Optimizing Physicians' Instruction of PACS Through E-Learning: Cognitive Load Theory Applied

P. Devolder, B. Pynoo, T. Voet, L. Adang, J. Vercruysse, and P. Duyck

This article outlines the strategy used by our hospital to maximize the knowledge transfer to referring physicians on using a picture archiving and communication system (PACS). We developed an e-learning platform underpinned by the cognitive load theory (CLT) so that in-depth knowledge of PACS' abilities becomes attainable regardless of the user's prior experience with computers. The application of the techniques proposed by CLT optimizes the learning of the new actions necessary to obtain and manipulate radiological images. The application of cognitive load reducing techniques is explained with several examples. We discuss the need to safeguard the physicians' main mental processes to keep the patient's interests in focus. A holistic adoption of CLT techniques both in teaching and in configuration of information systems could be adopted to attain this goal. An overview of the advantages of this instruction method is given both on the individual and organizational level.

KEY WORDS: Informatics training, computer-assisted instruction, PACS training, clinical image viewing, cognitive load theory, e-learning

BACKGROUND

The initial deployment of a picture archiving and communication system (PACS) in a hospital has considerable impact on work methods of all physicians who utilize it. The extent of its effect has been reported pertaining to the new way of working of radiologists^{1,2} and other hospital physicians.³ The referring physician can be seen as the end-user, a valuable stakeholder in the PACS process, one that is indispensable for making the filmless transition a success.

This digital work flow of radiology⁴ poses new challenges and opens up new possibilities. In days

gone by, film arrived by mail and could be treated like any other physical object. With a digital way of working, radiological information is presented in a digital format, making the procurement of radiological information less tangible. So, not only the radiologist but also the referring physician has to acquire new skills and learn new tools to be able to extract the same amount of information (or more) from the now digital radiological images. Moreover, the referring physician has to adopt a new paradigm of thinking. Images are no longer situated in the physical world but can now be found in the abstract realm of electronic data. Regardless of the technological way the images are transferred to the requesting physician (internal network, HIS-integration, Web), there are a number of operations the physician has to perform to depict the radiological images. Because in most cases these operations are new to the physician, training should be supplied. In our 1,169-bed hospital which employs about 4,800 people (600 physicians, 1,700 nurses,...), providing this training was a challenge and scale effects could easily have jeopardized it.

From the Department of Radiology, Ghent University Hospital and Ghent University, De Pintelaan 185, 9000 Ghent, Belgium.

Correspondence to: Pieter Devolder, Department of Radiology, Ghent University Hospital and Ghent University, De Pintelaan 185, 9000 Ghent, Belgium; tel: +32-9-3325875; fax: +32-9-3324421; e-mail: Pieter.Devolder@uzgent.be

Copyright © 2007 by Society for Imaging Informatics in Medicine

Online publication 13 November 2007

doi: 10.1007/s10278-007-9089-5

PACS and IT Infrastructure

The initial PACS installed was a General Electric (GE) Centricity PACS version 2.0 CRS5 SP2. The system can be considered full-featured, including advanced 3D possibilities and a web viewing solution for referring doctors.

PACS' implementation commenced in May 2004 with actual radiology integration and go-live in March 2005. The visible side of PACS for non-radiologists at the time was GE Centricity Enterprise WEB 2.0 (version at the time of writing: GE Centricity Enterprise WEB 2.1 SP06a). The web viewer was deployed on July 26th 2005 as an integrated add-on to the hospital information system (HIS) and is connected to it through a patient-based integration. The web application is ActiveX-based, connects directly to the main PACS database, and retrieves images from the PACS' central image repository, guaranteeing full access to all available imagery. Requesting doctors access HIS and PACS with hospital standard desktop personal computers ranging from older Pentium III-class machines to more recent hardware using various versions of the Microsoft Windows operating system. Non-Windows personal computers (non-standard hospital equipment) can be configured to access PACS by using a Citrix Presentation Server environment. Before the installation, all PCs were upgraded to meet the minimum requirements for the PACS web viewer. Older models were replaced or were upgraded to a new operating system (at least Windows 2000). Web browsers were upgraded to Internet Explorer 5.5 or higher.

Training Issue

One of the key concerns of our radiology service's management was that requesting physicians would not use the full potential of the new tools handed to them. Consequently, it became a priority to deliver a learning method where physicians could be trained in, and familiarized with, using PACS. This concurs exactly with the rationale for providing PACS training mentioned in Protopapas et al.⁵

Both an auditorium presentation and hands-on training sessions were considered as potential training methods. They were deemed impractical

respectively for reason of overly full physicians' agendas or unachievable amounts of time to be spent by the PACS project team. The above issue compelled us to develop a digital learning environment accessible both from within PACS and from the hospital intranet. Furthermore, it was envisioned that the learning environment had to be easy to use, yet had to cover all functionality of PACS. Cognitive load theory (CLT) was applied to fulfill the above prerequisites.

COGNITIVE LOAD THEORY

Learning puts strain on the mental processes of the learner. Thus, learning how to use a software application to review radiological images can be considered a mental burden for the requesting doctor. Cognitive load theory, introduced by Sweller and Chandler⁶ models different types of strain that occur when people learn. The application of the concepts resulting from the extensive research on the subject of cognitive load ensures the construction of a learner-friendly instruction system which maximizes learners' gains while minimizing mental effort. Mental strain appears when the human cognitive architecture processes mental tasks. CLT supposes a human cognitive architecture consisting of working memory and long-term memory.

Working memory is of a limited nature, both in capacity and in time. It can only keep a certain number of cognitive elements of information in focus. If this information is not refreshed, it is forgotten after some time. Next to temporarily storing information elements, working memory also processes this information, e.g., by associating interacting elements with each other.

As a result, multiple elements of information are combined into schemas in working memory and consequently stored in long-term memory. Schemas are groups of cognitive elements amalgamated together so that working memory sees them as a single information element. An example of this is the way most people perceive cars. An inner mental concept exists so that additional reasoning like—"This object has four wheels on the outside and a steering wheel on the inside so it must be a car"—is made to be obsolete. Much in the same way, lower order schemas can be combined into higher order schemas which take up less working

memory space. This process results in schemas of different order being stored in long-term memory.

Furthermore, schemas can be used either consciously where the schema is imported in the working memory or unconsciously where the schema is automatically executed. Ordinarily, the second method, schema automation, can only be achieved with practice. This makes schema automation the cognitive counterpart of the adagio, practice makes perfect. An example used in this context is learning to drive a car. The beginning driver needs to consciously import all necessary actions for driving (shifting gears, braking, accelerating,...) into working memory and process each one, whereas proficient drivers unconsciously execute them all.

Cognitive load appears when working memory processes elements of information. In a learning situation, this cognitive load can originate from different sources. CLT therefore distinguishes three types of cognitive load:

- Intrinsic load
- Extraneous load
- Germane load

The intrinsic cognitive load is inherent to the material to be learned. It is connected to the complexity of the presented material, i.e., the number of interacting elements in working memory. Interacting elements amplify cognitive load because working memory has to retain all elements while using its remaining memory space for building a schema of the entirety of interacting elements. For example, if we present the clinician with dozens of new image manipulation tools while introducing new terminology and new concepts, a high intrinsic cognitive load is likely.

Extraneous cognitive load is the strain put on mental processes either caused by the manner of presenting the material or because of extra non-significant items incorporated in the learning material. Designing efficient instructional environments relies heavily on its decrease.⁷ So, the use of plain text as a method of instruction can result in high extraneous load when compared with a visual representation of the same material.

Germane load is the cognitive load of processing the learning material and interpreting the links between the different information elements contained therein. It is the cognitive load linked with the construction of mental schemas.

CLT asserts that the sum of the above cognitive load types cannot exceed working memory limits if learning is to take place.⁷

We apply the concepts of CLT to the e-learning environment to reduce the mental burden of learning the features of web-based image viewing. Hence, the learning potential is maximized.

Levels of Cognitive Load

Cognitive load occurs when mental tasks are executed. Specifically, when learning, we can distinguish different levels that cause cognitive load. In our setting, the aim is to impart knowledge on the use of PACS by hospital physicians.

The intrinsic load is linked to the actual learning to use PACS and its tools whereas extraneous load is connected to the way PACS' instruction material is presented. Germane load is generated while the learner constructs mental schemas of PACS usage and its tool behavior. This is depicted in the middle part of Figure 1.

When using a digital learning environment as training method to convey knowledge regarding

Fig 1. Levels of cognitive load. The figure's columns depict three mental tasks: the (high level) medical task, the learning-to-use-PACS task, and the learning-to-use-e-learning task. Every task has intrinsic load inherent to the material to be learned, extraneous load due to the presentation of the material or superfluous material, and germane load due to the processing of the learning material. Hierarchically, the PACS task is extraneous to the medical task, and the e-learning task is extraneous to the PACS task, which provides the incentive to lower overall extraneous load.

PACS, the presentation of the necessary information causes extraneous load in learning PACS. Before being able to fully use the e-learning system, the learner has to be familiarized with the concepts underpinning the e-learning system. This learning of using the e-learning system again comprises the three different cognitive load types. This is shown on the right of Figure 1.

Symmetrically, we remark that learning to use PACS can be considered as part of the extraneous load of a higher (learning) task, as illustrated by the left side of Figure 1. All three cognitive load levels mentioned above should be subjected to the universal CLT tenets.

The medical intrinsic cognitive processes should be safeguarded as much as possible. Accordingly, it is important that all extraneous load is minimized as much as possible. As can be seen in Figure 1, PACS' intrinsic load is essentially part of the upper level's extraneous load. The intrinsic load of PACS is caused mainly by the vendor's choice of user interface. Mostly, the user interface can be tweaked and configured; however, major changes cannot be attained easily. This makes PACS' intrinsic load inherent to the choice of PACS vendor and to the configuration skills of the PACS implementation team.

Load Reduction Techniques

The digital learning environment is a form of multimedia-based learning. Multimedia learning opens up new ways to present instruction material to the users.

Extensive research has been conducted in an attempt to reduce cognitive overload in multimedia learning. Mayer and Moreno⁸ define five types of cognitive overload and propose nine ways to reduce load in these categories. The auditory channel is not applicable to this version of the e-learning system, so four types of cognitive overload and six propositions for reduction of cognitive load remain viable.

We distinguish the following cognitive load reduction methods (adapted from Mayer and Moreno⁸):

- *Segmenting*: present the information in bite-size segments; let the learner control the time lag between these segments
- *Individualizing*: accommodate for different amounts of learner experience

- *Pre-training*: offer the learner a sneak preview of the characteristics and terminology of the different components
- *Weeding*: eliminate interesting but extraneous material
- *Signaling*: emphasize the most important aspects of the lesson
- *Aligning*: present printed words close to the corresponding graphic material.

APPLICATION OF COGNITIVE LOAD THEORY: CONSTRUCTING THE E-LEARNING ENVIRONMENT

The digital learning environment was created using Microsoft PowerPoint 2003. An interactive presentation was built so that users can navigate through it. To avoid an excessive load time, the complete presentation was exported to HTML format. Navigation features like clickable buttons and/or interactive elements within the presentation were retained. The resulting HTML files were put on the PACS web server and were made accessible from within the web viewing application and from the hospital intranet. The opening screen of the digital learning environment can be seen in Figure 2. The load-reduction techniques described above are applied and will be discussed according to their occurrence.

Segmenting

Information on PACS is presented slide after slide so the learner can decide when to switch to the next slide. Information contained on one slide is aimed to be self-explanatory and addresses a single (sub)topic. Slides are set up so that all information is visible at a single glance without the need for scrolling inside the page. The segmentation effect as described by Mayer and Moreno is specifically triggered by this way of presenting information.

The buttons provided at the bottom of every slide offer the possibility to navigate through the presentation and are designed to be intuitive and flexible. This way, the user can control the time lag between different slides, go back and forward, and jump to specific parts within the presentation. These different parts are explained below.

Fig 2. The opening window of the e-learning environment depicts five choices: an introduction to the concept of PACS, instructions for use of the e-learning system, an entry point to the actual training, a link to the index of different topics, and a “New”-button linking to changes since previous versions of the e-learning environment. The e-learning system is invoked from within the PACS web viewer by clicking the question mark button.

Individualizing

The structure of the e-learning system, shown in Figure 3, provides people of all previous experience levels with a personalized path to learn to

work with PACS. The arrows in Figure 3 represent links between the different slides.

Three horizontal structures can be distinguished. These structures can be seen as the different pathways one can follow when learning to work with

Fig 3. Structure of the e-learning environment. This figure shows how different slides of the e-learning system link to others. *Full arrows* depict the navigation that is possible on every slide. *Dashed arrows* depict how slide-specific links to other slides are available for flexible information retrieval. The *horizontal lines* show pathways dependent on user experience through the system. In the index, a specific topic can be selected; the essential path gives summarized information, whereas the detailed path goes into the details of each topic. Seamless transition between the three levels is possible.

PACS. From top to bottom, we discern the index from where every topic can quickly be accessed, the essential path where only the necessary functionality is explained, and lastly a detailed pathway of how PACS functions.

Starting from the index, which is illustrated in Figure 4, links generally point to slides of the essential pathway. These give an overview of the topic that was selected without going into details. If more information is needed, one can then seamlessly follow the more detailed path.

Given the personal level of previous experience of the users, they can choose to either enter the e-learning system from the beginning or by selecting a specific topic about which they wish to know more from the index. When entering the system from the beginning, one can again choose to follow the essential path where the specific inner workings are left to be discovered by the user or one can choose to immediately start with the detailed pathway.

Because of the possibility to switch from the essential pathway to the detailed pathway at all

times during the learning session, it becomes possible for the learner to adapt the learning session to his wishes.

Together, the three pathways (including the index) cover the complete spectrum of learners' previous experience, as adept users looking for a refresher course can simply look up the function of their wishes in the index; computer-minded users can follow the essential pathway and be presented with a concise way of getting to know all functionality. Nevertheless, users with little to no computer experience can benefit from the extensive information found in the detailed pathway. They are guided step-by-step, where all actions to be taken are explained and where possible, depicted graphically.

Pre-Training

The structure itself of the e-learning system comprises a pre-training method. The occurrence of overview slides in the essential pathway through the e-learning system can be seen in this context. These

Fig 4. Index slide of the e-learning environment. It offers the possibility to select the topic of interest.

slides show in essence what will be explained in the detailed slides. This way, the learner becomes acquainted with the goal of the following slides and develops mental awareness of what concepts will be handled accordingly. Thus, a reduction of the germane load of learning to use PACS is obtained. The left screen of Figure 5 shows an overview screen which is part of the essential path. It explains that in the following slide, both the "Pictorial index" and the "Worklist" items will be discussed.

Pre-training is also used when the concepts and functionality of the e-learning system are explained at the start of a learning session. By providing the learner with the behavior of the different buttons within the e-learning system, its concepts are introduced before they have to be actually used. This lowers the germane cognitive load of working with the e-learning system.

Weeding and Aligning

The concept of both weeding and aligning has been thoroughly applied in Figure 5. It shows two consecutive slides from the e-learning system explaining basic PACS interface layout. The left slide is part of the essential pathway, whereas the right slide is part of the detailed pathway. The right slide focuses directly onto the worklist feature while grayling out the rest of the window informa-

tion. This gives the learner the opportunity to concentrate on what will be explained in more detail. The cutting away of extraneous information, weeding, which would otherwise complicate the visual image offered to the learner, renders the remainder calmer and removes visual clutter. This results in a lower extraneous load of learning the use of PACS.

The aligning technique is used in conjunction with the above method. As mentioned, cognitive load diminishes when related images and text are presented close to each other. This is illustrated on the right side of Figure 5 where weeding has made the extraneous material invisible and where the relevant text concerning the remaining visual image is presented close to this image. This way, two effects can be achieved. First, unnecessary visual scanning is eliminated by combining text and images, and second, no mental processing is necessary to handle the unnecessary visual information.

Signaling

The important aspects of the current slide are highlighted using a red box. The occurrence of this bright colored rectangle draws the attention to the information contained therein. The left side of Figure 5 uses this technique to highlight specific pieces of information.

Fig 5. Two consecutive slides: the *left slide* is part of the essential path, the *right slide* is part of the detailed path. The essential path explains that there are two parts of the PACS interface, pictorial index and worklist, whereas the detailed path goes into the detailed working of the worklist part (one slide shown out of four available).

E-Learning System

The resulting e-learning system closely adheres to the CLT concepts. The dynamic presentation consists of 126 separate and dynamic slides. All functionality, tools, and features of PACS are discussed and explained. The e-learning system is integrated into the PACS web viewer and can be accessed by clicking the question mark button. This integration can be seen in Figure 2.

DISCUSSION

Adoption of CLT

In this article, the authors try to acquaint the reader with the concepts of cognitive load theory. We believe that by taking the learners' interests at heart, we are able to produce a more robust training system which heightens the possibility of knowledge transfer with minimal mental effort for the learner. It is our understanding that in a complex environment like the healthcare environment, it is imperative that the main actors, the physicians, are safeguarded from extraneous cognitive load. This is especially important, as it is in the patient's interest that all attention is directed toward his problems and not to the mental task of what actions are to be taken to show the radiological images on the computer screen.

We believe that it would be wise to adopt CLT techniques in other healthcare training schemes so that the physician's mental effort is directed where it is supposed to be most beneficial.

Furthermore, not only training systems should be subjected to CLT techniques. If possible, any extraneous load to the medical mental processes should be avoided. It is therefore imperative that a PACS or any other healthcare information system is scored regarding the mental effort needed to operate it. To maximize available working memory, an assessment program should be set up before the procurement of information systems.

Advantages

The use of the e-learning has advantages which can be situated on the personal level. The system is accessible at all times from every hospital-supplied

computer on campus (and off campus through secure virtual private network). This way, physicians can use it on their own time, eliminating the need to reschedule their agendas to fit in PACS lessons while they can absorb the information at their own pace.

On an organizational level, once the e-learning environment has been developed and deployed, the organization no longer has to invest time and resources in providing training.

However, using a digital learning environment puts the responsibility for learning with the individual physician.

Future

Further steps in researching CLT concepts in the healthcare environment are necessary. Next to the development of a program for cognitive load assessment in healthcare software mentioned above, another possible research path is testing whether the proposed e-learning system effectively diminishes cognitive load and whether knowledge transfer is heightened. Additional research on the e-learning system will encompass a feasibility study of the inclusion of audible information.

CONCLUSION

An approach to instructing physicians on working with PACS by means of a cognitive load based e-learning environment was constructed. The application of CLT techniques ensures that the mental effort necessary to process the new information is minimized. Thus, physicians are not required to spend large amounts of time studying the new functionality. The different load-reducing techniques provide a basis for structuring both content and visual presentation.

The use of a digital learning environment leads to personal advantages for the learning physician while on an organizational level providing instruction does not become a continuous effort.

Ultimately, we posit that the adoption of CLT techniques both in educational setting as in production environments could lead to diminishing mental load levels for physicians; a result that can only be beneficial for both patient and physician.

ACKNOWLEDGMENTS

The authors would like to acknowledge Prof. dr. E. Mortier of the Ghent University for his valid comments regarding the study.

REFERENCES

1. Reiner BI, Siegel EL, Hooper FJ, Pomerantz S, Dahlke A, Rallis D: Radiologists' productivity in the interpretation of CT scans: a comparison of PACS with conventional film. *Am J Roentgenol* 176:861–864, 2001
2. Lepanto L, Pare G, Aubry D, Robillard P, Lesage J: Impact of PACS on dictation turnaround time and productivity. *J Digit Imaging* 19:92–97, 2006
3. Reiner BI, Siegel EL, Hooper F, Protopapas Z: Impact of filmless imaging on the frequency of clinician review of radiology images. *J Digit Imaging* 11:149–150, 1998
4. Reiner BI, Siegel EL: The Cutting Edge: Strategies to enhance radiologist workflow in a filmless/paperless imaging department. *J Digit Imaging* 15:178–190, 2002
5. Protopapas Z, Siegel EL, Reiner BI, Pomerantz SM, Pickar ER, Wilson M, Hooper FJ: Picture archiving and communication system training for physicians: lessons learned at the Baltimore VA Medical Center. *J Digit Imaging* 9:131–136, 1996
6. Sweller J, Chandler P: Why some material is difficult to learn. *Cogn Instr* 12:185–233, 1994
7. Sweller J, van Merriënboer JJG, Paas FGWC: Cognitive architecture and instructional design. *Educ Psychol Rev* 10:251–296, 1998
8. Mayer RE, Moreno R: Nine ways to reduce cognitive load in multimedia learning. *Educ Psychol* 38:43–52, 2003