrogate those located segments in a productive fashion. The dynamic material in animations can undergo various types of change including:

- Form change ('transformation') that involves alterations in graphic entities with respect to properties such as size, shape, colour, and texture.
- Position change ('translation') that involves the movement of whole entities from one location to another which can be perceived with respect to the border of the animation or other material within the animated display.
- Inclusion change ('transition') that involves 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 to, or removed from, other parts of the display.

Although the capacity to depict these changes gives animations the advantage of being able to represent dynamic situations explicitly, such changes also confer properties on these depictions that have perceptual and cognitive implications not present with static pictures. Further, the provision of interactive facilities for interrogating animations is likely to have its own perceptual and cognitive consequences for learning. Models concerned with the processing of graphic information proposed by workers such as Mayer (1994); Narayanan and Hegarty (2000), and Schnotz, Böckheler, and Grzondziel (1999) emphasise the importance of relational aspects in the building of coherent mental representations from pictorial materials. For animations, this would entail dealing with patterns of information that involve both spatial and temporal relations. Each of these different types of information patterning has its own distinctive implications for processing (such the conventions of *left to right* versus *before and after* as indications of causal relations). The nature of the strategies adopted for interrogating interactive animations is therefore likely to be a key determinant of success in extracting crucial information not only about the individual graphic entities comprising an animation, but also about their relationships.

3. Extracting information from interactive animation

In a previous study involving animated weather maps and meteorological prediction (Lowe, 2000), learning results appeared to be closely related to *dynamic contrast* between different types of display components. It was inferred that inappropriate field-ground distinctions associated with this dynamic contrast effect meant that learners preferentially extracted perceptually conspicuous information while neglecting more subtle yet thematically relevant aspects of the meteorological markings. In addition, the relationships between the markings they drew in their predictions tended to be confined to local rather than broader aspects of the display.

With specialist *static* pictures, novices in the depicted domain are typically unaware of the most productive spatial locations to examine for relevant information (Lowe, 1989). However, with *animated* pictures there is the additional possibility of a similar lack of awareness in novices' examination of *temporally* separated locations. Zhang (1997) suggests that the processing biases resulting from perceptual saliency characteristics of some external representations may have unfavourable results. Because the perceptual salience of material in animations can be associated with both visuospatial and dynamic properties, the effects of these two characteristics of animated displays on the extraction of information should be considered.

4. Searching in space and time

Evidence is accumulating that learners' extraction of information from animations can be deficient in at least two broad respects (Lowe, 2003). In some cases, it seems that learners tend to under-process the presented information because of lack of requirements for cognitive engagement ('underwhelming'). In other cases, the reverse situation seems to apply in which despite engaging with the animation intensively, learners are unable to process the presented material satisfactorily due to the excessive cognitive demands imposed ('overwhelming'). These excessive demands are associated with aspects of animation such as the high information load (particularly, if the subject matter is complex) and the temporally distributed nature of the presentation. In such cases, it appears that learners adapt by applying attention selectively to a subset only of the presented information. The associated competition for attention between different graphic elements constituting the animated display is likely to result in effects analogous to the split-attention effects that have been investigated between pictures and text (e.g. Mayer & Moreno, 1998). Limiting the scope of attention in this way therefore has implications for the effectiveness of search.

Fundamental to effective search processes is success in extracting thematically relevant information from animations. Ferguson and Hegarty (1995) characterize static diagrams as often being underspecified, a characteristic that can result in problems for learners in decomposing the whole display properly into appropriate graphic elements (features). Animations present the additional challenge of decomposing the temporal sequence into events involving features in the display that are thematically relevant (feature events). Winn (1993) has offered a tentative account of how learners search static diagrammatic displays for information that emphasizes the search's iterative nature. This notion is of course highly applicable to interactive animations that are repeatedly interrogated for information but involves temporal as well as spatial iterative search. A possible advantage of such iterative processing, particularly for complex information, is that subsets of information could be selected in each pass and processed in a serial fashion rather than simultaneously (Pollock, Chandler, & Sweller, 2002). However, this additional search dimension means that the task can be intrinsically more complex (demanding), and so learners need to find ways to cope with the associated demands and still maintain processing.

5. Strategies

Cognitive load considerations (Sweller, 1999) highlight the importance of controlling the demands on working memory in order to facilitate productive learning activity, something that can be done either externally by way of instructional design or internally by way of the strategies learners adopt. Opportunities for such control are available with respect to both the spatial and temporal dimensions of interactive animation. Constrained spatial interrogation strategies could be used to limit the proportion of the total display *area* searched and constrained temporal interrogation strategies could be used to limit the proportion of the total display *period* searched.

Previous studies of how learners use interactive animation (Lowe, 2000, 2003) suggest considerable variety in the strategies used by domain novices to interrogate the available information. In particular, there appeared to be wide variations in how comprehensively the set of information provided in the animation was searched and in the amount of attention given to relational aspects of the information that are the basis for coherence formation. Different classes of *spatial* strategy can be envisaged that may be categorized according to (a) the fraction of the area covered by display that is considered and the locations involved and (b) the extent to which the contents of those considered areas are related to each other:

(i) *Exclusive* strategies that concentrate on a specific feature to the exclusion of others within a particular narrowly defined location.
(ii) *Inclusive* strategies that also limit their scope to a narrowly defined location but include the various features it contains.
(iii) *Intra-regional* strategies that are wider in scope than the previous strategies in that they deal with the features in different locations within a broader region.
(iv) *Inter-regional* strategies that span individual broad regions.

In addition, different classes of *temporal* strategy can be envisaged that may be categorized according to (a) the fraction of the period covered by the display that is considered and the locations involved and (b) the extent to which the contents of those considered periods are related to each other:

(i) *Confined* strategies that concentrate on a small and highly localized section of the total animation sequence (such as the first few frames).
(ii) *Distributed* strategies that also concentrate on a small proportion of the total animation but involve frames that are spread throughout the whole sequence.
(iii) *Abstractive* strategies that are wider in scope than the previous strategies in that they survey the animation for several occurrences of a particular feature event then try to abstract a general principle from all available instances.
(iv) *Integrative* strategies that seek out combinations of feature events that change in association with each other.

Each of the above lists of spatial and temporal strategies is arranged hierarchically according to how much they should constrain information processing demand. Strategies towards the bottom of each list could be assumed to be more demanding for those who are novices in the depicted domain because they require a greater amount and variety of information to be taken into account.

6. The task

In the present study, subjects interrogated an interactive animated Australian summer weather map sequence in order to make a prediction about how the meteorological markings on a given static weather map (the ‘Original’) could be expected to change over a 24 hour period. The Original map used for this task was a typical summer weather map but not one of those comprising the animated sequence. The task therefore required subjects to extract and apply information available in the animation to a new situation that, while closely related to the fundamental meteorological events depicted in the animation, nevertheless differed from it somewhat in terms of superficial appearance.

7. How weather maps change

On a broad scale, the whole Australian summer weather map area can be divided into two meteorologically distinct regions that approximately correspond to the northern and southern halves of the map (Fig. 1). The sharply contrasting dynamic behaviour of the features occupying these regions arises from their very different meteorological origins.

The northern half tends to be populated by two main types of meteorological feature for which *form* change is a highly salient characteristic: persistent Heat Lows and Cyclones. In contrast, in the southern half of the map the two major feature types are fast-moving Highs and Cold Fronts for which *position* change is a conspicuous characteristic. These more transient southern features both exhibit *inclusion* change with respect to the weather map boundary (i.e. particular instances of these features periodically enter and leave the display). Although the northern and southern halves of the Australian weather map area are highly individualistic, nevertheless a substantial degree of coordination exists among the markings across the intermediate zone. This coordination *between* the northern and southern regions is additional to coordination in the pattern of markings *within* each region.

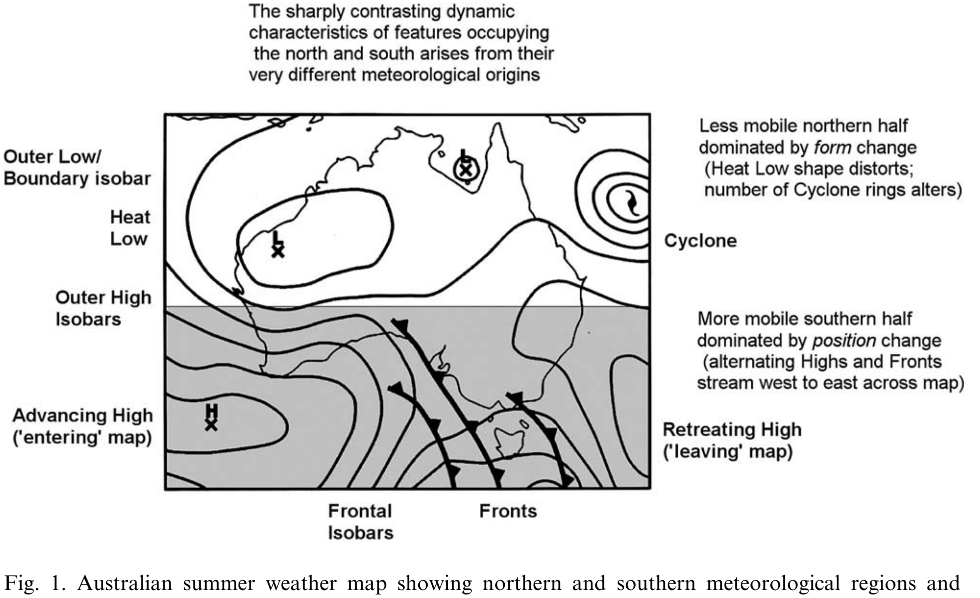

Fig. 1. Australian summer weather map showing northern and southern meteorological regions and their main change types in the animated sequence.

8. Using interactive animation successfully

Central to the potential of interactive animations in education is the learner's capacity to use the interactive facilities effectively to interrogate the animated information appropriately. A theoretical analysis of the challenges faced by domain novices in attempting to search such animations productively suggests that they are ill-equipped to cope with this interrogation. Under these circumstances, a pragmatic response for novices might be to adopt expedient, low-level, piecemeal strategies that help them constrain information processing demands rather than attempting more sophisticated strategies that would be necessary for extracting important relational information from the display.

The present study examined learners' interrogation of an interactive animation and how their approaches were shaped by intrinsic properties of the animated format. It addressed the following specific questions:

(i) What types of strategies do learners who are novices in a specific domain spontaneously invoke when interrogating an interactive animation?
(ii) How are these strategies related to the visuospatial and dynamic characteristics of the animation?
(iii) What are the consequences of these strategies in terms of their success in extracting key aspects of the presented domain content?

9. Procedure

Subjects were 12 undergraduate students from the Department of Education at Curtin University in Australia with no specialized knowledge of meteorology. The stages in the procedure were: (i) a learning task, (ii) a 'replay' task, and (iii) an application task. Subjects' responses for all these tasks were recorded on video. For the learning task, subjects were given the A4-sized Original Australian weather map and asked to draw on a separate blank map the pattern of meteorological markings they would expect to appear 24 hours after those shown on the Original.

Subjects were instructed to interrogate the animation via its video-like controls in order to help them complete the learning task prediction. After completing this prediction, they 'replayed' a demonstration of how they interrogated the animation while at the same time explaining the actions they had taken (using the mouse with one hand and pointing out the relevant material on their drawing with the other hand). Finally, they carried out an application task in which, without support from the animation, they applied what they had learnt. The present paper deals with stages one and two of this investigation.

10. Data analysis

Data reported here are based on (a) the sets of predicted meteorological markings drawn during the learning task, (b) subjects' interrogation of the animation in the course of producing these markings (c) the verbal and gestural explanations generated during the 'replay' task that detailed how the interrogation was used to determine the predicted markings.

Analysis of subjects' drawn maps focused upon selected aspects that could function as indices to capture the distinctiveness of the northern and southern halves of the meteorological pattern. Successful use of the animation for making a prediction involves the capacity to distinguish between (a) the characteristic *form*-related dynamic change that predominates in the northern half of the map and (b) the characteristic *position*-related and *inclusion*-related changes that predominate in the southern half. Analysis therefore evaluated changes of the Heat Low and the Cyclone in the north, and of the Highs and Fronts in the south. Making a meteorologically appropriate prediction also involves the capacity to coordinate the individual changes in map markings so that they are bound together by overarching patterns of organization. Changes to individual meteorological markings were therefore also assessed in terms of the extent to which they took account of the context provided by other graphic elements.

A combination of (a) several plausible alternative predictions generated from the Original map by a professional meteorologist and (b) information presented in the animation sequence were used to develop a set of criteria for evaluating the appropriateness of subjects' predictions. The criteria used to evaluate form changes involved measurement of selected index characteristics of the features concerned (the extent to which the Heat Low spread eastwards and the alteration in the number of isobars comprising the Cyclone). Position changes were evaluated by determining whether or not the feature's predicted new location had been drawn within the boundaries of a pre-defined limited region of the map (there were two discrete regions for the Advancing High and two overlapping regions for the Fronts). Evaluation of the inclusion changes was based upon the presence or absence of such changes, and their location. Coordination of markings was evaluated by examining the relationships with respect to the form of particular markings in subjects' drawn maps that existed for a number of critical configurations of features.

The videos were analysed to determine the order in which each subject added meteorological markings to the blank map during the learning task. Points in this drawing sequence at which the subject interrogated the animation using the controls were identified. Subjects' verbalizations and pointing behaviours during the 'replay' task were transcribed from the videos then analysed in terms of the explanations provided for their interrogations of the animation.

11. Results

11.1. Meteorological markings drawn during learning task

11.1.1. Changes in features

There was considerable variation in the accuracy with which changes in individual features were depicted in the southern and northern halves of the map. In general, the predictions of changes in the southern half of the map tended to be more reasonable than those in the northern half. For the southern half, all but one of the subjects drew the Advancing High in an acceptable position. The remaining subject positioned the High center correctly but showed the High as an open feature (i.e. not a closed loop) rather than as a closed cell. All subjects positioned the group of Fronts appropriately overall (but many subtle form changes in these Fronts were poorly handled). All but one of the subjects maintained the inclusion of the large retreating High that was crossing the eastern border of the map but five subjects failed to include the small isobar fragment in the extreme south west corner (that should actually have edged further into the display).

In the northern section of the map, key aspects of both the Heat Low and the Cyclone were drawn inappropriately by about half the subjects. The animation frames in Fig. 2 show how the animation's Heat Low and Cyclone actually change. However, instead of 'anchoring' the west side of the Heat Low and extending its eastern side (form change), six subjects translated the whole feature from west to east so that it moved in a fashion similar to the High—Front–High chain in the southern section of the map (position change). Five of these same subjects also failed to intensify the Cyclone by increasing the number of concentric isobars surrounding the cyclonic center.

11.1.2. Coordination of features

Two aspects of feature coordination are particularly important for accurate rendering of the weather map changes. The more straightforward of these aspects is the arrangement of meteorological features. For example, the animation's High—Front–High pattern that is characteristic of the southern half of the map, is typically maintained with relatively minor variations in the spacing of these features as

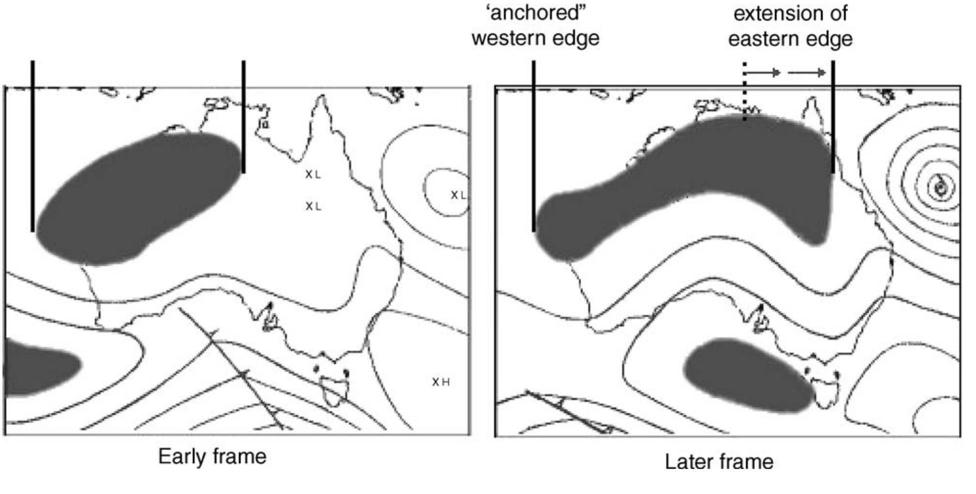

Fig. 2. *Note*: (a) form change via 'anchoring' of western edge of Heat Low and extension of eastern edge, (b) increase in number of Cyclone's isobars, (c) coordination of Heat Low's form with passage of high.

they progress from west to east across the map area. Similarly, the general positions of the Heat Low and Cyclone in the northern half of the map (located over the land and the sea, respectively) are largely maintained during the course of the animation. This aspect of feature coordination occurs *within* each of these broad regions (i.e. *intra*-regional coordination). However, there are also more subtle aspects of feature coordination that occur between the broad northern and southern regions of the map (i.e. *inter*-regional coordination).

For the materials used in this study, an aspect that is particularly critical for producing a high-quality prediction is the inter-regional coordination of the Heat Low in the north with the Advancing High and Fronts in the south (Fig. 3). As the High traverses the map, the eastward extent of the Heat Low and the shape of its southern edge change; for part of the Fronts' progress from west to east, the Heat Low develops a lobe that moves across the map in concert with the Fronts. Both these types of form change are 'echoed' in the intervening isobars between the features involved.

A coordination score for these two intra-regional and two inter-regional aspects of subjects' drawings was determined by allocating one point each for acceptable position, shape, and alignment of the features concerned. Scoring was done using a template based upon a professional meteorologist's estimate of the plausible range of these characteristics in the predicted meteorological pattern. Wilcoxon signed ranks test indicated that the combined coordination score for the two intra-regional aspects was significantly greater than the corresponding score for the two inter-regional aspects ($M_{\text{intra}} = 4.9$, $\text{SD} = 0.7$; $M_{\text{inter}} = 3.0$, $\text{SD} = 1.0$; $Z = 3.1$, $p < 0.005$). Subjects' drawings thus exhibited better coordination of meteorological features within each of the northern and southern regions than between these two regions. While deficiencies in the position and alignment of features both contributed to the poor inter-regional coordination scores, problems with shaping of the features (i.e. form) were particularly pronounced. Fig. 4 presents illustrative

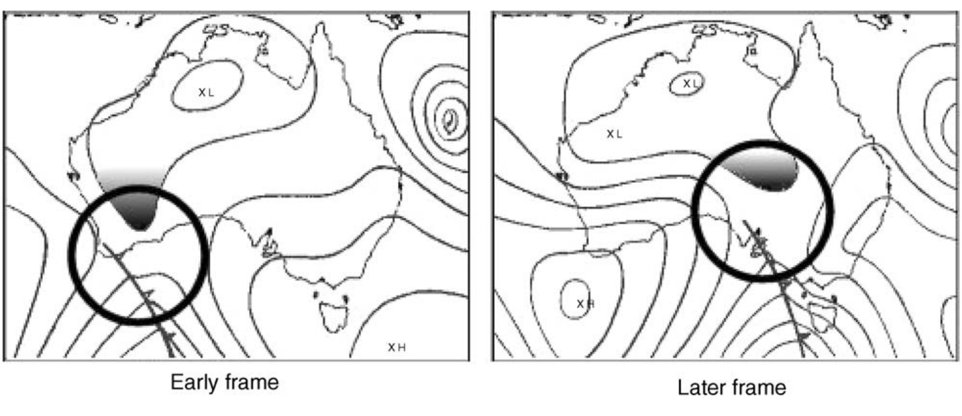

Fig. 3. Coordination of form of Heat Low with passage of Front. Note allignment of lobe on southern edge of Heat Low with Front.

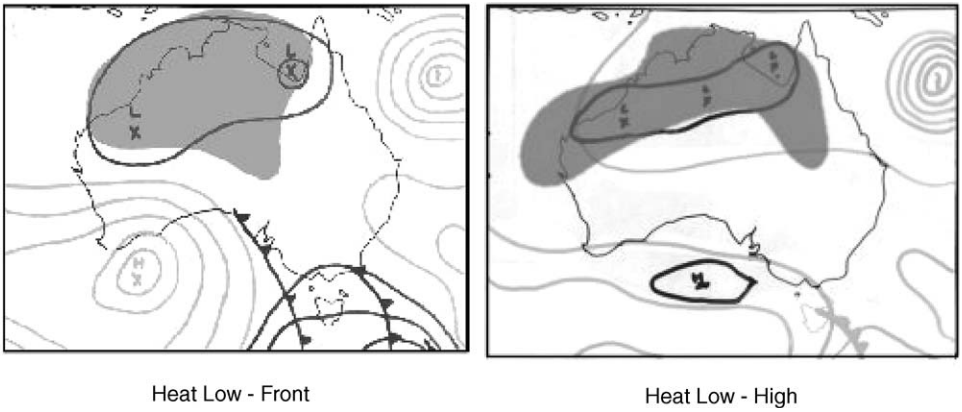

Fig. 4. Lack of Coordination of form of Heat Low with southern features. (grey shaded area shows appropriate form of Heat Low ex animation).

examples of the ways in which the form of the Heat Low was drawn essentially independently of the broader context of the position of features in the southern half of the map.

11.2. Interrogation frequency and strategies

Subjects varied considerably in how often they interrogated the animation during their drawing sequences. The six subjects who produced the least appropriate predictions for the northern half of the map carried out far fewer interrogations, ($M = 3.2$, $SD = 1.5$) than the six most successful subjects, ($M = 9.2$, $SD = 1.9$). Periods of interrogation tended to precede the drawing of perceptually well-defined features (High, Front, etc.). Although these features were often separated from each other by one or more intervening isobars, subjects generally 'skipped-over' these separating lines and worked from one main feature to the next. Interrogations were typically quite localized and limited in scope (often confined to the immediate region of a particular feature of current interest). The skipped isobars were usually dealt with only after the well-defined features had been drawn and appeared to be treated as if they had much lower status than other aspects of the map. This is reflected in the comments that were made during the learning task ('do I have to do all these lines as well?'), the comparative lack of interrogation that appeared to be specifically concerned with establishing the characteristics of the intervening isobars, and the relative absence of discussion of these markings during the replay task.

Subjects also tended to be highly selective in their interrogation of the animation sequence; once a general overview had been gained, a relatively small proportion of the total frames comprising the animation were usually studied so the temporal scope of much interrogation activity was very limited. On the basis of data from the replay task, the frequencies with which subjects used various categories of spatial and temporal interrogation strategies were determined (see Appendix A for representative examples of statements reflecting different strategies). For both spatial and temporal interrogation, records of subjects' verbalizations and pointing behaviour indicated they typically used one or two of the four strategies and these tended to be those that would help constrain their search (Fig. 5).

Subjects' transcripts provided some indication that they were limiting the scope of their interrogation in order to make a complex and demanding task more manageable:

> I just wanted to open with 'day one' because I got confused if I went any further. . .like there was too much to take in.

An effect of this limitation in scope appears to have been to restrict consideration of relationships between markings to the confines of the particular meteorological region (southern or northern) in which they occurred. With one exception, strategies targeting more sophisticated relationships amongst weather map components (i.e. inter-regional and integrative strategies) were not in evidence. In fact, this single exception was a case of the subject concerned incorrectly inferring a relationship between a northern and a southern feature on the basis of an incomplete survey of the animation. In contrast to the subjects who produced more appropriate predictions generally, this subject did not adopt an abstractive strategy but relied on a single instance based on a very limited temporal sampling of the whole animated sequence.

11.3. Pathway details

Although the High—Front–High chain moves in a general west-to-east direction overall, the details of this movement for the component features vary according to particularities of the context. For example, Highs tend to shift somewhat northward as they move into the Australian Bight, then return southwards around

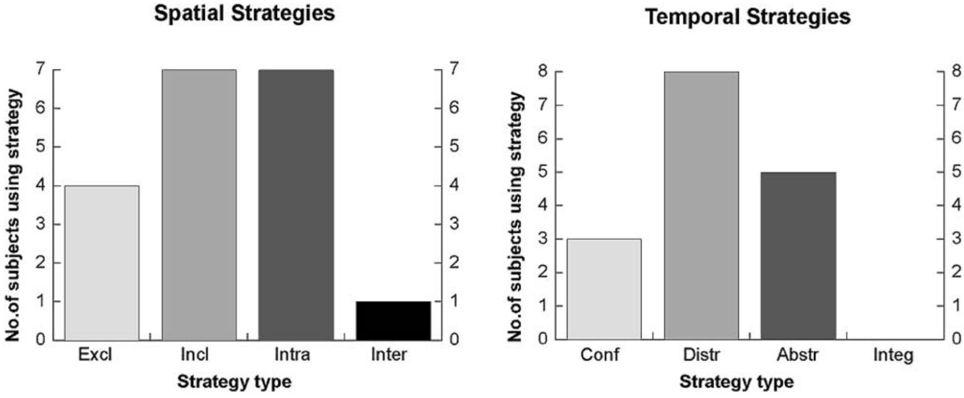

Fig. 5. Number of subjects using particular spatial strategies (exclusive, inclusive, intra-regional, interregional) and temporal strategies (confined, distributed, abstractive, integrative).

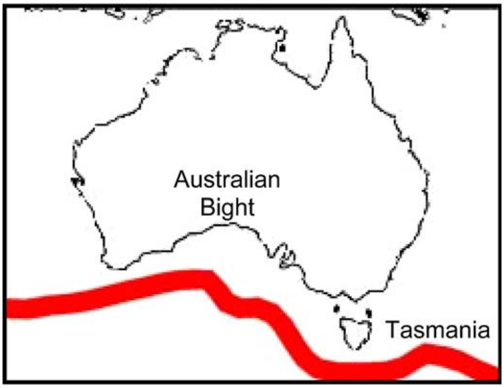

Fig. 6. Pathway followed by Highs during animation showing changes in trajectory with respect to Australian continent during west–east progress (derived from successive positions of the High centre).

Tasmania (Fig. 6); Fronts follow a curved sub-path in which they appear to rise into the main west–east flow, then slip away again. These variations are manifested as modulations embedded in the larger scale west–east movement. As indicated above, subjects were generally successful in positioning the Advancing High and Fronts appropriately. However, 10 of the 12 subjects positioned the Retreating High inappropriately northward of its likely location.

The section of the path near the eastern border of the map dips noticeably southward so according to the animation, a Retreating High should straddle the southern and eastern borders. Instead, 75% of the subjects positioned this High on the eastern border only which is much more closely aligned with the position they gave to the Advancing High on the other side of the map. In essence, it was as if the pathway for Highs moving across the map had been simplified by straightening it out so that it ran more directly west–east than was actually the case.

12. Discussion and conclusion

The results indicate that subjects adopted piecemeal approaches to their interrogation of the animation. They tended to use low level strategies that addressed isolated spatial and temporal aspects of the animation to the neglect of more inclusive dimensions. Their focus on fragments of the display meant that while they were quite successful in extracting and coordinating local aspects of the meteorological pattern, they did not produce coherent predictions in which the meteorological markings were tightly integrated across the weather map overall. However, even within a particular localized region there was an indication that the relationships deduced were simplified with respect to what was depicted in the animation.

The lack of broad coordination across the map in subjects' predictions is consistent with the limited nature of their interrogation strategies; they tended to explore one feature at a time and confined examination of relationships to those within a single meteorological region. Spatial and temporal restriction of subjects' search suggests a response to a demanding processing situation that is based on simple off-loading of information rather than approaches such as conceptual grouping of visuospatial and dynamic components into a smaller number of meaningful chunks (a strategy that should be available to those with more expertise in the depicted domain). Both the quantity and quality of interrogation appeared to play a role in how successfully subjects extracted information from the animation.

A major deficiency in subjects' predicted maps was the failure to integrate the intervening isobars that occupy the space between the more perceptually conspicuous features. The animation shows the behaviour of these markings as highly coordinated with fluctuations in other aspects of the meteorological pattern but this crucial aspect was not reflected subjects' predictions. Evidence from subjects' strategies suggests that these markings were not accorded the same status as other features and were selectively neglected during search in favour of perceptually conspicuous features that had been allocated a dynamic 'field' rather than a 'ground' role in the display.

As with previous studies of this animation, there are indications that changes in position were more likely to be extracted than changes in form. There is a range of possible explanations for this preferential extraction. It may be that position changes are intrinsically more compelling than form changes, although this would need to be investigated by comparing changes that were 'equivalent' in their extent and complexity (perhaps not the case in this animation). Alternatively, the nature of the position changes in this animation may have been simpler to cope with in terms of their information processing requirements. Another possibility is that the position changes in this animation were so perceptually compelling compared with the form changes that they had a 'swamping' effect which diluted the effect of changes in form. A somewhat different type of explanation is that subjects construed changes in position as more important (and therefore more worthy of attention) than form changes. Clarification of this relationship between form and position changes is an important issue for designers of animations.

The results of this study suggest that merely providing interactive facilities that allow learners to interrogate an animation may not be particularly beneficial with respect to learners' extraction of thematically relevant information. It seems that it is not sufficient to offer learners who are novices in a domain an accurate, comprehensive dynamic depiction of a dynamic referent situation and expect them to be able to interrogate it productively on their own. Designers of educational animations may need to adopt a more proactive role in manipulating the way content is presented so that the presentation goes far beyond being simply a dynamic record of events as they would happen in the referent situation. On the basis of findings from the present study, these manipulations would need to address those information processing consequences of animations that appear to limit the extent to which learners can extract thematically relevant material from such depictions.

Appendix A. Examples of subject statements reflecting spatial and temporal strategies

A.1. Spatial strategies

Exclusive:

... I looked at this here [*FRONT IN ANIMATION*], a cold front I think, and it seems to be moving away during the day so I sort of applied the same thing to this one [*FRONT ON MAP*] and made it move away...

Inclusive:

... I've taken the lines back, these ones here [*FRONTS*] and watched the lines [*FRONTS*] and the lines traveling with it [*FRONTAL ISOBARS*] so I made mine the same...

Intra-regional:

... this one [*HIGH*] was originally over here [*WESTERN EDGE*] and because it was moving from left to right, it moved across to there [*HIGH TO THE EAST*] and these are the new isobars that are coming in [*ISOBARS ON WESTERN EDGE*]...

Inter-regional:

... originally they [*CYCLONE ISOBARS*] were quite strong here and tight circles but as this [*HIGH*] was moving on they became looser and they circles, the spaces between them, became larger...

A.2. Temporal strategies

Confined:

... I used mainly the first day because it is quite similar to the original... I was going through the rest of the sequence originally but it didn't look anything like it. Otherwise I was confusing myself if I went on and looked at the rest of the sequence...

Distributed:

...So with the High, I followed that from about the same place [in the animation] ...With the Low, I found a section that was smaller, like that, right at the start of the animation... and the Fronts down the bottom, I just followed them over a day and they seemed to move quite quickly, like right across Tasmania...

Abstractive:

... [*Early transcript*] I noticed the Lows up here (I'm assuming they're Lows) stayed fairly stationary although there was some movement on this side...[*Later transcript*]. Up here [*HEAT LOWS*] I tried to see what they'd do over the full period [=*7 DAYS*], whether they'd move much...

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