The TEMPO of Battle: Designing a Temporally Enabled Map for Presentation

Nathan Prestopnik
School of Information Studies
Syracuse University
United States
napresto@syr.edu

Alan Foley
School of Education
Syracuse University
United States
afoley@syr.edu

Abstract: Despite their ubiquity and utility as teaching and visualization tools, battlefield maps for military history education have received little formal research attention. To address the problem space of maps in military history, as well as various research questions surrounding it, a design-based study was undertaken to design, develop, and implement a new tool, the Temporally Enabled Map for Presentation (TEMPO). This study explores the broad problem of battlefield maps, time visualization, and military history: past and current maps in this educational domain visualize space and terrain well, but, as static artifacts, are often unable to visualize timing, luck, and event sequences. Drawing from relevant information visualization, cartography, and geography literature, an animated, interactive map of the battle of Midway intended for use in the traditional lecture classroom was designed and tested through a design-based research process.

Introduction

The traditional paper battlefield map, a staple of military history education, has long helped historians to visualize and teach the events that take place during war. Scholars and soldiers often include maps with their writing to help illustrate battles (e.g. Grant, 1885; e.g. Keegan, 1989), and the battlefield map is a common sight in classroom lectures, books, museums, and historical battle sites.

Despite their ubiquity and utility as teaching and visualization tools, battlefield maps for history education have received little formal research attention. In cartography, geography, military history, and even information visualization, there is virtually no specific discussion of battlefield maps, even as highly related topics – cartographic design and labeling (Imhof, 1965, 1975), visual interaction effects (Tufte, 1990, 1997), map abstraction (Muehrcke, 1990), animation (DiBiase, MacEachren, Krygier, & Reeves, 1992; Kraak, Edsall, & MacEachren, 1997), and terrain in battle (Doyle & Bennett, 2002) – have been favored for their more general utility.

The lack of scholarly attention on maps for teaching military history is problematic, for such maps are usually not ideal for instructional purposes. The vast majority of military history maps are designed on static media – paper (books and hanging maps), acetate (for overhead projection), fixed displays (museums and in-situ battlefield markers), or relatively inanimate digital media (PowerPoint or other digital projection for use in the classroom). Battlefield maps purport to show students both space and *time*, but the media of choice for these visualizations succeed at only the first of these goals. While the best maps display the physical landscape of battle very well (e.g. Goldsworthy, 2005), they often fail when it comes to visualizing events. Events occur over time, but paper and acetate can show only individual moments. Arrows, unit and position marks, and even multiple views are able to represent only a shadow of what really happened during past moments of great consequence. This is unfortunate, because the timing of battlefield events is important; even seemingly inconsequential events such as an ill-timed aircraft launch have had fateful consequences (Prange, Goldstein, & Dillon, 1982; Spector, 1985).

Numerous potential research questions surround the “maps and time” problem space, positioned in areas of inquiry as widely diverse as education, computer science, and information visualization. These research areas can be conceptually divided into those orienting on *human* needs, those orienting on *technical* needs, and those found in the intersection of these needs – the *human-computer interaction (HCI)* space (e.g. information visualization). Because of the relatively unexplored nature of the “maps and time” in military history problem space, three key research questions were chosen as particularly suitable for this exploratory design-based research study:

- **RQ1:** How might “temporally enabled” visualization tools for military history change the student or instructor experience in a given educational context?

- **RQ2:** What information visualization techniques best position a “temporally enabled” visualization tool for successful use in its intended educational context, and how is the decision to implement with those techniques arrived at?
- **RQ3:** What computer-based technologies are suitable for developing “moving battlefield” visualizations for use in military history education?

Research on these questions may be undertaken in a variety of ways, but a design-based approach is especially promising; the intersection of human, technical, and interaction needs is a space ripe for design intervention and study. Furthermore, the possibilities for implementing “temporally-enabled” military history visualization tools using new and emerging development technologies are virtually limitless.

Accordingly, a design-based study was undertaken to develop and evaluate a new tool, the Temporally Enabled Map for Presentation (TEMPO). Drawing from relevant education, information visualization, cartography, and geography literature, an animated, interactive map of the battle of Midway was designed. Through the TEMPO design process, the broad and relatively unexamined problem space centered on battlefield maps, time visualization, and military history pedagogy was explored. This paper reports on the design process and initial findings from ongoing research, and lays out implications and next steps in the iterative design process.

Literature Review

Design-Based Research

A design-based research (DBR) approach was utilized to research the development and use of a temporally enabled map for history lecture instruction. DBR is an empirical technique that involves designing interventions with specific goals or objectives, testing them, evaluating the results, then refining or adjusting the intervention (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). At its core, DBR is about transforming educational practices in authentic situations, in this case refining and improving the TEMPO application in a specific instructional context.

As a research process, DBR is interactive, iterative and flexible. It requires interactive collaboration among researchers and practitioners, and without such collaboration, interventions are unlikely to affect changes in the real world context (van den Akker, 1999; Wang & Hannafin, 2005). DBR is often time-consuming because theories and interventions tend to be continuously developed and refined through an iterative design process from analysis to design to evaluation and redesign. However, the ongoing, recursive nature of the design process also allows greater flexibility than do traditional experimental approaches.

Lectures and Historical Pedagogy

The study of learning technologies has historically explored what impact technology has on learning efficiency, and has made content and media-delivery comparisons based on learning outcomes (Voithofer & Foley, 2002). Rather than solely focus on outcomes, a multidisciplinary approach to learning guided the design and development of TEMPO. This approach focused on broader complex ecological issues, rather than systemic rote learning questions.

Though a variety of learning contexts exist in military history education - books, online learning, museums, and battlefield sites - the traditional classroom lecture is still a key point of intersection, interaction, and learning for instructors and students. Accordingly, literature on multimedia and visualization tools in lecture settings was reviewed. This revealed a relatively sparse domain of study; the value of interactivity in lectures is not well-understood and has only seen cursory research, generally conducted from a content teaching perspective rather than a design perspective (e.g. Kunkel, 2004). Advocates have suggested that added interactivity in lecture environments can increase efficiency and instructional effectiveness while also building an instructor’s familiarity with the content being presented (Stacy, 2009), but there is little relevant research on lecture teaching methods; much of the research in this area focuses on the integration of interactive technologies like “clickers” (Nelson & Hauck, 2008), rather than other forms of student engagement and interactivity. A number of related instructional and pedagogic strategies are suggested in the literature to increase learner engagement. These approaches are referred to variously as authentic learning, problem-based inquiry, hands-on learning, and student-centered learning, etc. It is important to note that all of these strategies are rooted in constructivist learning theory. For the purposes of this project we sought effective technology integration - the use of technology that is interwoven into the curriculum to actively engage students.

There is also little research on historical visualization. One exception is Moss’s (2008) treatment on visual technologies and history. Moss's central argument is that younger generations receive most of their historical understanding from visual media – film, television, and computer technologies – and that modern historical education should seek to capitalize on this, rather than lament it. Moss's treatment of computer technologies is brief, but suggests that computer simulations or game-like environments could be beneficial for students under certain circumstances. Military history education is also discussed, especially with regards to simulation and computer gaming. Despite this, there appears to be little consensus on how computer technologies and other visualization tools should be utilized in the classroom or other educational contexts (Moss, 2008).

Information Visualization

Using a variety of examples, Tufte (1990; Tufte, 1997, 2001) describes several ways of visualizing information related to both space and time. One technique is the *1 + 1 = 3 effect*, where overlaid elements interact with each other to produce visual effects that seem to be more than the sum of their constituent parts. This effect is sometimes positive; in some maps, visual elements, labels, and numerical data (e.g. temperature or altitude) combine to tell a more compelling story than any individual layer could alone. In other circumstances, however, the 1 + 1 = 3 effect can be negative. Overlaid elements which have too much visual weight can also interact with each other, resulting in clutter and confusion instead of clarity. Muehrcke (1990) puts this another way, saying, "It is abstraction, not realism, that gives maps their power."

The *small multiple* (sometimes just referred to as a *multiple*), a series of thumbnail-sized images which capture sequential moments in time, is another approach for the co-visualization of temporal and spatial data (Tufte, 1990, 1997, 2001). Small multiples may be thought of as frames in a film reel; in a military history context, each frame might capture troop dispositions within the terrain of the battlefield. A series of such frames, when shown in order, would reveal the movement and interaction of troops over time.

Goldsworthy (2005) makes use of this technique in several well-designed maps. Key battles in Roman history are represented as a series of two small multiples, with one multiple showing the initial disposition of forces, and the second showing the key point in battle when one side began to overcome the other. Both geography and troop movements are represented by subtle but informative shading, avoiding the 1 + 1 = 3 effect. Units themselves are identified with bright points of red or blue color, showing both the number of troops engaged (more points equates to more troops) and the position and loyalty of the soldiers in question (red equates to roman forces, while blue equates to the enemy). Tufte (1990) suggests the use of bright points of color for this kind of display, quoting Eduard Imhof (1965) who says, "If one limits strong, heavy, rich, and solid colors to the small areas of extremes, then expressive and beautiful colored area patterns occur… Large area background or base-colors do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the former are muted, grayish, or neutral." Visualizing military engagements as more than just two or three small multiples at a time is impractical because of space constraints on page or screen. However, in a digital environment multiples can be capitalized upon through the use of two additional techniques: *animation* and *interactivity*.

DiBiase, MacEachren, Krygier, and Reeves (1992) describe three key variables in visualization animations: *duration*, *rate of change*, and *order*. Duration is the frame rate of an animation, or how long individual frames remain visible before the next frame is shown. Rate of change is related to duration, but is moderated by the magnitude of change which occurs between frames. An animation with short duration (frames held for fractions of a second) but a large magnitude of change between frames would appear choppy; an animation with short duration and minimal magnitude of change would be much smoother. Order is the sequencing of events within an animation. While chronological order is the most obvious way to present information, watching animation in other orders may elicit new information or new ways of seeing information that is already there (DiBiase, et al., 1992).

It is further argued that manipulation of these three variables may result in various types of temporal maps, suggesting three possibilities: maps that "emphasize the existence of a phenomenon at a particular location," maps that, "emphasize an attribute of the phenomenon," and maps that, "represent change in a phenomenon's position or attributes," (DiBiase, et al., 1992). Each of these types affords various forms of information.

Kraak, Edsall, and MacEachren (1997) describe two additional aspects of animated maps: *display time* and *world time*. Display time (or representational time) is the timing of events as they unfold for the viewer of a map. World time is the real time which passed as events unfolded. Display and world time may be equal (i.e. a "real time" map), but need not be. There are situations where a real time display of geographical data would not be useful, for example, a real time map of the Battle of the Somme, which took place over 4 ½ months (Marshall, 1964). While showing portions of this battle in real time to emphasize its prolonged and relentlessly violent nature could be extremely effective, it would be unrealistic to expect a group of students to watch an abstract map animation of it for much more than a few minutes.

There are pitfalls to changing the timing of events in maps. Tufte (1997) cautions against "dequantification," suggesting that many scientific visualizations employ animation techniques at the expense of critical data, especially temporal, scale and distance data. He argues in favor of leaving in this information, but with care taken to avoid 1 + 1 = 3 effects or other *chartjunk* and clutter. Tufte also argues for multiple channels of information, suggesting that juxtaposing additional data streams alongside the key animation can be a powerful way to convey more than any individual channel could alone (Tufte, 1997). This creates a dilemma: In historical battlefield visualization, it may sometimes be useful to include secondary data or show events in real time, but in other cases, this may become irrelevant clutter. Fortunately, the *interactivity* of digital systems offers a solution.

Unlike print media, computer systems grant users nearly unlimited control over data. According to Card, Mackinlay, and Shneiderman (1999), interaction, "fundamentally changes the process of understanding data. Rapid interaction… allows the user to explore more possibilities in a given time, but it also allows the user to shift effort to the machine by watching what happens as the controls are modified." They identify three time-based levels of interaction (0.1 seconds, 1 second, and between 5 and 30 seconds), which correspond to human ability to interact at various levels of perception and cognition.

In TEMPO, both the 0.1 second and 5-30 second levels are potentially important. The first is near the speed of most animation effects; allowing users to control this is to grant them control over duration (DiBiase, et al., 1992). At the 5-30 second level, users interact with the information system itself, controlling various features and display modes (including duration) in order to visualize information as needed. This will effectively overcome many of the seeming contradictions identified earlier, for example, the need to sometimes display additional streams of data and other times not. Controls for interaction at the 5-30 second level might include data visualization sliders (Eick, 1999), moveable or adjustable data filters (Fishkin & Stone, 1999), selectable handles or geometry controls (Chuah, Roth, Mattis, & Kolojejchick, 1999), or more traditional icons, buttons, and menus. Controls should be implemented in keeping with well-established principles of design and usability (Lidwell, Holden, & Butler, 2003; Nielsen, 1993, 1994, 1996; Norman, 2002, 2004).

Lecture and Lecturer

Use Context

A variety of contexts have merit for DBR into temporally-enabled maps in military history, and a tool to visualize luck and timing within them would have its place. The lecture setting was selected because of the nature of the problem being examined. Luck and timing cannot be explained through visualization technologies alone – there is a powerful element of storytelling in the best military history education. Luck and timing require that battlefield visualizations be accompanied by the story of what is happening. This might be delivered by the visualization technology itself (through an audio track or accompanying text), but to have a talented lecturer provide the story while using a visualization tool to illustrate it affords far greater flexibility and far better means to adapt the lesson to specific classroom needs for specific student groups.

Furthermore, the classroom lecture remains a key method of teaching military history. Books, museums, and battlefield visits are important and, indeed, may suggest more interesting or novel technical implementations than a simple "lecture companion." However, the classroom lecture is often where initial learning is done. Most museums can only scratch the surface of battlefield events, and visits to an actual battlefield mean little without foreknowledge of the events that occurred there. Some battles are difficult or impossible to picture, even in situ. Similarly, many military history books are written for students with a great deal of knowledge. Those for novice readers may omit topics like luck and timing as too complicated to cover in a text-only format. It seemed likely that the traditional classroom lecture, with a knowledgeable instructor providing the battle "story," should be an effective environment for deploying a visualization tool to better show lucky events, fortuitous timing, and other factors contributing to battlefield victory or loss.

Consultation with Practitioners

Subject Matter experts (SMEs) in the domain of military history education and classroom teaching were consulted about the role that maps and other visualization media play in their lectures, and the ways that temporally augmented media might improve the lecture experience. SME #1, a middle school history teacher, was contacted via email, and SME #2, a tenured military history professor at the undergraduate/graduate level, was interviewed in person. Both SMEs provided a wealth of detail about military history pedagogy, the lecture space, and visualization technologies in the classroom.

SME #1 described military history education at the middle school level. Common lessons include the differences between war as it is depicted in movies or on television vs. the reality of war, and the reasons that discipline and chain of command are important in the military. A major takeaway from SME #1 was that visualization technologies are very useful in the middle school history classroom, but that visualizations tend to focus on showing students how things looked or sounded (i.e. the *experience* of war), rather than more abstract depictions of battlefield maneuvers, decision-making, or timing (i.e. the *events* of war). Because of the young age of middle school students, most lessons are simplified or sanitized to make them appropriate for the age group.

SME #2 provided insights into the undergraduate lecture experience, focusing specifically on military history. While conveying the experience of war (e.g. the horror and violence of battle, the fundamental humanity of those involved) is important, the nature of wartime *events* is also explored in much greater detail. Lessons begin to delve into more specific material, and over time, students develop a greater understanding of how luck and timing may be important. In this vein, SME #2 described the notion of *friction* (Von Clausewitz, 1832), the way that battle plans change and lucky or unforeseen events occur when contact with the enemy is made. Friction is an important aspect of battle, and can be lectured upon in detail, but like timing and luck, it is very difficult to *show*. Providing a better way to visually depict such concepts early in a student's military history education should have a greater impact on subsequent learning than waiting until students are more advanced. The problem is not so much that luck and timing *cannot* be taught, but rather, that these concepts are *difficult* to teach and visualize.

From consultations with SME #1 and #2, it was clear that undergraduate lectures, rather than the middle school classrooms, would be a more appropriate context for a visualization tool designed to show battlefield events, timing, and luck. Furthermore, during consultation with SME #2, it was specifically suggested that a "lecture companion" able to visualize luck and timing would be useful in the undergraduate military history classroom.

The Battle of Midway (1942) was selected for recreation in the TEMPO system after it was suggested by SME #2 as a battle with clearly identifiable moments of luck and timing. For example, a Japanese scout aircraft from the cruiser *Tone* launched later than it should have because of a broken steam catapult, thus delaying Japanese awareness of the American carrier fleet. The convergence of U.S. aircraft on the Japanese fleet contained similar elements of luck, as planes from several different flights converged on the Japanese carrier force at exactly the right moment to inflict maximum damage (Prange, et al., 1982; Spector, 1985).

Pragmatic concerns were also important in the selection of Midway. The battle of Midway is relatively self-contained, with most key fighting taking place over just one 13 hour period. Furthermore, the battle is well-documented, with ship and aircraft logs, radio reports, and a fairly detailed and well-known chronology of events and event positions. This, plus the fact that Midway was a naval battle featuring a limited number of ships and aircraft, made recreating the battle of Midway a relatively straightforward - if sometimes complex - visualization task. Since Midway was also a highly important battle, it was an especially ideal visualization subject.

To obtain a better sense of how TEMPO might fit into an undergraduate class, a lecture given by SME #2 on the Pacific theatre of WWII was observed. This three hour lecture included a 20-30 minute discourse on the Battle of Midway. The use of visuals during this lecture was minimalist; a teaching assistant controlled a PowerPoint presentation composed entirely of images – portrait photographs, pictures of ships and aircraft, and maps. SME #2 directly referenced this PowerPoint only occasionally, usually letting the images "flow" as a visual background to his lecture, which was narrative in style – almost a form of storytelling. When interviewed, SME #2 suggested that this sense of story was an important way to convey to students that what they were learning was dramatic and meaningful, more than a collection of dates and names.

It was clear from these observations that TEMPO should be designed with large lecture spaces in mind; small fonts, fine detail, and poor contrast would inhibit understanding, especially for students located in distant areas of the room. Several times, SME #2 pointed out a map position that was much too small to see, and then offered a short apology along the lines of, "well, you can't see it, but Midway is just about here…" It was also clear that TEMPO should be easy to use and unobtrusive. Rather than interfering with the narrative form of lecture, TEMPO should fit easily into it, an illustration of the lecture, rather than a substitute for it. For many lecturers, pacing or walking the front of the room is common; TEMPO needed to accommodate this, not requiring extended or complicated use of playback controls, and not anchoring the instructor to a podium or teaching console.

TEMPO: A Temporally Enabled Map for Presentation

TEMPO was developed in two key phases: *design* and *implementation*. The design phase was oriented on translating the principles and theories surveyed during literature review and consultation with the SMEs into a visual design, and was accomplished in Adobe Photoshop. TEMPO underwent three major design revisions before it was ready for implementation. The finalized design shows a 1600 square mile ocean map north of the Midway Islands (where most of the Midway fighting took place). This view is designed to be projected in the 1024px X 768px display typical of most college lecture classrooms. The map "table" was drawn in a neutral color to improve unit contrast with the background, while the background used blue water imagery to elicit a sense of the Pacific ocean. The interface was designed with large fonts and a minimalist layout so that text and timelines would be readable and understandable when projected, even from the back of a large lecture hall. TEMPO was further simplified to include only units of specific importance to the outcome of the battle; Japanese ships and aircraft were depicted as red dots, U.S. ships and aircraft were blue. Interface controls were made smaller than other visual elements since their only user would be either the instructor or a TA, who could view them on a separate, closer desktop or laptop screen.

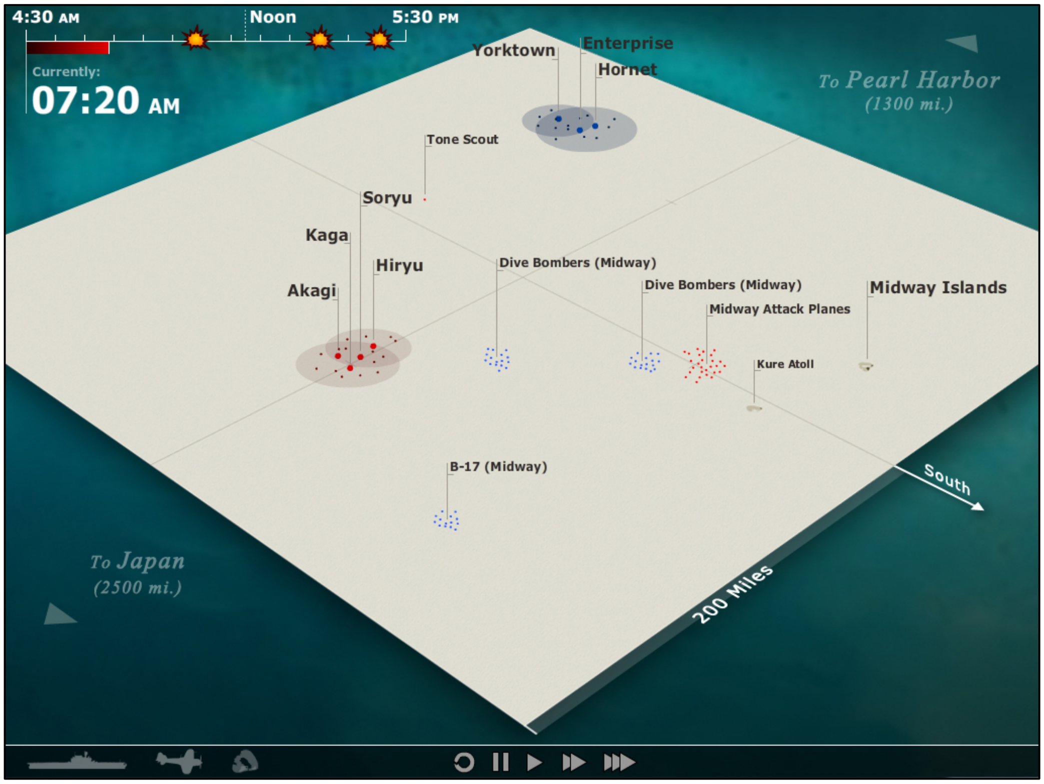

Figure 1: Final TEMPO design revision

Once this design had been established, implementation began. TEMPO was implemented using Adobe Flash, selected for its established nature, relative ease-of-use as a development platform, player ubiquity on most major computing devices, and ability to deploy on a variety of platforms, including desktops, some mobile devices, and over the web. While Flash has some drawbacks as a development platform (e.g. overuse of system resources and limits on certain visualization techniques like 3D), it was considered ideal for this prototype.

TEMPO was programmed similarly to many video games, with a main loop executing a series of functions to update unit positions over time. Unit movement and position data, as well as other events (showing and hiding units, or playing a simple "attack" animation) were stored in databases and read into TEMPO at runtime. TEMPO users could set the speed of the main loop to zero frames per second (paused), 1 fps (real-time), 60 fps (1 second of playback time equates to 1 minute of battle), or 600 fps (1 second of playback time equates to 10 minutes of battle). Users were also given the ability to toggle unit labels (ship, island, and aircraft names) on or off, and replay the animated map, as well as click on unit names to view an image of that unit (e.g. a photograph of the Japanese aircraft carrier *Akagi*, or a photograph of the *Dauntless Dive Bomber*). A 13-hour timeline showing current time of day and three key battle moments (when carriers were taken out of action) was overlaid in the upper left of the map. Inclusion of varying play speeds, the timeline overlay, playback controls, unit label controls, and the ability to view unit images were based upon literature and information provided by the SMEs.

TEMPO Evaluation

Framed within DBR, the nature of the research on TEMPO is emergent. Because the researchers sought to observe and interpret TEMPO in context, it was neither possible nor appropriate to finalize research strategies before data collection began (Patton, 2001). The ongoing research process draws on the tools used in usability-testing protocols (Rubin & Chisnell, 2008) to analyze TEMPO's use and effectiveness. Usability techniques provide effective methods of providing naturalized generalizability (Stake, 1978). Usability generally refers to the process of bringing the users' perspective into the design process, and making the product more user-friendly (Reeb, 2008).

To evaluate the version 1 implementation of TEMPO from an instructor's point of view, SME #2 was re-consulted. This took the form of a 60 minute interview where TEMPO was presented on a desktop computer in SME #2's office. SME #2 was consulted about specific design decisions, TEMPO's potential for success in the classroom, and potential improvements. A future research goal is to further evaluate TEMPO in the context for which it was intended: an undergraduate lecture on the Battle of Midway.

SME #2's reaction to TEMPO was highly positive, so much so that researchers were asked if it would be possible to use it (or an improved version of it) in upcoming lectures. SME #2 quickly saw the potential for similar systems in other historical contexts and was especially interested to see moments of luck and timing emerging as TEMPO played through the battle of Midway. He commented on how well it showed critical moments such as the fortuitous timing of the U.S. carrier plane attacks on the *Akagi*, *Soryu*, and *Kaga*. He was also suggested that TEMPO would be, "terrific for moving battlefields," and that, "what you need this for is to show the nature of battle itself and how luck plays a role." SME #2 was clear that TEMPO would serve to enrich the lecture (a key goal of this DBR) and would serve this purpose even better than still maps or photographs.

SME #2 noticed several areas where map accuracy might be improved. In most of these areas, the researchers had intentionally made a decision to simplify visuals for clarity – for example, the direction arrow indicating the direction and distance to Pearl Harbor shows Pearl Harbor to be further north than it really is. This inaccuracy was intentional, since the specific location of Pearl Harbor does not factor into the Battle of Midway and the map "read" better with the arrow showing a general direction toward Pearl Harbor, rather than a specific compass direction. This suggestion for improved accuracy was unexpected but valuable, and future iterations of TEMPO will likely place a greater emphasis on directional accuracy even outside the bounds of the battlefield itself.

Another key suggestion for improving TEMPO was to start the map system with a broader view of the Pacific theater, and then animate or zoom in to the specific Midway battlefield. This would give instructors an opportunity to explain the overall Japanese strategy and other aspects of the battle that are not shown in the TEMPO animation proper. The abstract nature of the battlefield visualization (e.g. limited color palette and abstracted views of ships and planes) was considered successful in providing good contrast between units, though presenting a more photographic or realistic environment at map startup and then switching to the abstract view was suggested.

A final evaluative comment was the suggestion to include some of the intentionally excluded ships or aircraft that, while not central to battle outcomes, might provide additional context for other battlefield events.

Discussion

Three key research questions were established as motivations for this research: 1.) How might "temporally enabled" visualization tools for military history change the student or instructor experience in a given educational context? 2.) What information visualization techniques best position a "temporally enabled" visualization tool for successful use in its intended educational context, and how is the decision to implement with those techniques arrived at? 3.) What computer-based technologies are suitable for developing "moving battlefield" visualizations for use in military history education? TEMPO and its associated DBR process suggest several possible answers.

While research question one has not yet been fully evaluated, feedback from SME #2 suggests that a temporally enabled map system like TEMPO would be highly beneficial in the military history classroom. Unlike static map presentations, TEMPO, in conjunction with a lecture, is capable of illustrating abstract concepts such as luck and timing in battle. In addition, this technology has the potential to augment traditional lecture teaching, a format that has fallen out of favor for many. As SME #2 describes it, many view the lecture format as a, "dead and destructive form of pedagogy." This characterization is unfair, as well delivered lectures are still able to enthrall students. Nonetheless, SME #2 suggested that the lecture is an, "art form... a chemistry between lecturer and student." A system such as TEMPO could help to make achievement of that chemistry easier.

To answer research question two, a variety of visualization techniques were studied for their utility in the

TEMPO implementation. Potentially useful techniques from literature included animation, avoidance of 1 + 1 = 3 effects and chartjunk, playback duration, rate of change, playback order, display time, world time, and interactivity. Observing a lecture on the Battle of Midway gave further credence to these techniques (for example, the large lecture classroom indicated that chartjunk and 1 + 1 = 3 effects would be especially desirable to eliminate), and most of them were incorporated into the evaluated version of TEMPO. In general, evaluation discussions about TEMPO with SME #2 showed that these techniques were appropriate for their intended purposes.

Several advanced multimedia development tools were shown to be highly appropriate for the design and development of temporally enabled visualization systems in military history, including Adobe Photoshop and Flash. In addition to these common toolsets, other technologies may also be useful. For example, 3D visualization technologies such as those used in video games or CAD programs have shown promise in real-time battlefield map implementations (Fong, Ng, & Huang, 2006; Hix, et al., 1999; Julier, King, Colbert, Durbin, & Rosenblum, 1999), and are likely to be similarly effective in visualizing historical battlefields. While these alternative technologies were not used in this iteration of TEMPO, a deeper examination of them would be highly desirable as research continues.

In addition to addressing the central research questions of this study, the TEMPO project also uncovered several interesting insights into the nature of the DBR process. DBR literature suggests that research of this type should start with theory, followed by an iterative design and evaluation process to test and validate theory and refine implementation (Cobb, et al., 2003). While true, this explanation of DBR conceals the many complications, challenges, and trade-offs that stem from merging design and research tasks. One such complication is achieving a balance between what theory and literature suggest should be successful and what practicalities of design dictate will be possible. This may be understood in the context of the *project triangle* (e.g. Gardiner & Stewart, 2000), which states that any design project will be shaped by a balance among three key factors: quality, development time, and cost. This is often stated as follows, "Good, fast, and cheap. Pick any two."

Since DBR ideally draws from theory to support specific design decisions, in a sense, how "good" a DBR implementation is will be a function of how well it addresses and adopts theory. DBR will be of little utility if theory incorporation is poor, so too many tradeoffs on the "good" corner of the project triangle are highly undesirable. This leaves production time and cost as potential areas where tradeoffs can be made. However, submission deadlines, funding limitations, and research schedules can make these tradeoffs difficult to successfully achieve.

TEMPO was the result of theoretical literature review and practical consultation, but due to the project timeline and limited funding of this project, certain theoretically-supported features were not included in the first version. One notable absence is the inability for users to "scrub" backward and forward through the battle to watch specific moments of battle in repetition or in reverse. Literature suggests that such functionality would be an excellent way to improve the usability of a system like TEMPO (e.g. Kimber, et al., 2007; Shneiderman, 1997), but because of time constraints, this functionality was omitted in the first version of TEMPO. Other functionalities that might be tested in future versions of TEMPO are the ability to zoom in or out, or to change the map perspective.

Another challenge of DBR is the sometimes overlapping nature of the literature review, design, and evaluation stages. In most DBR literature, these are indicated to be relatively distinct phases of a project, but in the implementation of TEMPO, it was found that they often overlap to a great degree. For example, early literature review suggested that Hägerstrand's (1970) theory of *time geography* would be a useful framework for conceptualizing and visualizing interactions in space and time. However, during the design phase of development, it became clear that while time geography theory might be helpful as a way of explaining interactions in space and time, it was much less useful as a way of visualizing such interactions in the context of an undergraduate military history lecture. That is, TEMPO started to resemble an interface to teach time geography theory and how it pertains to battlefield events, rather than an interface to teach military history and the Battle of Midway per se. In addition, visualization techniques stemming from this theory often resulted in 1 + 1 = 3 effects or other undesirable visualization results. Ultimately, time geography theory was set aside - a potentially useful theory that nonetheless required more study before it could be used in the TEMPO system. Notably, this decision was made during the design process, rather than after formal evaluation.

The role of the designer was a final unexpected challenge during development TEMPO. TEMPO was designed and implemented by one of the researchers, rather than an outside developer, placing that researcher in an relatively unique dual role. As a researcher, objectivity and an unbiased implementation of theory were necessary, as well as unbiased evaluation of the finished TEMPO system. At the same time, as a designer, tradeoffs, practicalities, and development schedules often became as important, if not more so, than research goals. Additionally, while it was expected that TEMPO would be well-regarded during evaluation, it was also critical - though sometimes difficult - to accept critiques and criticisms from SME #2 in order to achieve as unbiased an evaluation as possible. As a researcher, these critiques were desirable, as they would potentially lead to a more successful future implementations. As a designer, critiques were sometimes frustrating, especially when they did not take many practical development factors into account. At the same time, having one of the researchers undertake TEMPO's development was highly beneficial, resulting in much better integration of theory, literature, and SME input than would have been possible through the use of an outside developer. In a sense, having researchers also serve as designers creates new kinds of tradeoffs in DBR. Determining where one's roles as a researcher begin and end can be challenging but positive when handled well.

Conclusion

TEMPO was designed as an intervention for a real world setting, the lecture classroom. An iterative development and research process was conducted through cycles of design, trial, analysis, and redesign. This approach to inquiry on spatial and temporal visualization in military history education proved highly appropriate to the identified problem space and research questions of interest. Furthermore, it is likely that similar approaches would continue to motivate innovation in the lecture teaching format.

The design of TEMPO was theory-driven, with testing and evaluation leading to both refinement of the implemented artifact and a fuller understanding of theory in practice. Evaluation of TEMPO was focused on its utility. In design studies, the quality of a product rests ultimately in how well it works - its practicality and usefulness in the hands of its intended users. This research approach was especially helpful in explaining how TEMPO - or other, similar designs - might function in real settings and why such interventions behave as they do.

As implementation of systems like TEMPO become easier to conceptualize as well as cheaper and faster to produce, their use in the classroom will undoubtedly expand, redounding to the benefit of students and instructors alike. For students, the lecture experience will be augmented by incorporation of tailored information visuals. For instructors, a system such as TEMPO has the potential to improve teaching through the ability to depict historical chronologies or event sequences in heightened detail, or to visualize abstract concepts like luck and timing in approachable and understandable ways.

The TEMPO system is an excellent proof-of-concept, but more remains to be done. This paper presented several limitations of the existing TEMPO system, and through ongoing research it is hoped that these limitations can be overcome, the system can be improved, and more rigorous forms of evaluation may be undertaken.

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