Evaluation of Cognitive Loads Imposed by Traditional Paper-Based and Innovative Computer-Based Instructional Strategies

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ABSTRACT

Strategies of presenting instructional information affect the type of cognitive load imposed on the learner's working memory. Effective instruction reduces extraneous (ineffective) cognitive load and promotes germane (effective) cognitive load. Eighty first-year students from two veterinary schools completed a two-section questionnaire that evaluated their perspectives on the educational value of a computer-based instructional program. They compared the difference between cognitive loads imposed by paper-based and computer-based instructional strategies used to teach the anatomy of the canine skeleton. Section I included 17 closed-ended items, rated on a five-point Likert scale, that assessed the use of graphics, content, and the learning process. Section II included a nine-point mental effort rating scale to measure the level of difficulty of instruction; students were asked to indicate the amount of mental effort invested in the learning task using both paper-based and computer-based presentation formats. The closed-ended data were expressed as means and standard deviations. A paired *t* test with an alpha level of 0.05 was used to determine the overall mean difference between the two presentation formats. Students positively evaluated their experience with the computer-based instructional program with a mean score of 4.69 ($SD = 0.53$) for use of graphics, 4.70 ($SD = 0.56$) for instructional content, and 4.45 ($SD = 0.67$) for the learning process. The mean difference of mental effort (1.50) between the two presentation formats was significant, $t = 8.26$, $p \leq .0001$, $df = 76$, for two-tailed distribution. Consistent with cognitive load theory, innovative computer-based instructional strategies decrease extraneous cognitive load compared with traditional paper-based instructional strategies.

Key words: cognitive load theory, anatomy education, computer-based instructional strategies, canine skeleton

INTRODUCTION

Most current strategies for teaching veterinary gross anatomy rely on printed textbooks. The level of detail in these textbooks can be overwhelming for novice first-year students. However, careful design of innovative computer-based instructional strategies that are consistent with cognitive load theory (CLT) decreases unnecessary extraneous cognitive loads that may occur when using traditional paper-based instructional strategies. Computer-based materials that are designed to introduce basic information to novice students in a simple concise way that matches their cognitive system allow for better processing of information.

According to CLT,[1–4] effective learning occurs when instructions are aligned with learners' cognitive architecture. This cognitive architecture consists of a working memory (WM), which is limited in capacity and duration, that interacts with an unlimited long-term memory (LTM). New information must be processed through limited WM for learning to occur.[5,6] Successful processing of information through the WM is needed to encode and save information in the LTM. The WM's limited capacity becomes more effective when dealing with familiar material already stored in LTM in the form of a schema, which organizes and stores information in the LTM and reduces the load on the WM.

The strategies to present information and the intrinsic nature (difficulty) of the instructional materials affect the type of load that is imposed on the WM. The intellectual complexity of instructional material causes intrinsic cognitive load, whereas the strategies to present information may lead to either extraneous (ineffective) or germane (effective) cognitive load. Poorly designed instructional materials can result in extraneous cognitive load, whereas effective instructional strategies foster germane load. The sum of intrinsic, extraneous, and germane loads is equal to the total cognitive load, which should not exceed the memory resources available or learning will not be effective.[7]

Many instructional design principles have been identified to effectively decrease extraneous cognitive load and improve learning.[8] Strategies that give learners control while interacting with dynamic visualization help decrease extraneous cognitive load and increase germane load.[9] The strategies of using multiple modalities,[10] placing text and graphics according to contiguity principles,[11] and signaling or cuing emphasis[12] also help decrease extraneous cognitive load.

The aim of this study was to compare the load imposed by two instructional strategies for teaching the anatomy of the canine skeleton. We compared an interactive Web-based strategy with a paper-based strategy (e.g., textbooks). Our hypothesis was that using a computer-based format that incorporates the elements of CLT in teaching veterinary gross anatomy would be superior to using text-based format in reducing ineffective extraneous cognitive load. Data collection was guided by these research questions:

- What are the perceptions and attitudes of students toward the elements of the computer-based instructional materials?
- Does the cognitive load imposed by static paper-based instructional materials differ significantly from that imposed by interactive computer-based instructional materials when learning the anatomy of the canine skeleton?

METHODS

Educational Context

The small-animal gross anatomy course is taught in the fall semester at both Tuskegee and Auburn Universities. The course was delivered primarily through laboratory classes complemented by didactic lectures. The laboratory part of the course included the dissection of the dog and cat. Students spent around eight hours per week performing the dissection using the *Guide to Dissection of the Dog*.[13]

Design and Development of Instructional Materials

A computer-based canine osteology program (COP) was developed with structured text summarized from the course-listed references and interactive realistic images. The program's content was divided into four sections: skull, thoracic limbs, pelvic limbs, and vertebral column. Self-directed quizzes at the end of each section help students carry out self-evaluation exercises. The program's design was based on CLT principles[1,4] and the theory of multimedia learning.[14] Contiguity and signaling (cueing) strategies were implemented in the design of the computer-based materials. In the contiguity strategy,[11] textual explanation and visual material were presented contiguously to overcome split-attention effect[15] and decrease extraneous load. Cueing strategy[12] decreases intrinsic and extraneous load by providing cues that focus the learner's attention on the relevant parts of the anatomical images. Anatomical details were highlighted using overlaying colors to attract the learners' attention and focus on the specific details presented in the anatomical visuals.

Data Collection

A background survey and a two-section questionnaire were administered at the end of the fall semester.

The questionnaire evaluated students' perspectives of the educational value of a computer-based instructional program and compared the difference between cognitive loads imposed by paper-based and computer-based instructional strategies used to teach the anatomy of the canine skeleton. The paper-based materials relied on the course notes provided by instructors and two required textbooks, *Guide to Dissection of the Dog*[13] and *Textbook of Veterinary Anatomy*.[16] Section I included 17 closed-ended items that assessed the use of graphics (four items), content (six items), and the learning process (seven items). It used a Likert-type scale ranging from one (*strongly disagree*) to five (*strongly agree*). Section II included a nine-point mental effort rating scale developed by Paas[17] for measurement of the levels of difficulty of instruction after students interacted with both the computer-based and the paper-based instructional materials. Students were asked to indicate the amount of mental effort invested in each task on scale ranging from one (*very very low mental effort*) to nine (*very very high mental efforts*). The scale has been shown to be valid, reliable (Cronbach's alpha > 0.85), and unintrusive.[7,18,19]

Data Analysis

We analyzed demographic data collected by means of the background survey to gain participants' general characteristics. Means and standard deviations were calculated for the evaluation categories of the closed-end questions. The means were analyzed to obtain an overall rating of the computer-based instructional materials and to rate the use of images, the content, and the learning process. We also calculated means and standard deviations for the mental efforts recorded by the students for each of the four sections (skull, thoracic limb, pelvic limb, and vertebral column) in the paper-based and computer-based instructional materials. A paired t test with an alpha level of 0.05 was used to compare the differences between the mental efforts invested in each method of instruction (textbook vs. computer-based).

RESULTS

Eighty students from two veterinary schools volunteered to participate in this study. The protocol and design of the study was approved by both Tuskegee and Auburn Universities' Institutional Review Boards. Participants included 37 freshmen students (4 men, 33 women) enrolled in a Doctor of Veterinary Medicine (DVM) program at Tuskegee University (Tuskegee, Alabama) and 43 freshmen students (13 men, 30 women) enrolled in a DVM program at Auburn University (Auburn, Alabama). Participants' ages ranged from 20 to 25 (69 participants), 25 to 30 years (eight participants), and 31 or older (three participants). Participants had diverse educational backgrounds, ranging from three years to more than four years of college education before enrolling in the DVM program, with most (66 participants) having four years or more. Participants' computer skills were very good, with 95% of the participants indicating they had used

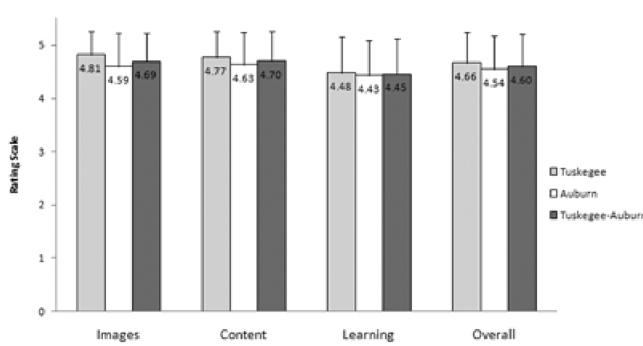

Figure 1: Students' ratings of the evaluation categories of the Canine Osteology Program on a Likert-type rating scale (1 = strongly disagree, 5 = strongly agree). Each bar represents the mean rating for each category.

Table 1: Students' evaluation of the different categories of the computer-based canine osteology program

Evaluation categories	Tuskegee University			Auburn University		
	N	*M*	*SD*	*N*	*M*	*SD*
Use of graphics						
The graphics are appropriate and relevant to the content.	37	4.86	0.35	43	4.79	0.41
The graphics are clearly labeled.	37	4.76	0.43	43	4.56	0.59
The graphics add to the instructional value.	37	4.84	0.50	43	4.63	0.58
The graphics helped me in reaching the desired instructional objectives.	37	4.78	0.48	43	4.40	0.62
Content						
The information is clearly organized and easily understood.	37	4.76	0.49	42	4.57	0.59
The content is easy to read.	37	4.86	0.42	43	4.70	0.46
The content is easy to understand.	36	4.67	0.53	43	4.74	0.49
The information on the topic is thorough.	37	4.59	0.60	42	4.19	0.92
The information is accurate.	36	4.92	0.28	43	4.81	0.45
The instructional materials are relevant to my program of study.	37	4.84	0.44	43	4.77	0.43
Learning process						
The COP is beneficial in learning the laboratory materials.	37	4.78	0.42	43	4.77	0.43
The COP is beneficial in learning the lecture materials.	37	4.32	0.75	43	4.28	0.80
The COP is beneficial in learning both lab and lecture materials.	37	4.43	0.67	43	4.44	0.67
The COP provides interactivity that increases its instructional value.	37	4.62	0.59	42	4.67	0.48
The COP accommodates multiple learning styles.	37	4.32	0.71	41	4.05	0.74
The COP and its activities hold my interest and attention.	37	4.38	0.76	43	4.28	0.59
As I used the COP, I was confident that I could learn the content.	37	4.49	0.65	43	4.51	0.63

Note: COP = Canine Osteology Program.

computers for three or more years. The student body at Tuskegee University is very diverse, with an African-American majority. The student body at Auburn University has a Caucasian majority.

The results of the closed-ended questions indicated a very high rating for the computer-based canine skeleton program by the students from both Tuskegee and Auburn Universities (Figure 1). The different evaluation categories that were used to assess the effectiveness of the computer-based instructional materials received high ratings (Table 1). Students perceived that the use of graphics in the COP was appropriate and added to the instructional value of the computer-based program. They indicated that the program's content was clearly organized and easy to understand and the program was beneficial in learning both lab and lecture materials.

The overall mean difference (1.50) between the mental efforts invested in the paper-based (6.88) and computer-based (5.38) learning methods was significant, $t = 8.26$, $p \leq .0001$, $df = 76$, for two-tailed distribution. The mean difference was also significant for all the sections of the instructional materials (Table 2). The mean difference was significant for the thoracic limb ($t = 8.71$, $p \leq .0001$, $df = 76$), pelvic limb ($t = 7.55$, $p \leq .0001$, $df = 76$), vertebral column ($t = 7.05$, $p \leq .0001$, $df = 76$), and skull ($t = 6.51$, $p \leq .0001$, $df = 76$). Similar results were obtained from the data collected from both Tuskegee and Auburn Universities (Table 2).

DISCUSSION

This study's results show an acceptance of and positive attitude toward the use of a computer-based COP, which is reflected by the students' overall high ratings. Other studies have also reported medical students' positive attitudes toward and acceptance of computerized learning of the basic sciences.[20–22] Although students' achievement scores did not differ significantly between computer-based and paper-based strategies, students perceived computer-based strategies to be better in the assimilation of anatomical information.[23] Moreover, students expressed a strong preference for the use of realistic anatomical images over black-and-white drawings. Likewise, a strong preference was evident for the dynamic labeling of the images over static labeling. In this study, students perceived that the use of realistic interactive images found in the COP are appropriate and add to the computer-based program's instructional value. They indicated that the program's content was clearly organized and easy to understand and the program was beneficial in learning both laboratory and lecture materials.

Table 2: Mean differences between the mental efforts invested in the paper-based and computer-based instructional materials

Instructional materials	N	Computer-based		Paper-based		Two-tailed paired t-test		
		$M1$	$SD1$	$M2$	$SD2$	$M2-M1$	t	p
Tuskegee University								
Thoracic limb	36	5.03	1.72	6.89	1.39	1.86	6.18	$<.0001$
Pelvic limb	36	5.11	1.89	6.75	1.40	1.64	5.06	$<.0001$
Vertebral column	36	4.94	1.72	6.61	1.27	1.67	5.15	$<.0001$
Skull	36	5.28	2.25	6.86	1.46	1.58	4.28	.0001
Overall	36	5.09	1.76	6.78	1.21	1.69	5.76	$<.0001$
Auburn University								
Thoracic limb	41	5.61	1.14	7.10	1.20	1.49	6.14	$<.0001$
Pelvic limb	41	5.46	1.27	6.90	1.24	1.44	5.61	$<.0001$
Vertebral column	41	5.54	1.42	6.78	1.31	1.24	4.81	$<.0001$
Skull	41	5.85	1.39	7.05	1.14	1.20	5.21	$<.0001$
Overall	41	5.63	1.19	6.97	1.12	1.34	5.95	$<.0001$
Tuskegee–Auburn								
Thoracic limb	77	5.34	1.46	7.00	1.29	1.66	8.71	$<.0001$
Pelvic limb	77	5.30	1.59	6.83	1.31	1.53	7.55	$<.0001$
Vertebral column	77	5.26	1.58	6.70	1.29	1.44	7.05	$<.0001$
Skull	77	5.58	1.85	6.96	1.29	1.38	6.51	$<.0001$
Overall	77	5.38	1.50	6.88	1.16	1.50	8.26	$<.0001$

In this study, the computer-based program imposed less cognitive load than paper-based materials. All sections of instructional materials (e.g., thoracic limb, hind limb, vertebral column, and skull) showed a significant difference in the amount of cognitive load imposed by the computer-based versus the paper-based materials. The difference in cognitive load indicates that the computer-based materials imposed less extraneous (ineffective) cognitive load. As indicated by CLT,[1,4] intrinsic and extraneous loads are less effective and not relevant to learning. However, effective germane load directs learners to cognitive processes that are relevant to learning. For better learning, the total load, which represents the sum of extrinsic, extraneous, and germane loads, should not exceed the WM capacity. If the total load exceeds the available mental resources, students will find it difficult to process the new information, which may be detrimental to learning. The lesser cognitive load imposed by the computer-based materials could be explained by the effective design strategies adopted to decrease extraneous cognitive load. The contiguity principle,[11] signaling or cueing,[12] and learner control[9] were the main strategies used to design the computer-based program. These strategies help in decreasing extraneous cognitive load and freeing up cognitive resources to be utilized by the effective germane load. CLT emphasized the alignment of the novel information with the novice cognitive architecture.[1] That is, the novel information should be communicated to the learner at the right grain size.[24] Therefore, understanding the types of cognitive load and how they affect the way in which people process new information is important.

In addition to the positive effects of computer-based learning materials in decreasing ineffective cognitive load, the dynamic labeling and the embedded quizzes in the COP provided the opportunity for self-testing and questioning, a process used by expert learners.[25] Expert learners use self-testing to monitor the progress of their learning and to decide whether they need further practice to master the learning objectives. This study's results encourage institutions to transition to more computer-based instructional strategies in teaching complex subjects such as veterinary gross anatomy and to adapt their teaching methods to accommodate millennium students' needs. Implementation of these strategies fits nicely with our current policy that encourages freshman to use computers in the class and focuses less on paper notes.

CONCLUSION

The strategies used to present information affect the type of cognitive load imposed by instructional materials on the learner's WM. These design strategies should be analyzed from a cognitive load perspective that considers the WM's limitations. Careful attention is needed when introducing novel information to novice learners. Design strategies should be based on cognitive load principles that focus on decreasing ineffective, extraneous cognitive load and increasing effective germane load. Computer-based instructional modules that introduce novice learners to basic information in a simple, concise, and interactive way help in the processing of additional information. Because extensive details in textbooks can be overwhelming for novice students, an introduction with computer-based modules would be helpful to facilitate additional learning from textbooks.

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