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The cognitive impact of interactive design features for learning complex materials in medical education

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Abstract

To identify the most effective way for medical students to interact with a browser-based learning module on the symptoms and neurological underpinnings of stroke syndromes, this study manipulated the way in which subjects interacted with a graphical model of the brain and examined the impact of functional changes on learning outcomes. It was hypothesized that behavioral interactions that were behaviorally more engaging and which required deeper consideration of the model would result in heightened cognitive interaction and better learning than those whose manipulation required less deliberate behavioral and cognitive processing. One hundred forty four students were randomly assigned to four conditions whose model controls incorporated features that required different levels of behavioral and cognitive interaction: Movie (low behavioral/low cognitive, $n = 40$), Slider (high behavioral/low cognitive, $n = 36$), Click (low behavioral/high cognitive, $n = 30$), and Drag (high behavioral/high cognitive, $n = 38$). Analysis of Covariates (ANCOVA) showed that students who received the treatments associated with lower cognitive interactivity (Movie and Slider) performed better on a transfer task than those receiving the module associated with high cognitive interactivity (Click and Drag, partial eta squared = .03). In addition, the students in the high cognitive interactivity conditions spent significantly more time on the stroke locator activity than other conditions (partial eta squared = .36). The results suggest that interaction with controls that were tightly coupled with the model and whose manipulation required deliberate consideration of the model's features may have overtaxed subjects' cognitive resources. Cognitive effort that facilitated manipulation of content, though directed at the model, may have resulted in extraneous cognitive load, impeding subjects in recognizing the deeper, global relationships in the materials. Instructional designers must, therefore, keep in mind that the way in which functional affordances are integrated with the content can shape both behavioral and cognitive processing, and has significant cognitive load implications.

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Keywords

Cognitive interactivity; Behavioral interactivity; Cognitive load; Multimedia learning; Medical education

1. Introduction

To prevent devastating consequences, physicians must recognize the early signs of embolic stroke syndromes, rapidly evaluate the patient, and implement thrombolytic therapy if warranted. A strong working knowledge of the vascular supply of the brain enables a clinician to recognize these warning signs and save lives as a result.

To help medical students learn the association between specific stroke symptoms and blood supply to regions of the brain, we developed an interactive instructional multimedia presentation. During the instructional activity students were presented with descriptions of patients' experiences during different stroke episodes. They then interacted with animated sequences depicting migration of an embolus through a model of the major arteries of the brain. In so doing, they learned to associate the origin and path of an embolism with the patient's evolving symptoms and signs.

The Integrated Model of Multimedia Interactivity (INTERACT) (Domagk, Schwartz, & Plass, 2010) describes interactivity as a dynamic process by which a learner receives and responds to instructional events. In this bidirectional relationship the learning experience may be shaped to some extent by the behavior of the learner. Interaction encompasses three levels of processing. *Behavioral* interactivity refers to the way in which learners engage with the instructional sequence by physically acting upon the features of the learning environment. *Cognitive* interactivity refers to the receipt, processing and formulation of learner's internal thoughts and other cognitive processes in response to events in the instructional environment. *Emotional* interactivity refers to the learners' affective response to the learning environment. Cognitive processing of instruction is mediated by *behavioral* processing since it is through physical interaction that the intentions of cognitive processing are expressed. It is also mediated by affective processing (Plass, Heidig, Hayward, Homer, & Um, in press; Um, Plass, Hayward, & Homer, 2012). In this paper, we are interested in the relation between cognitive and behavioral interactivity, i.e., in the way the design of the learning environment constrains the learner's ability to act. Adjusting a variable in a simulation to test a hypothesis, for example, requires that the physical environment supports such manipulation and communicates the outcome back to the learner to affect their cognition.

A key consideration in the design of interactive materials is the degree and nature of learner control, cognitive or behavioral, that the materials allow. Several studies have shown that the incorporation of interactive features in multimedia instructional designs can enhance learning outcomes in some instructional contexts (Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009; Mayer & Chandler, 2001). Schwan and Riempp (2004), for example, have demonstrated that interactive features aided learning of a procedural skill under certain conditions. In their study, students used the interactive features of an application to manage the pace and sequence of an instructional multimedia presentation. They propose that interactivity can enhance instruction by allowing students to tailor learning experiences to their individual needs. Mayer, Dow, and Mayer (2003) found that receiving interactive instructional materials led to better performance on a problem solving task compared with non-interactive materials and posit that control of navigation and pacing allowed learners to better understand the instructional content.

There has been interest in the impact of different forms of physical activity during instruction and cognition (Barsalou, 2008; Koning & Tabbers, 2011), and some research has suggested that action during periods of learning may aid in knowledge acquisition. Cook, Mitchell, and Goldin-Meadow (2008), for example, showed that hand gestures made by children while learning about mathematics improved retention of the learned concepts. Glenberg, Goldberg, and Zhu (2011) found that students who read stories and manipulated associated images on a computer screen performed better on a comprehension test. Other studies indicate that the manipulation of both virtual and real-world objects may have equivalent or complimentary cognitive effects (Triona & Klahr, 2010; Zacharia & Olympiou, 2011). Paas and Sweller (2012) have suggested that learners' observation or use of motion, gesturing, and object manipulation during instruction may aid in knowledge acquisition. They hold that the acquisition related knowledge might be less mentally taxing than the acquisition of knowledge associated with traditional instruction and activities such as reading.

The presence of interactive features alone does not enhance learning, however (Kraiger & Jerden, 2007). Lowe (2004), for example, found that novice learners used the features of an interactive animation ineffectively when learning to make predictions using weather maps. Students tended to use the animation controls to focus on isolated elements of the content rather than the deeper meaning reflected in the global relationships between elements. Despite the integration of interactive features with the instructional materials, learners, with limited prior knowledge and no external support to guide examination of the maps, failed to use them effectively. The study suggests that interactive features are of little value if the learner lacks the domain knowledge needed to formulate an appropriate learning strategy.

Rasch and Schnotz (2009) found that students receiving an interactive instructional animation describing the relationship between geographic location and time, performed significantly better when solving time difference problems, but did not show an advantage when solving circumnavigation problems. They suggest that the interactive features had an enabling effect, allowing students to engage in more elaborate mental processing of time-difference scenarios despite cognitive capacity constraints. In the context of circumnavigation problems however, interactive features had no benefit as students were able to conduct equivalent simulations in working memory without external support. The benefit of interactivity therefore may be dependent upon the level of learner expertise as well as nature of the cognitive task.

Researchers suggest that meaningful cognitive processing results when interactivity is both cognitively and behaviorally relevant to the learning task (Domagk et al., 2010; Gavora & Hannafin, 1995). Task-inappropriate physical interactions are distracting and thus impede learning. Kalyuga (2007, 2012) notes that while interactive multimedia may engage students in the construction of more robust and richer mental models, interaction itself requires cognitive resources. Interactivity may therefore tax limited working memory particularly among novice learners (Homer & Plass, 2009; Wouters, Tabbers, & Paas, 2007). In a study of a multimedia instructional module to teach medical students to examine the abdomen, Kalet et al. (2012) found that a moderate level of interactivity (clicking on buttons to perform the exam) was associated with small to moderate improvements in performance of clinical skills on a Standardized Patient immediately after completing the module compared with less interactivity (watching an animation of the exam) and more interactivity (dragging tools to perform the exam). The study suggests that there may be an optimal level of interactivity that enhances engagement with instructional material when teaching procedural skills. It has been suggested that in some contexts, system controlled learning experiences may be appropriate (Kalyuga, 2007).

To better understand the role of interactivity in multimedia instruction in medical education, this study examined the influence of different levels of interactivity on learning outcomes in a cognitively and visuospatially complex learning domain. Informed by the INTERACT Model (Domagk et al., 2010) and empirical evidence, a multimedia computer assisted learning tool to teach students to rapidly identify treatable strokes was developed. Through the deliberate manipulation of interactive design features to promote varying levels of cognitive and behavioral processing, the study was designed to identify the most effective strategy for inducing transferable learning. We hypothesized that learners exposed to design features inducing more cognitive interactivity would outperform learners receiving less cognitively interactive designs and that learners receiving more behavioral interactive design features would outperform learners receiving less behavioral interactive designs. The study supposed that students who more directly engaged with the learning materials would regulate their learning experience more effectively. We also hypothesized that cognitive and behavioral processing would interact to produce the best outcomes and lead to enhanced transfer of the knowledge to new clinical cases.

2. Methods

2.1. Development of stroke locator

The Stroke Locator is a browser-based learning module that presents the learner with four different cases describing the symptoms experienced by a patient during a stroke episode in text, located on the left side of the page (Fig. 1). An animated model of the human brain and its major arteries is provided at the right side. The animated model incorporates four views: a *distant anterior view* including the internal and external carotid arteries, a *close anterior view* including the right or left carotid arteries, a *left lateral view* depicting major arteries in the left hemisphere, and *a right lateral view* showing major arteries of the right hemisphere. A red dot is used to represent an embolus. For each case in this study, the distant view was used to identify the most likely starting position of the embolus as either the left or right carotid artery. After indicating the starting position, the embolus was then moved through the vascular structures toward the location of the blockage associated with the stroke. When the embolus could no longer be moved in the anterior view, the model transitioned to a left or right lateral view and the embolus migration was continued. At the end of the sequence for each case a "solution" showing the final location of the embolus and indicating the functional areas of the brain whose blood supply had been compromised was presented. Animated sequences depicting changes in three-dimensional orientation were used to transition between views. The transitions were intended to help learners more easily visualize anatomical structures and to maintain orientation with the starting location of the embolus. The materials were developed using Macromedia Flash™ and JavaScript™.

Four versions of the intervention were developed incorporating the different level of cognitive and behavioral interactivity: Movie (low, low), Slider (low, high), Click (high, low), and Drag (high, high). Fig. 1 shows each condition's interface. Users in the *Movie* condition observed an animation of the embolus migration, controlling only the pace of the presentation through simple pause-and-play functionality. The controls were activated by a simple mouse click and required behavioral processing with low complexity. Since the controls were not physically integrated with the vascular model and interaction with the controls required only limited consideration of the information represented by the model itself, the conditionwas categorized as inducing low cognitive interactivity. Those in the *Slider* condition dragged a handle below the model to move the embolus along a predefined path. Although this condition was behaviorally more demanding and therefore behaviorally more interactive, use of the controls required only limited consideration of the model and therefore induced low cognitive interactivity. In the *Click* condition, students moved the embolus to a location in the model by clicking directly on vascular structures. In this case, the physical demands of the controls were simple, but interaction with the model required careful consideration of its content. This condition was classified as inducing high cognitive interactivity. Those in the *Drag* condition had to click and drag the embolus to emulate its movement in the vasculature. In this condition, the embolus was dragged along the path of the arteries, requiring more complex behavioral interactivity. As in the click condition, control of the embolus required more deliberate cognitive processing. A four-case version of the Stroke Locator website is available for teaching and learning at http://informatics.med.nyu.edu/StrokeLocator.

2.2. Pilot test of stoke locator

The stroke locator was piloted in a randomized controlled design with 53 volunteer second-year medical students.We found that among those who received the treatments with high cognitive interactivity (Click and Drag), regardless of the level of behavioral interactivity, performed better on a knowledge test (Cohen's $d = 0.52$; 95% CI: 0.0, 1.0). However, in the transfer test measured by asking the student to match a text based clinical case with a Magnetic Resonance Image (MRI) of the brain, students in the Click group performed better than those who received the Drag treatment (Cohen's $d = 0.73$; 95% CI: −0.1, +1.5). An observed interaction effect for cognitive and behavioral interactivity ($F(1, 48) = 3.91$, MSE = 84.38, $p = .05$) suggests that the increased behavioral complexity of the drag action may have elevated demand for cognitive resources beyond that of the click treatment, impeding deeper learning.

This pilot study revealed a significant methodological flaw in the materials. The high cognitive interactivity groups (Click and Drag) received feedback, in the form of brief text, which provided additional clinical information when they placed the embolus in the wrong location. The low cognitive interactivity groups did not receive this feedback since they could not “go the wrong way”. Since this additional information may explain part or all of the effects shown, the study materials where modified to insure equivalent feedback was provided in all conditions. In addition, a review of the discrimination power of posttest questions indicated that 6 of 20 items were not effective. The items were removed from the posttest used in the main study.

2.3. Methods of main study

2.3.1. Participants—The study was carried out at a large medical school in the northeastern United States. The participants were second year medical students who had completed their preclinical Neurosciences block and were about to start their clinical clerkship year.

Of 158 students invited, 144 students (91%) consented to participate in the study. They were scheduled to attend a session and asked to use an on-line instructional module (Stroke Locator) to learn about common neurological emergencies. Students were randomly assigned to one of four conditions: *Movie (40)*, *Slider (36)*, *Click (30)*, or *Drag (38)*. This study was approved by the institutional review board (IRB).

2.3.2. Procedures and measures—In a 90-min computer lab session, the students received a brief introductory lecture entitled “Common Neurological Emergencies” focused on stroke diagnosis including orientation to neuroimaging and indications for urgent treatment. They then completed an 8-item multiple-choice prior-knowledge test. Subjects were randomized to complete one of four versions of the Stroke Locator followed by a 14-item post-test (internal consistency coefficient, a = .68) where they considered stroke cases similar to those in the module and identified the likely anatomic correlates. Finally, as a transfer test, participants were asked to identify abnormalities on 14 MRIs with clinical descriptions of actual cases (internal consistency coefficient, a = .45). Examples of immediate post-test and MRI reading transfer test are provided in Fig. 2. In addition, the students were asked to complete a 2-item cognitive load questionnaire (Paas, 1992), on a scale of one to seven with seven being the highest, asking how much mental effort they invested in the learning task, and how easy or difficult it was to work with this exercise. All measures were scored by an individual unaware of group assignment. After all subjects had completed the procedures, they received a debriefing on all activities and reviewed the cases with a clinical faculty member.

The SPSS (Statistical Package for the Social Science) version 18 was used to analyze the data and answer the research questions. An alpha level of .05 was applied to examine whether the null hypotheses could be rejected.

3. Results

To examine the effects of the level of cognitive and behavioral interactivity on clinical knowledge acquisition and transfer, two-way ANCOVAs were conducted. Before ANCOVAs were conducted, the basic assumptions of ANCOVA including linearity, homogeneity of regression slopes, and independence of the covariate were verified. Although there was no difference in prior knowledge across the four conditions, prior knowledge was entered as a covariate in the ANCOVAs to account for the corresponding variance. Table 1 shows the descriptive statistics for outcomes measured in each of the four conditions. For clinical knowledge acquisition, measured by a multiple-choice test, there was no difference among the four conditions. However in the MRI transfer test, students who received the treatments associated with lower cognitive interactivity (Movie and Slider) performed better than those receiving the module associated with high cognitive interactivity (Click and Drag, partial eta squared = .03). Table 2 reports the overall results for the 2X2 ANCOVA on each outcome measure.

A review of the cognitive load measures indicated that students in the conditions associated with high cognitive interactivity (Click and Drag) perceived the stroke locator as more difficult to work with than those in the conditions associated with low cognitive interactivity (Movie and Slider, partial eta squared = .27). In addition, there was a significant interaction between behavioral interactivity and cognitive interactivity on cognitive load (partial eta squared = .05).

We also found the students in the high cognitive interactivity conditions spent significantly more time on the stroke locator activity than other conditions (partial eta squared = .364). Therewas a significant interaction between behavioral interactivity and cognitive interactivity on time on task (partial eta squared = .13). Table 3 provides the descriptive statistics for cognitive load and time on task across the four conditions and Table 4 shows the overall results for the 2x2 ANCOVA on cognitive load and time on task.

4. Discussion

The study predicted that conditions in which interactive application features induced increased cognitive and behavioral interactivity would lead to more effective cognitive processing and better learning outcomes. Contrary to expectations, there was no significant difference in knowledge acquisition across groups, and subjects in the high cognitive interactivity conditions (Click and Drag) performed *worse* on the transfer task than did those in the conditions with low cognitive interactivity (Movie and Slider). Learning from the high cognitive interactivity conditions, however, was more demanding as indicated by the differences in cognitive load and time on task measures. These findings suggest that the difference in the cognitive demands induced by the treatments' interactive design features resulted in differences in subject performance.

Cognitive load theory (Sweller, 2005; Sweller, van Merriënboer, & Paas, 1998) suggests that the acquisition of knowledge is constrained by individual working memory capacity limitations. As learners interact with a learning environment, mental effort is expended to interpret, persist, and respond to instructional events. Intrinsic cognitive load refers to the effort that must be invested due to the innate complexity of material to be learned. Germane cognitive load describes the productive effort through which the individual constructs a mental model of the material. The effort invested in mental processing due to features of the instruction presentation which do not contribute directly to the learning task, is referred to as extraneous cognitive load. The effects of the components of cognitive load are cumulative. Within the limits of working memory, cognitive resources can be allocated to manage the total load or complexity of a task (Merriënboer & Sweller, 2005; Paas, Tuovinen, Tabbers, & Van Gerven, 2010). When the task becomes overly complex and excess resources are scarce, however, the combined cognitive load of a learning experience may exceed an individual's working memory capacity and impede knowledge acquisition.

The process of understanding representations, both individually and collectively, is constrained by the limitations of working memory (Seufert, Jänen, & Brünken, 2007) and learning from multiple representations is a cognitively demanding task (Bodemer, Ploetzner, Bruchmüller, & Häcker, 2005; Seufert, 2003). Although the use of dynamic visualizations, such as the vascular model in this study, can be effective in demonstrating the characteristics of a dynamic process, they may elevate the burden on working memory resources, particularly among novices (Chandler, 2009; Schwan & Riempp, 2004). It has been also found in medical education studies that multimedia learning of complex materials can be optimized when it is equipped with guided support features such as a how-to video clip (Govaere Jan, de Kruif, & Valcke, 2012; Holzinger, Kickmeier-Rust, Wassertheurer, & Hessinger, 2009).

The lack of differences in post-test scores suggests that the elevated demands of the high cognitive interactivity treatments neither aided nor impeded the subjects' ability to acquire information about specific stroke cases. The learning task evaluated by the post-test measure however, was not complex. Using textual and pictorial representations that were similar to those used in the instructional materials, the post-test asked students to simply reproduce information in the same form that had been presented during instruction. It did not require a deep understanding of the relationships between a patient's symptoms and their neurological implications. It is likely that subjects in all four conditions had sufficient cognitive resources to similarly encode features of the presentation in memory. Although those in the high cognitive interactivity conditions were faced with the elevated processing demands of the Click and Drag conditions, the combined demands of interaction and encoding do not appear to have neither exceeded the resource limitations of working memory (thus impairing learning) nor aided learning for this simple task.

The transfer questions, however, incorporated a novel pictorial representation, the MRI, and asked the students to consider the relationship between the case text and the image in a way that was not directly modeled during instruction. To perform this task, a deeper conceptual understanding, one that extended beyond the surface characteristics of text and animations, and captured features and relationships that spanned across both representations, was required (Schnotz, 2005; Schnotz, Böckheler, & Grzondziel, 1999; Seufert, 2003).

Despite receiving materials that were equivalent in their content and representational characteristics, subjects *interacting* with features associated with high cognitive *interactivity* (Click and Drag) performed worse on the transfer task than did those in the low cognitive interactivity (Movie and Slider) groups. This suggests that the nature of the interactivity itself may have interfered with mental model formation. Faced with the complex cognitive task of constructing a globally coherent mental model (Seufert & Brünken, 2006) of stroke symptoms and their anatomical underpinnings, subjects would have had little working memory capacity available to simultaneously manage the demands associated with interactivity. Since behavioral interaction with the model was necessary to uncover relevant instructional content, subjects in all conditions would have little choice but to allocate attention to manipulation of the model.

Manipulation of the animation was less demanding in the low cognitive interactivity groups, as the behavioral controls were fixed in place and less visually integrated with the animation. Behavioral interaction with these materials required less careful consideration of the model itself and was therefore influenced less by changes in visual perspective. It is likely that subjects in the low cognitive interactivity groups were able to more evenly allocate working memory resources across the text and images in order to understand the global relationships reflected in the materials. With a more robust mental model of the relationship across the patient case and the anatomical animation, these students were able to more effectively contrast features of the textual case and with those of the novel image during the transfer task.

Manipulating the animation in the high cognitive interactivity conditions required careful consideration of the anatomical model. In addition, changes in perspective may have been more cognitively challenging. Although all conditions incorporated multiple perspectives, subjects in the Click and Drag groups would need to more carefully reorient themselves with each change in order to continue moving the embolus. The demand for cognitive resources due to interactivity in the Click and Drag groups, as demonstrated by elevated cognitive load and time on task measures, may have impeded the formation of a coherent and generalizable mental model by limiting the resources available for germane processing activities.

Other studies have found that learners may exhibit different learning behaviors when faced with instructional activities incorporating complex representations, Huff and Schwan (2011) demonstrated that differences in the complexity of a representation changed the processing demands it placed on learners and influenced the time required to perform an associated classification task. Lowe (2003, 2004) found that subjects adopted simple comprehension strategies that focused on easily perceived surface features when learning from complex and unfamiliar dynamic visualizations. The studies suggest that subjects' strategy selection may have been a response to the complex cognitive processing required by the visualizations.

The findings of this study have both theoretical and practical implications for instructional designers. As Domagk et al. (2010) and Kennedy (2004) emphasized, the effectiveness of interactivity in instructional contexts lies in its ability to stimulate cognitive processing. The nature of learners' behavioral interaction with the learning environment can enhance or impede the way in which instructional events are cognitively processed. Our findings support this perspective. Altering the characteristics of behaviorally interactive features in a multimedia-learning module influenced the amount of cognitive effort needed to learn from the instructional materials and impacted learning outcomes.

Designers must, therefore, keep in mind that the way in which interactive features are implemented in a multimedia design has both behavioral and cognitive implications. As has been previously shown in the domain of procedural skill learning, behavioral processing underlying behavioral interactivity, which is extraneous or excessive, may hamper rather than facilitate meaningful learning (Kalet et al., 2012). In this study, the increased demands of manipulating the embolus in the context of the vascular model focused cognitive processing on specific elements of the implementation and limited participants' ability to construct a more general and transferable mental model of the instructional content. One must therefore ask not only if interactivity is extraneous or germane to a learning task, but how the interactivity will shape cognitive processing. For instance, as suggested by Gegenfurtner and Seppänen (2013), behavioral interactivity elements of multimedia instructional design should incorporate what is known about how experts move their eyes and identify salient image structures rather than a more literal reenactment of the path of the embolus causing the blockage of the blood supply to the brain. Similarly, perhaps cognitive interactivity should be designed to provide novices with models of expert strategies in retrieval and decoding of task-relevant prior knowledge and interpretation of visual clues rather than basic explanatory pathological mechanisms.

Several limitations of this study must be acknowledged. First, although use of the interactive features did not involve complex manipulation and the physical demands of the implementations were equivalent across levels of cognitive interactivity, the integration of the controls with the animation may have resulted in a steeper learning curve in the high cognitive interactivity conditions. Although instructions describing the use of each treatment were provided, students did not have an opportunity to practice before the instructional presentation. Second, the instructional sequence was relatively short. Although students worked independently and no time constraint was place on the instructional portion of the exercise, the module included only four cases in which subjects could master use of the modules' interactive features. Given more opportunity to work with each treatment, subjects in the high engagement group may have become more adept in the use of the interactive features. With the development of this expertise, the cognitive load associated with the interactivity itself may have waned, freeing up cognitive resources.

Third, the subjects of this study were drawn from a population with limited clinical experience. Although the case descriptions were brief and contained few extraneous details, no explicit support was provided during the presentation to assist subjects in the evaluation of the textual patient history. Inexperience may have elevated the demands of the learning task as more cognitive effort was required to interpret the text and construct mental representations of each case. Learners with more clinical experience may have experienced less cognitive load when working with the materials as they could draw on a broader base of prior knowledge and more automated strategies (Kalyuga, 2010; Sweller & Chandler, 1994) to guide their interpretation of the materials, freeing working memory resources for other tasks, such as comprehension of the overall coherence of the presentation.

Finally, despite filtering out items with low discrimination power after the pilot study, the internal consistency of the outcome measures remained low. The Cronbach's alpha for relatively short tests was less than 0.5. This reduced our ability to detect small but meaningful differences in learning across conditions, especially for the immediate post-test.

5. Conclusions

This study has demonstrated that the design of behaviorally interactive features in an instructional application can influence the way cognitive processing unfolds in a high stakes and complex learning domain. For the benefits of interactivity to be realized, the instructional designer must carefully consider the way in which interactive features shape a learner's cognitive experience of the learning materials and thus the construction of elaborated mental models. Continued efforts to understand the influence of specific functional features on cognitive processing would inform the application of multimedia technologies in health sciences education and instructional design in general.

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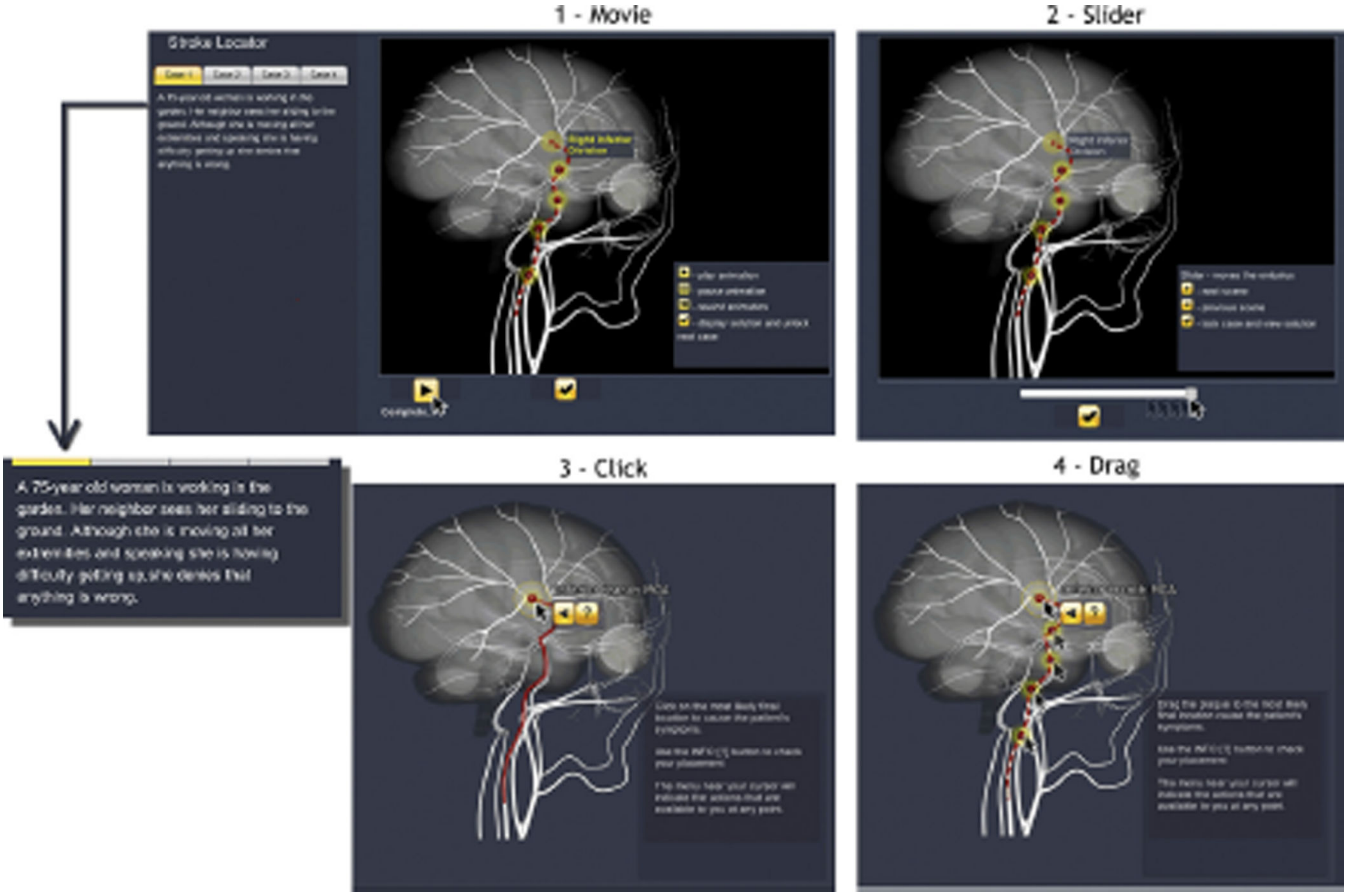
Highlights

- Low cognitive interactivity lead to better performance in a transfer task.
- Students in the high cognitive interactivity spend more time on the materials.
- Cognitive effort that manipulates contents may cause extraneous cognitive load.
- Instructional designers must consider cognitive load in interaction design.



A 75-year old woman is working in the garden. Her neighbor sees her sliding to the ground. Although she is moving all her extremities and speaking she is having difficulty getting up, she denies that anything is wrong.

Fig. 1.

Interface of Stroke Locator (Four conditions). Fig. 1 indicates the overall layout of the study treatments and the interactive elements specific to each condition. Text for the patient case appears in the upper left for each. Arrow icons indicate the location and type of mouse manipulation required to interact with the model. Dotted lines in the model itself represent the path of “embolus” movement, from origin to blockage that was depicted in the animated treatments. The Movie condition (Panel 1) is controlled by manipulating video controls (pause/play/rewind) located below the model. In the Slider condition (Panel 2) the embolus is moved along the arteries by manipulating the slider bar located below the model. In the Click condition (Panel 3) the embolus is placed at a blockage location with a mouse click and the path to that location is automatically indicated. In the Drag condition (Panel 4) the mouse is used to drag the embolus along the arteries to the blockage point. In all conditions only one path is available. Clicking or dragging outside of the correct pathway results in no change to the model.

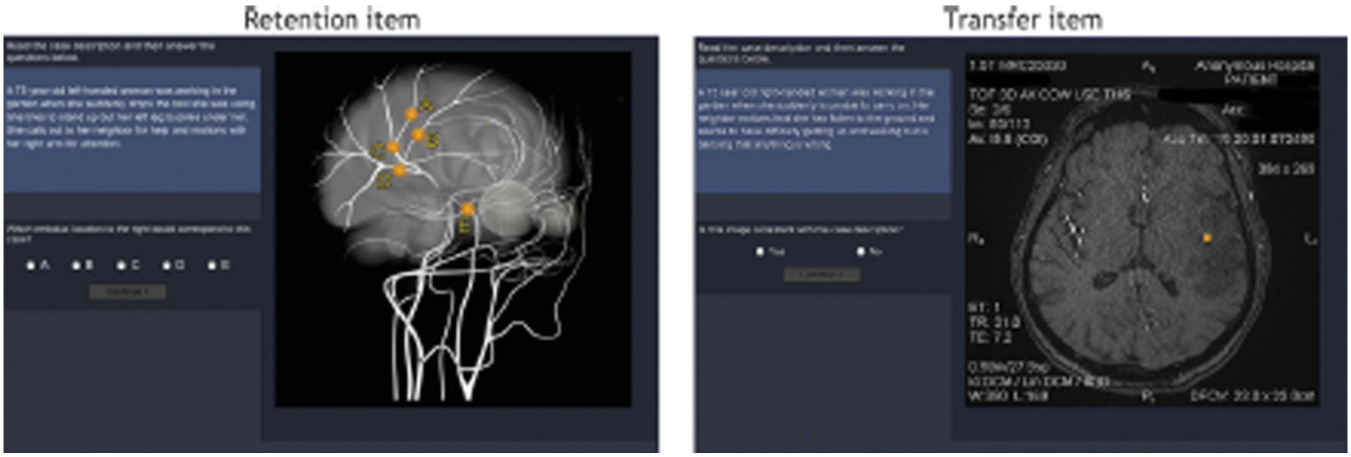


Fig. 2.
Examples of the post-test and transfer test.

Table 1

Descriptive statistics on immediate posttest and transfer test scores for each group.

Test	Group	*N*	Mean	Std. Deviation	Min	Max
Immediate posttest score	Movie	40	8.12	2.86	1	13
	Slider	36	7.44	2.50	2	12
	Click	30	7.47	2.91	1	12
	Drag	38	7.39	2.67	3	12
	Total	144	7.63	2.72	1	13
Transfer test score	Movie	40	26.60	3.84	17	35
	Slider	36	25.44	4.55	11	34
	Click	30	24.67	4.96	10	32
	Drag	38	24.11	4.42	15	32
	Total	144	25.25	4.48	10	35

Note: The total score of each test is 14 points (Immediate Posttest) and 37 points (Transfer).

Table 2

ANCOVAs for immediate posttest and transfer test achievement.

Dependent variables	**Source**	***df***	***F***	**Partial eta squared**	***p***
Immediate posttest score	Prior knowledge	1	7.48	.05	.007
	(A) Cognitive interactivity	1	.85	.01	.359
	(B) Behavioral interactivity	1	.16	.00	.687
	A × B (interaction)	1	.75	.01	.388
	Error (within groups)	139			
Transfer test score	Prior knowledge	1	7.89	.05	.006
	(A) Cognitive interactivity	1	5.74	.04	.018
	(B) Behavioral interactivity	1	.54	.00	.464
	A × B (interaction)	1	.36	.00	.547
	Error (within groups)	139			

Table 3

Descriptive statistics on cognitive load and time-on-task for each group.

Test	**Group**	***N***	**Mean**	**Std. Deviation**	**Min**	**Max**
Cognitive load	Movie	40	2.35	1.56	1	6
	Slider	36	2.78	1.57	1	6
	Click	30	4.97	1.52	1	7
	Drag	37	4.03	1.83	1	7
	Total	143	3.44	1.91	1	7
Time-on-task	Movie	40	168.80	57.59	99.39	316.10
	Slider	36	231.35	54.52	123.89	317.99
	Click	30	365.36	148.42	210.34	777.93
	Drag	37	294.39	70.33	184.08	484.66
	Total	144	258.28	112.24	99.39	777.93

Notes 1: The range of Cognitive Load is 1–7.

2: The unit of Time-on-task is second.

Table 4

ANCOVAs for cognitive load and time-on-task.

Dependent variables	**Source**	***df***	***F***	**Partial eta squared**	***p***
Cognitive load	Prior knowledge	1	.66	.01	.419
	(A) Cognitive interactivity	1	50.01	.27	.000
	(B) Behavioral interactivity	1	1.10	.01	.296
	A × B (interaction)	1	6.47	.05	.012
	Error (within groups)	138			
Time-on-task	Prior knowledge	1	1.05	.01	.307
	(A) Cognitive interactivity	1	79.11	.36	.000
	(B) Behavioral interactivity	1	.36	.00	.549
	A × B (interaction)	1	20.73	.13	.000
	Error (within groups)	138			