Graphic User Interface Embedded Timelines (GETs) as Visualization Tools for Distributed Instructor Teams in Simulation Exercises

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ABSTRACT

A principal component of the vision of future simulation based training is the collaboration of distributed instructor teams (Walwanis Nelson, Owens, Smith, & Bergondy-Wilhelm, 2003). The members of such teams are expected to coordinate and integrate the planning, control, and debriefing of an exercise while residing in physically different locations (Fowlkes, et al., 2004). In the absence of a shared team environment, we suggest that members of distributed teams will be highly dependent on a sophisticated interfacing system such as team-shared, multi-functional timelines. Thus, there is a need for specific guidance for the design of Graphic User Interface (GUI) solutions (Nosek, 2001).

This paper presents solutions for GUI design based on an analysis of the impact of distributed team environments on individual cognition. We suggest that minimal social interaction and perceptual limitations are likely to exert harmful effects on memory performance. Consequently, key instructor tasks (planning, monitoring, and debriefing) are likely to be affected at the individual instructor level and lead to performance degradation of the instructor team. Based on a review and reappraisal of cognitive science, we present a three-part examination, including a classification scheme for timelines as a team-ready, low-workload GUI tool that has the potential to amend individual and team effects of Distributed Asynchronous Team Environments (DATEs).

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THE COLLABORATION CHALLENGE FOR FUTURE INSTRUCTOR TEAMS IN SIMULATION-BASED TRAINING

A principal component of the vision of future simulation based training is the collaboration of distributed instructor teams (Walwanis Nelson, Owens, Smith, & Bergondy-Wilhelm, 2003). The members of such teams are expected to coordinate and integrate the planning, control, and debriefing of multi-platform, simulation-based exercises, while residing in physically different locations (Fowlkes et al., 2004). During their collaboration within a Distributed Asynchronous Team Environment (DATE), such virtual teams (Stone & Thach, 1999) or electronic groups (Finholt & Sproull, 1990), rely on technology to enable group interactions. The optimal choice and design of this technology is crucial to reduce DATE effects. Specifically, interaction via asynchronous text-based communication lacks nonverbal feedback and inhibits awareness of shared circumstances. Therefore, this type of environment may decrease a member's sense of interaction with the group and may lower perceived topic continuity and motivation to respond (Finholt & Sproull, 1990). Similarly, when information is exchanged in a text-based environment, there appears to be a limited ability to direct group attention, coordinate activities and solve problems (Finholt & Sproull, 1990).

Research has shown that both quality and quantity of communication may suffer in distributed teams. Student groups that interact electronically have lower communication quality and duration than traditional face-to-face groups (Scifres, Gundersen, & Behara, 1998). Furthermore, researchers suggest that the loss of nonverbal communication (e.g., interpersonal cues such as facial expressions, body language, eye contact, voice tone), within text-based electronic communication, requires greater structure to facilitate successful communication (Stone & Thach, 1999). Given the potential for suboptimal communication, the related finding that virtual teams experience high levels of conflict is not surprising (Hinds & Bailey, 2003). Generally, we must regard DATEs as challenging environments for teams and their members and appreciate the need for software solutions that address and reduce adverse motivational, social and above all, performance effects (Nosek, 2001).

In the absence of a shared team environment, we suggest that members of distributed teams will be highly dependent on a sophisticated interfacing system such as team-shared, multi-functional timelines. Thus, there is a need for specific guidance for the design of Graphic User Interface (GUI) solutions (Nosek, 2001). The paper consists of three parts: Parts 1 and 2 relate the state of cognitive science to individual cognition with respect to DATEs and timeline processing. Part 3 introduces a GUI embedded timeline (GET) functionality table within the task domains of distributed instructor teams of simulation-based exercises (GET tools).

PART 1: REVIEW AND REAPPRAISAL OF COGNITIVE SCIENCES APPLIED TO INDIVIDUAL COGNITION IN DATES

Approach

Cognitive fitness and readiness of the individual team member are implicated in overall team performance. For instance, developing trust in virtual teams appears to be influenced by the responsiveness to communication requests and the level of dependability of individual team members (Icanao & Weisband, 1997). It follows that compromised performance, due to forgetfulness or distractedness, may undermine team trust and could thereby mediate team performance (i.e., low trust in virtual teams has been linked to poor team performance, indicated by missed project deadlines, Icanao & Weisband, 1997).

Hence, our focus for this section is an initial examination of DATE effects on the information processing of the *individual* from a cognitive perspective. We suggest that correcting for the negative effects of distribution and asynchrony, by supporting individual team member's information processing, may ultimately benefit the entire team. An overview of relevant literature on interruption, interference, task switching and human memory follows.

Interruption

The lack of face-to-face communication in distributed meetings increases the possibility of task interruption and switching when compared to collocated group meetings (O'Conaill & Frohlich, 1995). A majority of workplace environments do not afford uninterrupted, undisturbed blocks of time to their populations (e.g., Hudson, Christenson, Kellogg, & Erickson, 2002). Rather, interruptions due to incoming communication such as email, instant messaging, phone calls and social calls, tend to not only suspend the execution of an ongoing task but potentially lead to the termination of the interrupted task (O'Conaill & Frohlich, 1995). Recent research investigating the effects of task interruption suggests that the reacquisition of a complex task after an interruption is perceived as difficult and time-consuming (Czerwinski, Horvitz, & Wilhite, 2004). Because individuals in DATEs lack the benefits of spatial proximity, including joint conferencing in their "natural habitat," a review of the interruption effects on cognition appears beneficial.

Interference

The recently popular research on task interruption in the work environment appears closely related to a body of research on interference and its effect on memory performance (see Bower, 2000; Postman, 1971). Interference can be expressed as the effect of interrupting an ongoing task on memory performance. For instance, when interrupted during a learning task by a secondary task, individuals tend to recall the interrupt***ing*** (interfering) task rather than the primary task they were instructed to study (Bower, 2000). The possibility exists that the difficulty of reacquiring an interrupted task reported by individuals in professional environments may involve similar cognitive processes and could be attributed to interference effects. Thus, adverse effects of task interruption may be a result of compromised memory encoding or retrieval. Nonetheless, empirical evidence suggests that not all interruptions are created equal. The similarity of the interrupting task appears to influence the size of the interference effect. Generally, the more similar the interrupting task is to the ongoing task, the greater the interference effect (e.g., Bower, 2000). When studied within the laboratory environment, interference effects have been found in a broad range of tasks, from studying multiplication tables to recalling stories (Anderson, 1995). Overall, the effects of interference have been established as a robust cognitive phenomenon.

Task Switching

In addition to unplanned interruptions and interference effects, purposeful task and attention switching are a likely reality of DATEs. The costs associated with voluntary task switching usually involve increases in error counts and response times (Arrington & Logan, 2004; Monsell, 2003). The extra time needed during reacquisition appears to be due to the time required for retrieval processes (Voigt & Hagendorf, 2002). Recent studies indicate that "switch costs" can be reduced by task preparation (Monsell, 2003) as well as by similarity of task demands (e.g., it may be easier to switch between two tasks that are similar in procedure than two tasks that place different demands on information processing and memory; Arrington, Altmann, & Carr, 2003). In line with Voigt and Hagendorf (2002) who suggest that memory processes largely contribute to total switching costs, it appears that mnemonic aids are likely to facilitate switching by providing task overviews and memory cues to support retrieval processes (e.g., Ausubel, 1960, 1978; Corkill, 1992; Mayer, 1978; Langan-Fox, Waycott, & Albert, 2000).

Memory

Memory performance appears as a central theme emerging in the domain of DATEs. Abundant personal experience as well as the wealth of scientific works on the topic, offer compelling evidence that human memory is far from robust but malleable, spontaneous and reconstructive in nature (Loftus, 1995, 2004; Friedman, 1993). Due to task interruptions and switching, it appears that DATE characteristics intensify the potential for memory degradation, including encoding and retrieval errors. The question arises how memory can be supported within a DATE GUI framework. The types of memory particularly critical to DATEs appear to be the memory for future events and tasks (prospective memory, see e.g., McDaniel, Guynn, Einstein, & Breneiser, 2004), as well as memory in the traditional sense of recall of past events and tasks (retrospective memory). In the case of instructing a distributed exercise it is important *during* exercise control to recall briefs presented by trainees and the general game plan discussed among instructors. Moreover, instructors must be able to anticipate what tasks are going to occur during a given scenario in order to understand, evaluate, and provide feedback on trainee performance.

Researchers have argued that failure to retrieve properly encoded information may be due to a number of reasons. For instance, knowledge in the sense of a memory trace might decay over time. Non-decayed, obsolete information may compete and interfere with desired recall, such as recalling one's previous but not current phone-number. Lastly, lack of retrieval may be due to a lack of retrieval cues associated with the desired information. (For hythotheses' reviews see G. Bower [2000] and J. R. Anderson [1995]). The latter explanation is in line with the utility of mnemonic aids such as calendars and graphic organizers (Klink & Newman, 2000; Langan-Fox, Waycott, & Albert, 2000). From a cognitive psychological perspective, memory cueing is the most powerful mechanism we can embed in a GUI to facilitate recall. Nonetheless, the implementation of a cueing tool requires consideration regarding another memory type: working memory.

Working memory (WM), also known as short term memory (STM), has been described as the active part of our memory system that allows for management and encoding of new information as well as manipulation and recall of prior information. WM/STM has been characterized by processing types and capacity limitations. For instance, Miller (1956) put forth that human STM is limited to 7 plus or minus 2 items or chunks. A simple rule of recall is that novel material will be more easily remembered if the individual items are packaged as meaningful chunks (Bower, 2000). For instance, most individuals find it is easier to remember the eight musical syllables "do-re-mi-fa-so-le-mi-o" than "lo-me-ro-di-fi-so-ma-e" because the former stimuli are processed as a single chunk while the latter, although the exact same letters, appear as eight random syllables.

The facilitating nature of chunking does not only apply to the alphanumeric stimuli but to visual representations of knowledge as well. Visual input is spontaneously organized into patterns and shapes based on their spatial location relative to each other (Toccafondi, 2002; Wertheimer, 2000). For instance, highlighting the three corners of an invisible triangle with dots is sufficient to create the appearance of a triangle. Likewise, placing dots along an imaginary line creates the appearance of a trajectory. Such effects of Gestalt (emergent form) appear virtually instantaneously. It follows that two-dimensional displays that capitalize on Gestalt effects for instantaneous visuo-spatial chunking may potentially reduce the burden on our limited WM/STM for meaningful stimulus processing and aide information storage. Spontaneous organization of shapes and patterns and their likely alleviation of STM/WM capacity limitation may explain the workload reducing, at-a-glance property of well-designed displays.

In summary, carefully designed knowledge visualizations in the form of visuo-spatial GUIs have the potential to reduce the processing load on working memory by consolidating information into chunks. Further, these visualizations have the potential to support prospective and retrospective memory by providing retrieval cues and event records. As a possible design solution that affords the benefits described for visuo-spatial GUIs, the next section examines GUI embedded Timelines (GETs) in detail.

PART 2: REVIEW AND REAPPRAISAL OF THE STATE OF THE SCIENCE APPLIED TO GUI TIMELINES

Timelines and Their Potential as Cognitive Aides

To determine the potential of GETs as GUI knowledge visualization tools that minimize workload on users and counteract memory degradation, we reviewed and reappraised literature relevant to the following timeline design elements: visuo-spatialty, imagery and orientation.

Visuo-spatiality and Pop-out Searches

The term visuo-spatiality refers to displays such as graphic timelines that express information in two-dimensional space. Because of their two-dimensional nature (x and y axis), such timelines require minimal cognitive resources to process information compared to textual formats (Larkin & Simon, 1987). For instance, visual-spatial displays support pop-out effects (i.e., virtually instantaneous visual recognition of an irregularity in pattern, structure, color or movement; Treisman & Paterson, 1984). Such detection is likely to expedite the grasp of planning and execution irregularities and support deconfliction of assets. A number of consistent research findings indicate that the pop-out phenomenon in visual search is not learned but innate and does not require training (Oprecio & Adler, 2003; Schubo, Schroger, & Meinecke, 2004). Thus, the expedient detection of pattern irregularities will be common to all team members without a need for training. Display designs that incorporate features that present new data within a pop-out graphic will be instantly recognized as new by all team members, allowing for a much more rapid processing of the new information.

Visuo-spatiality and Surfacestructure

The term surfacestructure refers to the depiction of relationships between part and bites of building blocks of information, such as individual events (Kintsch & van Dijk, 1978; Kintsch, 1986). In the case of a timeline, this definition expresses the relationship of individual events and tasks to each other *over time.* Examples of surfacestructure information made available in timelines are the display of multi-platform exercises where timelines of individual elements are depicted in parallel thereby providing a global view. See Figure 1. Such multi-timelines are likely to reveal density and pacing of events, as well as event relationships within and between elements (e.g., event order, parallelism, clustering). Similarly, Gestalt principles (continuity, proximity, closure, etc.) allow for the rapid detection of patterns and pattern irregularities organizational information through gestalt principles (e.g., Wertheimer, 2000). Examples include cascades of triggering events, overlaps, and simultaneity. By comparison, the surfacestructure of text is relatively uniform and does not provide organizational information at the same level as two-dimensional displays.

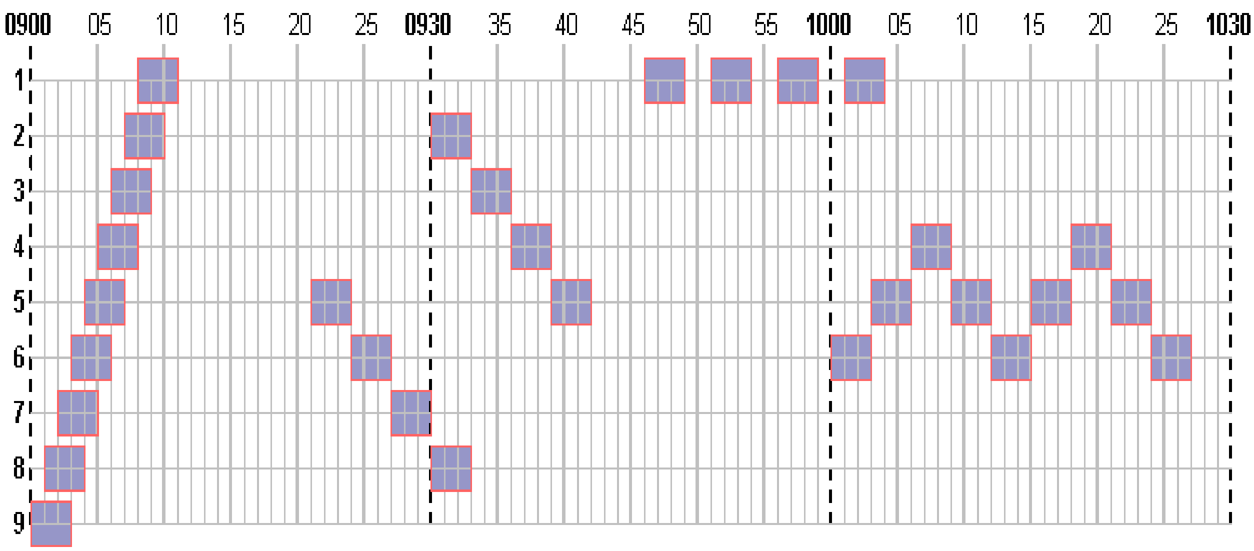

Figure 1. Idealized Global View of Multiple Elements (i.e., Timeline Indicated by Number on Vertical Axis) Revealing Event Patterns

Visuo-spatialty and Computational Efficiency

When investigating the information processing of text compared to graphic representations, Larkin and Simon (1987) proposed the distinction between informational and computational efficiency. Informational efficiency refers to the content that is being provided and the ability to capture such content accurately, while computational efficiency is understood as the number of steps necessary to extract or infer such content information. Related to the notion of meaningful surface structure, Larkin and Simon found that quantitative graphs were more computationally efficient than text that contained the same information. When applied to timeline displays, it appears that two-dimensional timelines compared to textual timelines or threads of email are more likely to be computationally efficient (more quickly processed) with regard to quantitative information such as the number of events or events patterns.

Imagery and Memory Cues

Dual coding refers to the processing of visual, as well as verbal-semantic information. During recall in particular, after information was stored in two separate channels, the presence of additional cues from a second code is likely to enhance memory (Paivio, 1978; Sadoski & Paivio, 2001). The depiction of a timeline by virtue of its two dimensional nature serves as an (abstract) image for the embedding of recall cues, such as event markers, along a temporal axis. Research in the educational sciences, cognition and perception suggests that by explicitly providing recall cues in visuo-spatial representations, such as timelines, information retrieval may be enhanced *in general,* in particular when the same presentation format is used during study and recall (e.g., Chu, Handley & Cooper, 2003).

Intuitive Orientation and Left-to-right Bias

We suggest that linear, horizontally oriented formats imply a chronological progression from left to right, enhancing ordering, sequencing and timing of event information. It has been known for decades that there is a preference or bias for the right-handed majority to prefer left-to-right directional qualities in graphic art (Beaumont, 1985; Gaffron, 1950; McLaughlin, Dean, & Stanley, 1983). Although it has also been shown that this preference may be attributed to cerebral lateralization of function and eye movement patterns (Levy, 1976; Loftus & Mackworth, 1978; Mclaughlin, 1986), left-handed individuals, who show the opposite lateralization of right handed individuals, demonstrate the left-to-right preference and the same visual scan patterns as right-handed individuals (Mead and McLaughlin, 1992). For efficient graphic design of chronological data presentation, these studies suggest that a left-to-right timeline would be the optimal design for the vast majority of viewers.

Summary

While relatively little empirical research has directly investigated GUI timeline display for individual users (Ringel, Cutrell, Dumais, & Horvitz, 2003; Willis, 2001), several lines of investigation appear to merge on the conclusion that timeline displays are likely to facilitate information processing of individuals by supporting computational efficiency, pop-out searches, meaningful surface structure, and left to right bias.

PART 3: GUI EMBEDDED TIMELINE (GET) TOOL – CLASSIFICATION FOR DATE BASED INSTRUCTORS

Although it has been suggested that traditional (non-GUI) team tools such as work plans, Gannt charts and timelines, could be utilized to enhance virtual teams by tracking progress (Stone & Thach, 1999), relatively little research on GETs has been conducted (Ganoe et al, 2003). Moreover, GET design solutions have been described as inefficient and inadequate for lack of sophisticated functionalities (Jensen, 2003). An investigation of GETs seemed appropriate not only to fill a gap in GUI design guidelines but also to serve as an example where science meets user needs:

(a) Various interviews with subject matter experts in multi-platform training missions revealed the need for GUI-embedded information visualizations that capture temporal components and provide an overview of a complex situation (e.g., CHI systems, 2003)

(b) The GUI for the Common Distributed Mission Training Station (CDMTS) under the initiative of PMA-205s Air Warfare Training Development Program is currently in development. The CDMTS is intended to support instructor teams collaborating in DATEs by providing a number of functions, including GETs (Fowlkes, et al., 2004; Walwanis Nelson, Owens, Smith, & Bergondy-Wilhelm, 2003).

Complementing our brief review of cognitive science and how timeline displays may aide individuals in coping with the adverse effects of DATEs, Table 1 describes various possible functionalities of GETs (GET tools) and their support of individual cognition to benefit the team.

We describe possible GET tools and their anticipated benefits for individuals and teams within the three primary collaboration domains of distributed instructor teams as envisioned within the CDMTS framework: (a) planning (scenario development), (b) exercise control and exercise manipulation, and (c) debrief. The GET tool functions we investigated were freeze-frame, scalability, hierarchical nesting, animation and interactivity. Our investigation was based on the assumption that a given timeline display consists of a master timeline and additional multiple parallel timelines, each representing a particular platform or element of the exercise.

Table 1. GUI Embedded Timeline (GET) Tools and Their Cognitive Benefits by Instructor Task

GET Tools (Functionality)	Task Domain		Cognitive Benefits
Freeze Framing (scenario snapshot) Single or multiple parallel timelines provide display of event markers and event duration bars	Planning	- Limitation: Static design cannot display progressive instructor inputs - Limitation: Cannot be updated	- Overview allows for chunking of information to support working memory and reduces demand on correct recall of planned and past events - Display provides contextual knowledge - Team level: Individual's cognitive capacity is freed up to maintain awareness of team status and situation
	Scenario Control	- Limitation: No progression indicator - Limitation: Requires mental simulation - Limitation: Cannot be annotated (e.g., no insertion of markers for critical events or comments)	
	Debrief	- Static timeline serve as a summary of events - Provides post-hoc overview of actual vs planned scenario	
Scalable Single or multiple parallel timelines are zoomable from detail view to overview level	Planning	- Supports individual as well as team by providing status quo picture at the level of resolution desired	- Reduce load on working and long-term memory by allowing rapid access to multiple levels of knowledge resolution - Team level: Maintain situation awareness by supporting rapid shifting between detail and overview within one display
	Scenario Control	- Supports view of ongoing scenario as well as micro views of ongoing event	
	Debrief	- Aides and corrects recall by allowing for access to details	
Hierarchically Nested Timeline events or markers support access, entry and manipulation of nested data (i.e., embedded information may be accessed via event icons along a given timeline)	Planning	- Allows insertion and recall of detailed data of entities or events during scenario development	- Create and access memory aides/markers to facilitate and correct recall of detail information - Download of working memory into shared display - Team level: Consolidates multi-platform information into single display
	Scenario Control	- Allows access, entry and editing of detail data such as event, entity, hit status	
	Debrief	- Allows data access and annotation during debrief	
Animated (living timeline) In addition to the display of event markers and event duration bars, advancing progress indicators visually track the time that is elapsing during a given exercise	Planning	- Useful for preview if driven by instructor input (see conclusion section)	- Reduce load on working memory by providing actual animation instead of requiring mental simulation of future events - Highlights areas of interest and aids in focusing attention to immediate tasks - Team level: Maintain situation awareness by narrowing area of focus to the area of immediate relevance, tracking progress, and synchronizing multiple elements
	Scenario Control	- Show progression of pre-planned mission - Show progression of actual simulator and SAF behavior	
	Debrief	- Show progression of actual vs. planned mission	
Interactive (scenario snapshot with mark-up tools and data access) Event markers and event duration bars on a given timeline can be modified and changed. For instance, new event marker icon may be inserted to assist in recall; existing icons may be modified (move, adjust, recode, delete, add text); display may be adjusted by zooming/scrolling including scalable functions (see above)	Planning	- Timelines are modifiable and thereby support scenario construction, and modification - Progressive mark-up produces diagram overview of complete scenario based on multiple inputs	- Provide mnemonic aides (memory triggers) by allowing individual instructors to flag important events prior to and during exercise control - Team level: Mnemonic aides can assist and correct individual recall, allowing for smoother review and discussion of exercise events
	Scenario Control	- Allows for insertion of markers as memory aids	
	Debrief	- Static display serves as summary of events - Inserted or marked critical events serve as debrief cues for discussion and playback of scenario - Allows for post hoc mark-up of timeline to illustrate relationships or additional critical events	

Conclusion

Research on shared displays has provided the recommendation for carefully designed team displays but has not yet produced design guidelines (Bolstad & Endsley, 1999). Based on the contents of Table 1, we suggest that the optimal GET for DATE teams would combine the functionalities of scalability, hierarchical nesting, animation and interactivity (see Table 2). While each of these tools in singularity may provide individuals with some benefits, it appears that a GET that

- merges data access and entry,
- provides detail views and overviews,

- supports personal mark-ups and shared annotations, and
- controls preview, review and tracking control of a training scenario,

may best aid a team of instructors on the individual level as a sophisticated mnemonic aide while also supporting the team in the sharing, updating and recalling of information.

Table 2. Suggested GET Toolbox and Associated Cognitive Benefits by Instructor Task

GET Tools	Task Domain		Cognitive Benefits
Dynamic GET Toolbox (Scalable, Hierarchically Nested, Animated, Interactive) Single or multiple parallel timelines provide a display of event markers and event duration bars that can be modified and changed. Embedded event data may be accessed via event icons. Progress indicators track time progression visually. Animation supports playback, preview and replay. Interaction allows for animation control (choice of speed), selection of in and out-points.	Planning	- Consolidates scenario construction and modification into single display - Produces diagram overview of complete scenario - Animation capability allows for preview of planned scenario	- Team level: supporting the team in the sharing, updating and recalling of information - Overview allows for chunking of information to support working memory and reduces demand on correct recall of planned and past events. - Reduce load on working and long-term memory by allowing rapid access to multiple levels of knowledge resolution - Create and access memory aides/markers to facilitate and correct recall of detail information - Reduce load on working memory by highlighting areas of interest and aid in focusing attention to immediate tasks - Provide mnemonic aides (memory triggers) by allowing individual instructors to flag important events prior to and during exercise control
	Scenario Control	- Supports monitoring of scenario progression and insertion of markers to serve in debrief as cues for discussion and as playback control for scenario - Allows rapid access to embedded information	
	Debrief	- Display serves as summary of events - Marked, critical events act as debrief cues for discussion and replay of scenario - Detail information is accessible as embedded data - Multiple views allow focus on individual timelines as well as bird's eye overview of scenario	

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