British Journal of Educational Technology Vol 40 No 4 2009 636–651
doi:10.1111/j.1467-8535.2008.00848.x

Multimedia learning and individual differences: Mediating the effects of working memory capacity with segmentation

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Abstract
Research in multimedia learning lacks an emphasis on individual difference variables, such as working memory capacity (WMC). The effects of WMC and the segmentation of multimedia instruction were examined by assessing the recall and application of low (n = 66) and high (n = 67) working memory capacity students randomly assigned to either a segmented instruction (SI) or non-segmented instruction (NSI) version of a multimedia tutorial on historical inquiry. WMC was found to have a significant, positive effect on participants' recall and application scores; however, the use of segmentation mediated the effects of WMC to allow learners with lower WMC to recall and apply equal to those with higher WMC.

Introduction
Recent research in multimedia learning has tended to focus on multimedia design, such as the modality and segmentation principles (eg, Mayer & Chandler, 2001; Mayer & Moreno, 1998); cognitive structures, such as cognitive load and dual coding (eg, Paas, Renkl & Sweller, 2003; Sweller, 1994); scaffolding components, such as pedagogical agents and help support (eg, Craig, Driscoll & Cholson, 2004; Kim, Baylor & PALS Group, 2006) and delivery systems, such as the Web and mobile devices (eg, Cole & Todd, 2003; Wei, Chen, Wang & Li, 2007). Less well researched is the relationship between individual difference variables, such as working memory capacity (WMC;

Unsworth & Engle, 2007), and the design, structure, scaffolding and delivery of multimedia learning. For example, WMC has been demonstrated to vary significantly from individual to individual (Rosen & Engle, 1997) and is positively related to higher-order cognitive tasks such as reading comprehension (Daneman & Carpenter, 1980), attentional control (Kane, Bleckley, Conway & Engle, 2001), general fluid intelligence (Engle, Tuholski, Laughlin & Conway, 1999) and mathematical performance (Ashcraft & Kirk, 2001). Is there a relationship between WMC and learning in multimedia environments?

One area in which higher-order cognitive tasks is receiving significant attention is the domain of multimedia learning. Learning in multimedia environments has been studied extensively, resulting in the cognitive theory of multimedia learning and a series of design principles (see Mayer, 2001, 2005). However, simply constructing sound multimedia environments is insufficient for learning to occur (Kozma, 1994). Rather, learners must attend to these multiple forms of media, create conceptual knowledge representations and integrate these knowledge representations in order to learn and build effective mental models (Schnotz & Bannert, 2003). Thus, the effectiveness of these principles depends on both instructional designers creating sound multimedia learning environments and individual learners actively engaging in constructing understanding.

Unfortunately, despite this interaction between the multimedia instructional environment and the individual learner, little attention has been given to the role individual differences have on Mayer's (2005) multimedia design principles. The present study examines this relationship, specifically, the relationship between segmentation and WMC in multimedia learning.

Multimedia learning and the segmentation principle
The segmentation principle simply states that a multimedia tutorial that provides the user with pacing control, through use of a Start/Stop button or Continue button, will result in greater learning than a tutorial that plays from beginning to end (Mayer & Chandler, 2001). The rationale for the segmentation principle is that this pacing control provides the learner with the opportunity to stop the flow of information when necessary. In stopping the flow of information, the learner is less likely to be overloaded by information, resulting in degraded learning, and is more likely to be able to process the information more deeply, resulting in enhanced learning (see Mayer, 2005).

Mayer, Dow and Mayer (2003) investigated segmentation by having students engage in a 20-minute multimedia tutorial addressing the working of an electric motor in segmented (S) and nonsegmented (NS) versions. Mayer *et al* found that students who experienced the S version had better transfer of information than students who experienced the NS version. Similarly, Mayer and Chandler (2001) explored the segmentation principle by creating two versions, an S version and an NS version, of a 140 second multimedia tutorial addressing the cause of lightning. Mayer and Chandler had students experience both versions, sequentially, either S-NS or NS-S (Exp 1). Mayer and

Chandler found that the S-NS group performed better on a transfer task, but not on a recall task, than the NS-S group. Mayer and Chandler attributed the superior transfer performance of the S-NS group to participants avoiding cognitive overload and being able to build models of the component parts of the lightning cause-and-effect relationship during this first engagement (S). During the second engagement (NS), the participants were then able to connect and organise the component parts.

The results of Mayer and Chandler (2001) and Mayer *et al*, (2003) provide partial support for segmentation, benefiting transfer but not recall. This partial support of segmentation is in agreement with a large body of research addressing the broader concept of learner control. Learner control includes not only pacing control (segmentation), but also control over the inclusion of content, the depth of content experiences, the order of content presentation, the amount of practice and the type of feedback (Pollock & Sullivan, 1990). When examining the learner control literature addressing specifically learner control of pacing, the results tend to be conflicting (see Aly, Elen & Willems, 2005; Dalton, 1990).

WMC

WMC represents an individual's ability to simultaneously (1) process a primary task in working memory, (2) maintain relevant information regarding the primary task in working memory and (3) access and retrieve relevant information regarding the primary task from long-term memory—especially in the presence of distraction (Unsworth & Engle, 2007). This concept of WMC moves beyond more traditional measures of working memory storage capacity (see Miller, 1956) to include both storage and processing capacity (see Daneman & Carpenter, 1980). This measure of storage and processing capacity has been interpreted as an assessment of *attentional control*, the ability to control the processing and maintenance of information in working memory, especially in the presence of internal (eg, thoughts, drives and feelings) or external (eg, talking, music and motion) distractions taxing the attentional system (Unsworth & Engle, 2007).

The literature on WMC provides evidence that high WMC benefits performance on complex mental tasks including general fluid intelligence (Conway, Cowan, Bunting, Therriault & Minkoff, 2002; Kane *et al*, 2001), long-term memory activation (Cantor & Engle, 1993), attentional control (Kane *et al*, 2001), resistance to proactive interference (Kane & Engle, 2000), primary memory maintenance and secondary memory search (Unsworth & Engle, 2007) and resistance to goal neglect (Kane & Engle, 2003). Beyond these cognitive construct effects, individual differences have been indicated in a variety of cognitive performance measures; that is, individuals with high WMC have been demonstrated to perform better than individuals with low WMC in reading comprehension (Daneman & Carpenter, 1980), language comprehension (Just & Carpenter, 1992), vocabulary learning (Daneman & Green, 1986), reasoning (cf. Buehner, Krumm & Pick, 2005; Conway *et al*, 2002) computer language learning (Shute, 1991), lecture note taking (Kiewra & Benton, 1988), Scholastic Aptitude Test performance (Turner & Engle, 1989), mnemonic strategy effectiveness (Gaultney, Kipp & Kirk, 2005)

and story telling (Pratt, Boyes, Robins & Manchester, 1989). This research has demonstrated a strong, positive relationship between variations in WMC and variations in complex cognitive task performance.

One domain of complex cognitive tasks that has seen little research related to WMC is multimedia learning. The examination of individual differences in WMC on multimedia learning is of interest as both WMC and multimedia learning are influenced by attentional control (see Mayer, 2001, 2005). Specifically, Mayer (2001) describes multimedia learning as based on three essential processes requiring attentional control: selecting relevant information, organising relevant information and integrating relevant information. Each of these processes requires attentional control in much that same way as WMC—the learner must (1) attend to and maintain the goal of the learning episode; (2) attend to the available information; (3) select the information relevant to the learning goal from the available information; (4) organise the selected information based on the goal of the learning episode; (5) maintain the learning goal and organised information in working memory while retrieving necessary information from long-term memory; and (6) integrate the working memory and long-term memory information to achieve the learning goal. Given this potential overlap between the structures and processes of WMC and multimedia learning, might learners with low WMC find it difficult to engage in the selecting, organising and integrating processes necessary for learning? Also, if learners with low WMC are indeed having difficulty selecting, organising and integrating the flow of information, might it be beneficial to provide these learners with control of the flow of the information? The purpose of this research is to examine the effects of WMC and segmentation on learning in a multimedia instructional environment.

Methodology

Previous studies of segmenting multimedia instruction have indicated that dividing multimedia instruction into short, user-controlled segments leads to increased recall and transfer of the multimedia content (Mayer & Chandler, 2001; Mayer & Moreno, 2003). These studies, however, did not take into account individual difference variables that may mediate learner performance. Thus, the purpose of this study is to assess the effects of WMC on content recall and application resulting from S and NS multimedia-based instruction.

Participants

The participants were 133 undergraduate students (59 men and 74 women) with a mean age of 20.1 years. All students received course credit for participation. These participants were a subsection of a larger group of undergraduate students ($n = 249$) that completed the OSPAN working memory span test. After completing the Operation Span (OSPAN) test, only those students that scored in the upper ($n = 67$) and lower ($n = 66$) quartiles were included as participants. In addition, the original students were randomly assigned to either a segmented instruction (SI) or nonsegmented instruction (NSI) group. After completing the OSPAN test, the remaining 133 participants included

80 participants in the SI group and 53 participants in the NSI group. Finally, the design of the present experiment was a 2 (low WMC, high WMC) × 2 (NSI, SI) factorial design.

Materials and apparatus

WMC OSPAN task

The OSPAN operation-span task (Kane *et al*, 2001) was used to measure participants' WMC. The OSPAN task involves participants solving a series of basic math problems while simultaneously attempting to remember a series of unrelated words. For example, participants were shown a series of math-word sentences in the form of 'IS (5 + 2) − 4 = 3? Dog" or "IS (6 − 1) / 2 = 3? Brown'. Participants were required to read and solve the math statement aloud, responding 'yes' or 'no' as to whether the math statement was true or false respectively. Then, without pausing, participants read the unrelated word aloud. Participants viewed and read aloud one math-word sentence at a time on a computer screen and clicked a 'Continue' button to advance to the next math-word sentence. Participants viewed and responded to a total of 60 math-word sentences. These 60 math-word sentences were presented in sets of two to six math-word sentences before participants were asked to recall the unrelated words from that set in order. Participants were asked to type the words into a text box on the computer screen. Participants only received points if they recalled all of the words in a sentence set in order. Thus, if a participant recalled *all* three words in order from a math-word sentence set with three sentences, the participant would receive three points. Participants viewed 15 sets of math-word sentences, with three sets each containing two to six math-word sentences. The order of the math-word sets and the math-word sentences within each set were randomised for each participant. Potential scores ranged from 0 to 60. Participants were assigned to the high WMC group if they scored in the upper quartile and to the low WMC group if they scored in the lower quartile of the original 249 participants' scores. The mean OPSAN scores for the high WMC and low WMC groups were 21.79 (SD = 6.53) and 6.39 (SD = 2.46) respectively.

Multimedia instructional unit

The multimedia instructional unit was the first section of the larger Summarizing, Contextualizing, Inferring, and Monitoring (SCIM) Historical Inquiry Tutorial (see Hicks, Doolittle & Ewing, 2004). The SCIM Historical Inquiry tutorial was designed based on research addressing (1) historical inquiry (see Wineburg, 2001); (2) cognitive strategy instruction (see Collins Block & Pressley, 2002); (3) instructional multimedia development (see Mayer, 2001, 2005); (4) scaffolding in technologically rich instructional environments (Reiser, 2004); and (5) classroom-based history teaching (see VanSledright, 2002). These foundations were synthesised to create a multimedia tutorial comprised of three sections: strategy explanation, strategy demonstration and strategy application. A complete description of the three sections is detailed elsewhere (see Hicks *et al*, 2004). The present study, however, involved only the strategy explanation section; thus, only that section is discussed here.

Strategy explanation

Technically, the tutorial was created using Adobe's Flash and involves narrated instructional multimedia. It should be noted that Figures 1–4 illustrate the optional 'Show

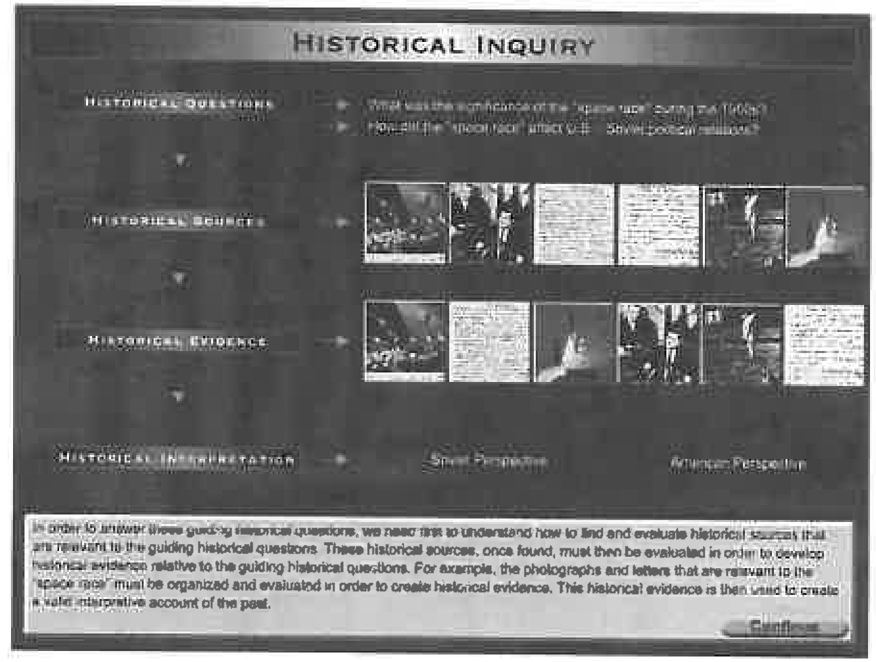

Figure 1: The SCIM tutorial and the historical inquiry process

Text' feature so that the reader can see what the tutorial user would hear. The *strategy explanation* section was designed as a direct explanation of historical inquiry and the SCIM strategy and consisted of 14 narrated multimedia segments of approximately 45–60 seconds per segment. In total, the tutorial was 11 minutes in length, comprising 1120 words. The SCIM tutorial begins with an introduction that provides an explanation of the broad picture of historical inquiry as a process that starts with the asking of *historical questions*. These questions are then addressed by locating and analysing relevant *historical sources* in pursuit of *historical evidence*. Finally, this historical evidence is used to construct an *historical interpretation* relevant to a guiding historical question. The tutorial then moves from the broad picture of historical inquiry to a specific strategy for analysing primary sources—the SCIM strategy. The SCIM strategy explanation is illuminated through the use of a letter from President Kennedy to Vice President Johnson, written in 1961.

The first phase of the SCIM strategy, *summarising*, is explained and demonstrated by highlighting the letter's author, recipient and purpose, as well as additional specific and readily available details (see Figure 1). This highlighting of relevant information is then followed by the presentation of the four specific summarising questions:

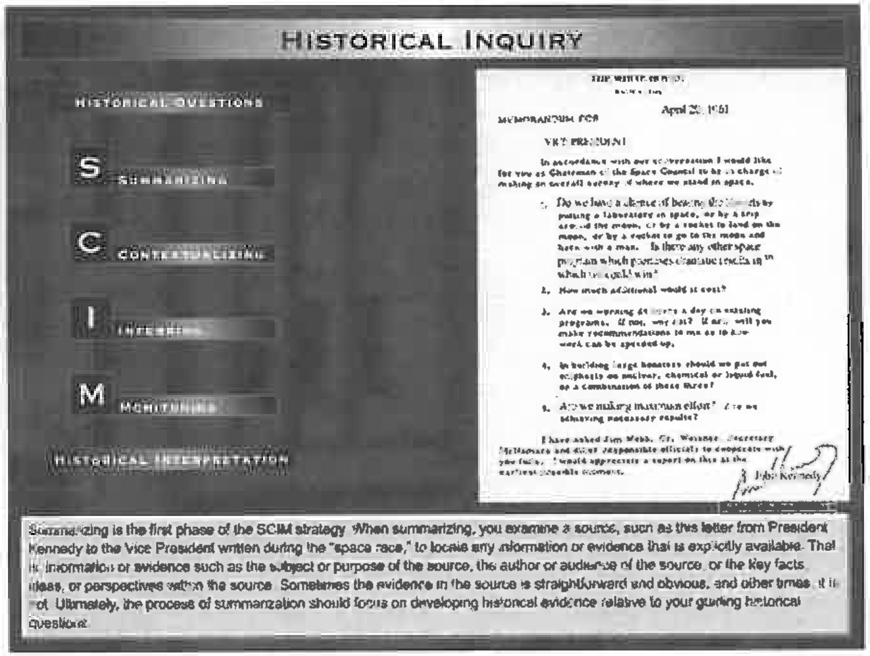

Figure 2: The SCIM strategy and the summarizing phase

1. What type of historical document is the source?
2. What specific information, details and perspectives does the source provide?
3. What are the subject and purpose of the source?
4. Who are the author and audience of the source?

The second phase, *contextualising*, is explained and demonstrated by first highlighting when, where and why the letter was produced. Following this highlighting, the letter is then spatially oriented to both a timeline of the Cold War and a timeline of the US-Soviet space race to demonstrate the immediate and broader context in which the letter was produced (see Figure 2). This highlighting and spatial representation is then followed by the presentation of the four specific contextualising questions:

1. When and where was the source produced?
2. Why was the source produced?
3. What was happening within the immediate and broader context at the time the source was produced?
4. What summarising information can place the source in time and place?

The third phase, *inferring*, is explained and demonstrated by first highlighting relevant information within the letter. This relevant information is then extracted from the letter

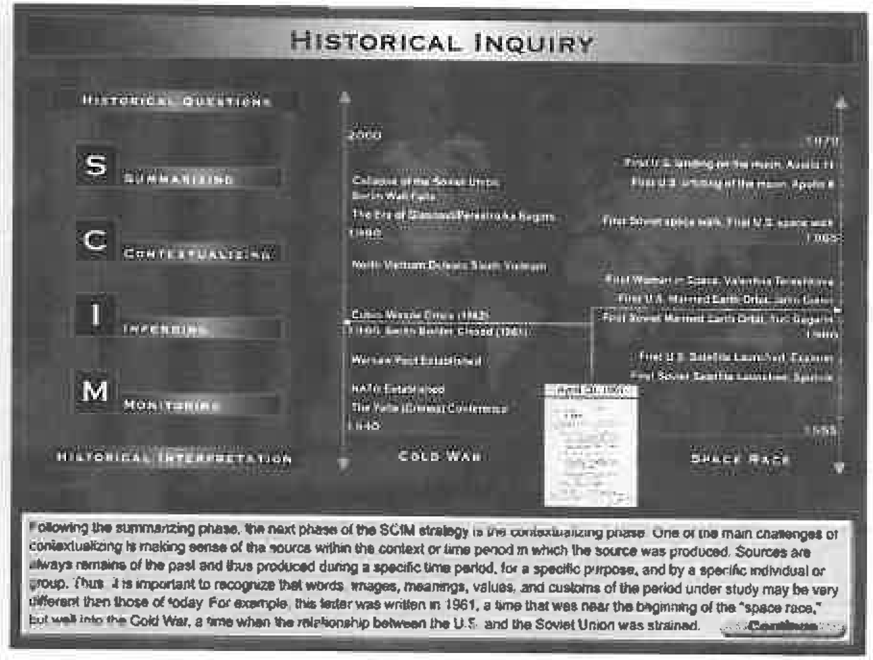

Figure 3: The SCIM strategy and the contextualizing phase

and placed in boxes titled 'Evidence from the Source'. This evidence is then integrated to create new inferential evidence and placed in a box titled 'Inference' (see Figure 3). This highlighting, extracting and integrating are followed by the presentation of the four specific inferring questions. What the tutorial makes clear is that inferential evidence arises from the source itself.

1. What is suggested by the source?
2. What interpretations may be drawn from the source?
3. What perspectives or points of view are indicated in the source?
4. What inferences may be drawn from absences or omissions in the source?

The fourth phase, *monitoring*, is explained and demonstrated by providing relevant questions that may emerge from analysing the letter (see Figure 4). These example questions are followed by the presentation of the four specific monitoring questions. This final phase of the tutorial encourages reflection on the first three phases of the SCIM strategy for the purpose of re-examining current understandings and initial assumptions in relation to the letter, the generated evidence, and the guiding historical question.

1. What additional evidence beyond the source is necessary to answer the historical question?

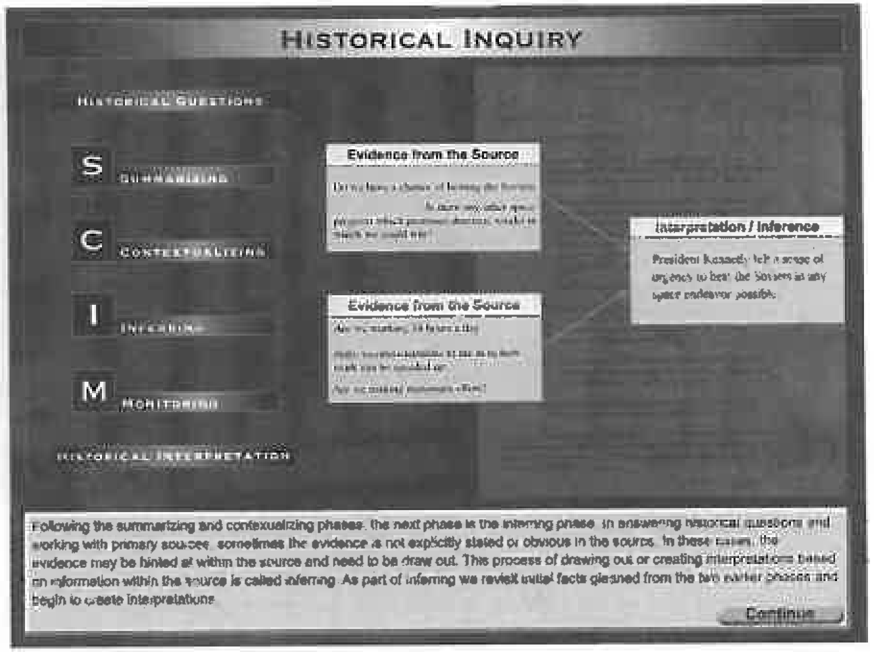

Figure 4: The SCIM strategy and the inferring phase

2. What ideas, images or terms need further defining from the source?
3. How useful or significant is the source for its intended purpose in answering the historical question?
4. What questions from the previous stages need to be revisited in order to analyse the source satisfactorily?

Recall and application tests

The recall test included answering the following question on the computer: 'You have just watched a multimedia tutorial addressing the explanation and application of the SCIM strategy for historical inquiry. Please identify, define and describe the SCIM strategy for historical inquiry. Please be as clear and descriptive as possible.' The recall question was provided on its own screen with a response box located directly below it. The application test included writing an interpretation of an historical letter. The directions above the letter stated, 'Historical sources, such as the letter below, may be used to answer historical questions. Use the letter below to help you in answering the following question: Using the SCIM strategy, what does this source tell us about what the life of a boy was like during the Depression?' The historical letter, guiding question and response box were all located on the same screen.

Procedure

All data collection and media presentations were completed on wireless laptop computers. Participants first completed the OSPAN task. After completing the OSPAN task and following a brief introduction, the participants viewed the appropriate version of the SCIM historical inquiry tutorial given their multimedia group assignment (ie, SI or NSI). Following the viewing of the SCIM historical inquiry tutorial, participants were given 5 minutes to complete the recall test. Finally, after the recall test was completed, participants were given 20 minutes to complete the application test.

Scoring

Recall test

Two trained raters evaluated each participant's recall response (interrater reliability, $r = 0.88$). Responses earned one point for identifying each of the four SCIM strategy components (ie, summarising, contextualising, inferring and monitoring), one point for defining each of the four SCIM strategy components and one point each for providing at least one of the four questions associated with each of the four SCIM strategy components. The maximum recall score was 12 points.

Application test

Two trained raters evaluated each participant's application response (interrater reliability, $r = 0.81$). Responses earned four points for including specific information addressing each of the four SCIM strategy components, for a maximum score of 16 points. Responses earned, based on summarisation, one point each for indicating the author, audience, subject and specific details of the letter. In addressing contextualising, each response earned one point for indicating when, where and why the letter was written, as well as specific details regarding the immediate and/or broader context in which the letter was written. A response earned two points each, based on inferring, for including explicit and/or implicit inferences, and inferences based on absences or omissions within the letter. Finally, a response earned two points each, based on monitoring (see Figure 5), for indicating a need for information beyond the letter and for indicating the usefulness or significance of the letter in addressing the historical question (ie, 'Using the SCIM strategy, what does this source tell us about what the life of a boy was like during the Depression?').

Results

The present experiment was designed to (1) evaluate the WMC hypothesis that students with high WMC will learn and transfer more from a multimedia tutorial than students with low WMC and (2) confirm previous results related to the segmentation effect (citations). These two questions were analysed using two 2 (low WMC, high WMC) × 2 (SI, NSI) factorial design based on the recall and application data.

WMC effect

According to WMC theory, students with high WMC should learn and transfer more information from a multimedia tutorial than low WMC students as a result of high WMC students exhibiting better attentional control, and thus greater attention to the

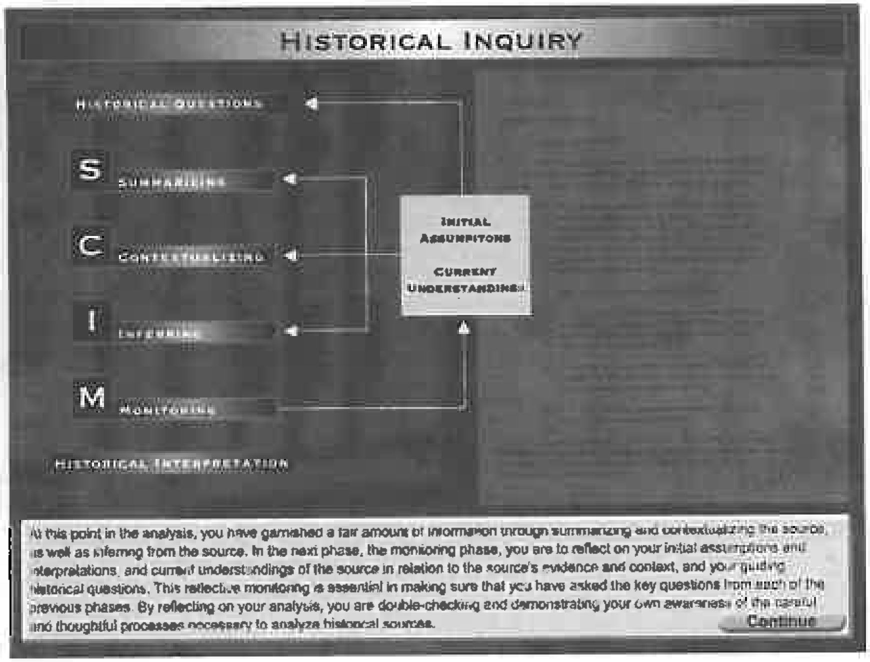

Figure 5: The SCIM strategy and the monitoring phase

Table 1: Means and standard deviations of SCIM strategy recall and application scores

	Recall				Application			
	NSI		SI		NSI		SI	
	M	SD	M	SD	M	SD	M	SD
Low WMC	3.31	2.15	5.95	2.61	4.59	2.51	6.84	3.27
High WMC	5.58	3.20	5.51	2.41	6.83	2.68	6.79	2.79

Note: Maximum recall score = 12; maximum application score = 16.
NSI, non-segmented instruction; SI, segmented instruction; WMC, working memory capacity.

tutorials' content (Kane & Engle, 2000, 2003). This WMC effect was confirmed for recall as high WMC students recalled more than low WMC students (see Table 1), resulting in a significant main effect for WMC, $F(1129) = 4.02$, $p = 0.04$, Cohen's $d = 0.34$. Similarly, based on the application data, the high WMC students generated more valid historical interpretations than low WMC students, resulting in a

significant main effect for WMC, $F(1129) = 4.66$, $p < 0.03$, and Cohen's $d = 0.37$. These results are consistent with the predictions of the WMC hypothesis.

Segmentation effect

According to the cognitive theory of multimedia learning (Mayer, 2001), students should learn more from a multimedia tutorial that is composed of several small segments that allows the user to control when the next segment plays (SI), as opposed to one large segment that plays from beginning to end (NSI). The ANOVA for recall data resulted in a significant main effect for segmentation, $F(1129) = 7.82$, $p = 0.00$, and Cohen's $d = 0.49$ (see Table 1). Similarly, based on the application data, there was a significant main effect for segmentation, $F(1129) = 4.70$, $p = 0.03$, and Cohen's $d = 0.38$. These results are consistent with prior research (Mayer & Chandler, 2001; Moreno & Mayer, 2000) and provide support for the segmentation effect.

WMC and segmentation interaction

Finally, according to WMC theory, low WMC students should be more adversely affected by the NSI condition than the high WMC students. Students with low WMC are more likely to have difficulty synthesising the knowledge introduced during the instructional tutorial and integrating this knowledge with prior knowledge (Cantor & Engle, 1993); students with low WMC are also more likely to have difficulty maintaining multiple knowledge representations in working memory, a necessity for constructing complex, integrated representations (Feldman Barrett, Tugade & Engle, 2004). The WMC and segmentation interaction reveals the proposed differential effect. The significant interaction for recall, $F(1129) = 8.73$, $MSE = 57.97$, $p = 0.00$, appears to be based on participants with low WMC in the NSI condition recalling less historical inquiry and SCIM strategy components than participants in any other condition (see Figure 6). A contrast analysis was used to statistically confirm this appearance by comparing the low WMC-NSI group to the remaining three groups (ie, high WMC-NSI, low WMC-SI and high WMC-SI), $F(1129) = 8.02$, $MSE = 6.64$, $d = 0.93$, $p < 0.01$. There was also a significant interaction for application (see Figure 7), $F(1129) = 5.07$, $MSE = 8.20$, $p = 0.02$. This interaction appeared to be the result of

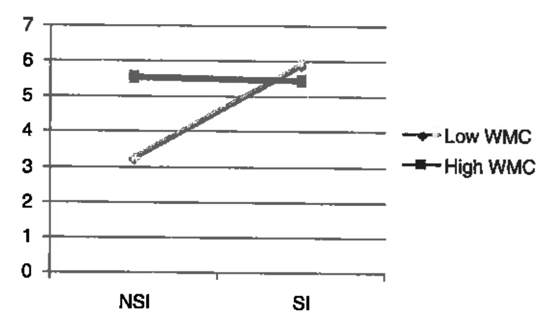

Figure 6: The interaction effects for recall

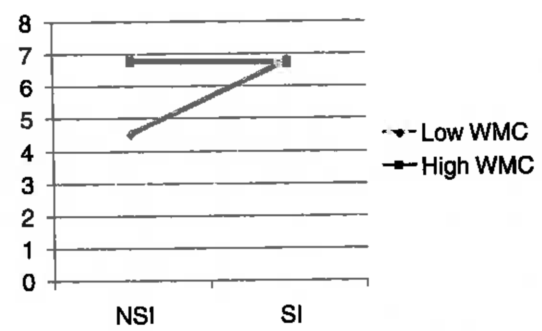

Figure 7: The interaction effects for application

participants with low WMC in the NSI condition applying less historical inquiry and SCIM strategy components than participants in any condition (see Figure 4). This appearance was statistically confirmed using a contrast analysis comparing the low WMC-NSI group to the remaining three groups (ie, high WMC-NSI, low WMC-SI and high WMC-SI), $F(1129) = 6/79$, $MSE = 8.20$, $d = 0.81$, $p < 0.02$. These results are consistent with the view that low WMC students will have difficulty learning from complex multimedia tutorials and that segmentation is one strategy for mediating this difficulty.

Discussion

The goal of this research was to examine the possible existence of individual difference effects in WMC on learning from segmented and nonsegmented multimedia instruction. While previous research in segmentation has indicated at least partial support for the use of segmentation in multimedia instruction (see Mayer & Chandler, 2001; Mayer *et al*, 2003) and has demonstrated a general advantage to individuals with high WMC versus low WMC in a broad array of cognitive tasks (see Conway *et al*, 2002; Unsworth & Engle, 2007), no research to date has examined the interaction between WMC and segmentation.

The results of the present study support the previous findings that the segmentation of multimedia instruction facilitates basic (recall) and deep (application) knowledge acquisition. This finding is important given that previous multimedia research provided only partial support for segmentation (see Mayer & Chandler, 2001; Mayer *et al*, 2003). In addition, the general literature on learner control, of which segmentation is a part, has also only provided partial support for the positive effects of learner control on achievement, generally (see Niemiec, Sikorski & Walberg, 1996; Steinberg, 1989), and on pacing control (ie, segmentation), specifically (Aly *et al*, 2005; Dalton, 1990).

The results of the present study also support the previous findings that individuals with higher WMC outperform individuals with lower WMC on tasks requiring basic (recall) and deep (application) knowledge acquisition. The current findings are important as they provide evidence for an individual difference variable that affects learning in a multimedia instructional environment. Previous research has indicated that prior knowledge (Cooper, Tindall-Ford, Chandler & Sweller, 2001) and spatial ability (Moreno & Mayer, 2000) serve as individual difference variables that affect multimedia learning to which WMC can now be added.

While the current study has demonstrated the positive effects of segmentation and WMC, it is important to note that both of these differences were due to low WMC of individuals learning with NSI. This finding clearly indicates that specific learners (ie, low WMC) may be disadvantaged in specific multimedia instructional environments (ie, NS). On a positive note, however, the results also indicate that using segmentation benefits low WMC individuals to the point where low WMC and high WMC individuals perform equally in multimedia instructional environments that use segmentation.

Ultimately, the present study provides a useful bridge between basic research, designed to develop new knowledge related to multimedia learning, and applied research, designed to implement new knowledge to solve a specific problem using multimedia instruction. Specifically, while the basic research principles of segmentation and WMC have been demonstrated to have a positive effect on the recall and application of knowledge in a multimedia instructional environment, the application of these basic research principles must take into account the individuals under instruction as these basic principles are differentially effective.

References

Aly, M., Elen, J. & Willems, G. (2005). Learner-control vs. program-control instructional multimedia: a comparison of two interaction when teaching principles of orthodontic appliances. *European Journal of Dental Education*, *9*, 157–163.
Ashcraft, M. & Kirk, E. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 2, 224–237.
Buehner, M., Krumm, S. & Pick, M. (2005). Reasoning = working memory ≠ attention. *Intelligence*, *33*, 251–272.
Cantor, J. & Engle, R. W (1993). Working-memory capacity as long-term memory activation: an individual-differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 5, 1101–1114.
Cole, R. & Todd, J. (2003). Effects of web-based multimedia homework with immediate rich feedback on student learning in general chemistry. *Journal of Chemical Education*, *80*, 1, 1338–1343.
Collins Block, C. & Pressley, M. (2002). *Comprehension instruction: research-based best practices*. New York: Guildford.
Conway, A. R., Cowan, N., Bunting, M. F., Therriault, D. J. & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*, 163–183.
Cooper, G., Tindall-Ford, S., Chandler, P. & Sweller, J. (2001). Learning by imagining procedures and concepts. *Journal of Experimental Psychology: Applied*, *7*, 68–82.
Craig, S., Driscoll, D. & Cholson, B. (2004). Constructing knowledge from dialog in an intelligent tutoring system: Interactive learning, vicarious learning, and pedagogical agents. *Journal of Educational Multimedia and Hypermedia*, *13*, 2, 163–184.

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Dalton, D. W. (1990). The effects of cooperative learning strategies on achievement and attitudes during interactive video. *Journal of Computer-Based Instruction*, *17*, 1, 8–16.
Daneman, M. & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *9*, 450–466.
Daneman, M. & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466.
Engle, R., Tuholski, S., Laughlin, J. & Conway, A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*, 3, 309–331.
Feldman Barrett, L., Tugade, M. M. & Engle, R. A. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin*, *130*, 4, 553–573.
Gaultney, J. F., Kipp, K. & Kirk, G. (2005). Utilization deficiency and working memory capacity in adult memory performance: not just for children anymore. *Cognitive Development*, *20*, 205–213.
Hicks, D., Doolittle, P. E. & Ewing, T. (2004). The SCIM-C strategy: expert historians, historical inquiry, and multimedia. *Social Education*, *68*, 3, 221–225.
Just, M. & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review*, *99*, 122–149.
Kane, M. J. & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 2, 336–358.
Kane, M. J. & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*, 1, 47–70.
Kane, M., Bleckley, M., Conway, A. & Engle, R. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, *130*, 2, 169–183.
Kiewra, K. A. & Benton, S. L. (1988). The relationship between information-processing ability and note taking. *Contemporary Educational Psychology*, *13*, 33–44.
Kim, Y., Baylor, A. & PALS Group (2006). Pedagogical agents as learning companions: the role of agent competency and type of interaction. *Educational Technology Research and Development*, *54*, 3, 223–243.
Kozma, R. B. (1994). Will media influence learning? Reframing the debate. *Educational Technology Research and Development*, *42*, 2, 7–19.
Mayer, R. (2001). *Multimedia learning*. New York: Cambridge University Press.
Mayer, R. (Ed) (2005). *The Cambridge handbook of multimedia learning*. New York: Cambridge University Press.
Mayer, R. & Chandler, P. (2001). When learning is just a click away: does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology*, *93*, 2, 390–397.
Mayer, R. E. & Moreno, R. (1998). A split-attention effect in multimedia learning; evidence for dual processing systems in working memory. *Journal of Educational Psychology*, *90*, 2, 312–320.
Mayer, R. E. & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*, 1, 43–52.
Mayer, R. E., Dow, G. T. & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: what works in the design of agent-based microworlds? *Journal of Educational Psychology*, *95*, 4, 806–813.
Miller, G. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.
Moreno, R. & Mayer, R. E. (2000). A coherence effect in multimedia learning: the case for minimizing irrelevant sounds in the design of multimedia instructional messages. *Journal of Educational Psychology*, *92*, 1, 117–125.

Niemiec, R. P., Sikorski, C. & Walberg, H. J. (1996). Learner-control effects: a review of reviews and a meta-analysis. *Journal of Educational Computing Research*, *15*, 2, 157–174.
Paas, F., Renkl, A. & Sweller, J. (2003). Cognitive load theory and instructional design: recent developments. *Educational Psychologist*, *38*, 1, 1–4.
Pollock, J. C. & Sullivan, H. J. (1990). Practice mode and learner control in computer-based instruction. *Contemporary Educational Psychology*, *15*, 3, 251–260.
Pratt, M. W., Boyes, C., Robins, S. & Manchester, J. (1989). Telling tales: aging, working memory, and the narrative cohesion of story retellings. *Developmental Psychology*, *25*, 628–663.
Reiser, B. (2004). Scaffolding complex learning: the mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences*, *13*, 3, 273–304.
Rosen, V. M. & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*, 3, 211–227.
Schnotz, W. & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction*, *13*, 141–156.
Shute, V. J. (1991). Who is likely to acquire programming skills? *Journal of Educational Computing Research*, *7*, 1–24.
Steinberg, E. R. (1989). Cognition and learner control: a literature review, 1977–88. *Journal of Computer-Based Instruction*, *16*, 4, 117–124.
Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*, 295–312.
Turner, M. L. & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127–154.
Unsworth, N. & Engle, R. W. (2007). The nature of individual difference in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*, 1, 104–132.
VanSledright, B. (2002). *In search of America's past: learning to read history in elementary school*. New York: Teachers College Press.
Wei, F., Chen, G., Wang, C. & Li, L. (2007). Ubiquitous discussion forum: introducing mobile phones and voice discussion into a web discussion forum. *Journal of Educational Multimedia and Hypermedia*, *16*, 2, 125–140.
Wineburg, S. (2001). *Historical thinking and other unnatural acts*. Philadelphia: Temple University.