Multilayer model for on-line learning resources based on cognitive load theory

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ABSTRACT: Learning interaction is a two-way exchange of communication by which the learners obtain, interpret and challenge points covered in the learning. As a major means of knowledge transfer, good learning interaction can facilitate the learners' learning outcomes. In the on-line learning process, the interaction between learners and learning resources is the most important interactive mode. However, the lack of interactive elements in the design of existing on-line learning resources leads to a higher cognitive load for learners during the process and the learning outcomes are hard to guarantee. The work outlined in this article was based on cognitive load theory. Analysis of the deficiency of instructional design in on-line learning resources is presented. Also put forward is an open and interactive e-learning multilayer model and a human machine interface design that can be achieved by applying focus and context methods from visualisation technology. This enhances the interactivity of on-line learning resources and reduces the cognitive load of the target learners.

INTRODUCTION

On-line learning is a crucial learning method and an effective way for people to obtain knowledge and realise lifelong study in the era of knowledge economy. On-line learning refers to a learning interaction where the learner uses the Internet to access learning resources and interacts with other learners and teachers on-line [1]. Three common interactions in the e-learning process are: interaction between learners, between learners and teacher, and between learners and learning resources [2].

Some suggest that interaction between learners and learning resources can also be classified as interaction between learners and the teacher, given that the teacher is the one who designed the material [3]. However, existing Web-learning resource design lacks interactivity as a consideration. Most are just simple copies of paper textbooks with a simple interface design and no deep content. This fails to fully exploit the advantages of hypermedia learning or form an effective learning interaction. As a result, learners have a high cognitive load during the learning process and learning outcomes are not guaranteed.

The work reported in this article is based on cognitive load theory. The deficiency of instructional design in on-line learning resources is analysed first. Subsequently, proposed is an open and interactive e-learning multilayer model and a human-machine interface design. Focus and context methods from visualisation technology are deployed to enhance the interactivity of on-line learning resources and reduce the cognitive load of the target learner.

COGNITIVE LOAD THEORY

Cognitive load theory was first proposed by John Sweller, a cognitive psychologist from the University of New South Wales, Australia, in 1988 [4]. This theory mainly was developed from working memory research in psychology. It states: working memory capacity is limited, while long-term memory is infinite in nature; the learning process requires learners to actively understand (and process) learning materials within the working memory and, then, store the information learnt or schema into long-term memory; learning will become ineffective in case of working memory overload. Three basic factors contribute to cognitive load in people: the previous experience of the individual, the essential characteristics of the learning materials, and the organisation and presentation method of the content.

Cognitive load theory derives instructional design principles from aspects of the cognitive architecture [5]. Cognitive load can be divided into three types based on its source: intrinsic, extraneous and germane. Intrinsic cognitive load depends on the complexity of materials; how many elements are involved and how they interact with each other. The more elements and more complicated the interactions, the higher the intrinsic cognitive load [6].

Extraneous cognitive load depends on the instructional method, material organisation and presentation method. With a poor instructional design and bad presentation method, users have to process non-relevant content, which leads to an increased extraneous cognitive load. Germane cognitive load is related to individual subjective information, which refers to the quantity of mental cognitive resources learners are willing to devote during schema acquisition and automation process. It is related to the cognitive efforts of learners. By decreasing the germane cognitive load, users can use the remaining cognitive resources for in-depth cognitive schema acquisition. It is a tool for schema acquisition and automation [7].

After 20 years' development, cognitive load theory has become a crucial psychological theory by which to guide instructional design after constructivism theory. The research direction is moving from the traditional learning field, where paper is the medium to Web-based learning [8].

ISSUES OF INSTRUCTIONAL DESIGN FOR ON-LINE LEARNING RESOURCES

Learning resource is one of several research subjects of education technology. Research related to Web site learning resource has been the focus of education technology. In China, the research and construction of Web-based learning resource has been carried out from early days, but its effect when used is not ideal [3].

One of the main reasons is lack of guidance in theory for network learning resource instruction, as well as big gaps between instructors of education technology knowledge. Incomplete content and inappropriate interface design impact on learning behaviour during the interactive learning process and result in low utilisation of on-line resources. From the aspects of interactivity and cognitive load theory, the main design issues of existing on-line resources are outlined below.

No Consideration for the Previous Experience of the Individual

Cognitive load theory suggests that prior experience of an individual is an important factor affecting the cognitive load. For e-learning, the prior computer experience, learning styles, learning base and background knowledge of the learner will have a great impact on learning outcomes [9].

Since on-line learning is open learning, anyone can log in to the platform to learn a course. However, the differences between individuals' experience will make many learners feel an extra burden of cognitive load, which will affect their learning outcomes [10].

Currently, the design of most of the on-line learning materials has no in-depth consideration of these factors. There is no classification of learners and inconsistent interface design. It does not deal effectively with different learning needs of individuals, which affects learning performance and user experience.

Lack of Background Introduction and Sufficient Case Studies

Constructivism suggests learning is not to copy the information contained in knowledge into people's memory, but is a process of knowledge construction [11]. In the traditional classroom teaching mode, the instructor uses various methods, such as background knowledge and examples, to guide learners through the knowledge construction of key points. By contrast, the current on-line resources are generally just transported from the textbook to the Web site, i.e. it is simply a *textbook relocation*. Without a background introduction or case studies, such material is highly likely to trigger an interruption in learning. Learners might stop current learning and seek help by searching on-line, which will increase the extraneous cognitive load. Segers and others have studied the harmful effects of learning interruption [12]. An on-line learning outcome experiment required a division of 229 students into two groups. One group was allowed to use Google searches during the study, while the other was forbidden it. The test result shows the group without access to the search function had the better performance [12].

Shallow Learning

Chen Lin et al state that …*Currently on-line learning [seems to have gained] a superficial understanding … For the majority of on-line learners, e-learning is ... shallow learning* [13]. Shallow learning is in contrast to deep learning. These refer to the cognitive level of the learner in memorising and understanding. If the learner passively accepts learning content, memorises and duplicates what was learnt without deep understanding, then, this is shallow learning. In this case, the learner easily can, and soon, forget what has been learnt. Most on-line learning resources only support shallow learning mainly because there is no consideration for the different levels of learners; there is a lack of in-depth content or of structural layers. The information is quite simple and superficial, and often is just partial information. Therefore, the learner cannot obtain the knowledge required for deep learning on-line.

Content isolation

Most on-line learning resources address one specific course (such as the Excellent Courses Web site), with few effective connections to related courses. However, in real learning, a series of courses have close interrelationships.

Take computer series courses as an example. There is strong orderliness of learning and dependency among courses. For example, many concepts of an operating system course are from a data structure course. During classroom teaching, the instructor usually brings together the relevant concepts from all the related courses. By comparison, while learning on the Web, the learner has to rely on Web searching to discover relevant concepts from related courses. This will create cognitive overload for the learner and influence his/her performance.

Cognitive Overload Caused by Information Presentation

During learning, a human being actively constructs meaning. Correlation, comparison and context are used to understand knowledge and to discern meaning. In the classroom, the teacher uses a variety of teaching methods to help students with construction of meaning and to find the organisational structure of the content of learning, e.g. process, compare, list and classify. By contrast, during on-line learning, the learner themselves must summarise, if the content structure is not clear from the presentation of the material. This, obviously, will increase the cognitive load on the learner.

There is no uniform standard in terms of interface and interactivity design for on-line learning systems and, there are problems in the presentation method of learning materials, viz. key information not highlighted, inconsistent interface controls and no effective operation feedback to users. These seriously damage user experience and increase their extraneous cognitive load.

MULTILAYER MODEL FOR NETWORK LEARNING RESOURCES

Design Principles for On-line Learning Materials

In order to enhance the interactivity of on-line learning resources and reduce the cognitive load of the learner during learning, on-line learning resources design should adhere to the following principles:

- Show the key information in a clear and concise way, and present the organisational structures and contexts of the learning materials through the interface design.
- Have deep content to meet the needs of learners at different levels and, hence, provide a deep learning opportunity.
- Follow multimedia learning and human-machine interactivity theory to design the human-machine interface and support visual feedback of operations.
- Provide an open learning resources framework to allow learners to participate in the materials construction and improve the resource quality through collaboration.
- Allow learners to exchange opinions on the learning experience and evaluate the material.

Future learning resources could be open architecture. After completion of the initial construction of the learning resources by the teacher, learners could amend and improve the content through collective collaboration during the course.

Collaborative construction of on-line materials is not new. Both Baidupedia and Wikipedia are built in this collaborative way. This allows the user to participate in the editing and amendment of material. The success of the on-line encyclopaedia model shows that a collaborative operation can enrich the content, remove errors and, hence, make the resource more complete and correct. As a result, an open resource framework is a main guiding principle in on-line resources design.

Multilayer Model for Network Learning Resources

There is a huge amount of learning resource on-line. However, most are just simple copies of print textbooks and lack depth and interactivity. Hence, the advantages of hypermedia learning resources have not been fully exploited. The goal of the work reported in this article was to change the single layer structure of key learning points into a multilayer structure by using advanced information technology to add background information, case studies, other relevant information and a communication module to the base of existing learning materials.

This multi-level structure model of on-line learning resources is open, allowing the addition of new levels for resource expansion. The specific framework is shown in Figure 1a. During learning, the learner can access other layers through the learning content and key points become the connections between different layers as shown in Figure 1b.

For example, the learner can click the hyperlink for key point A and access the background information in the background layer; the case study information in the case study layer, the correlation information in the relevant information layer with the correlation in the context (process, compare, list and classify, etc) and communicate with other learners in the exchange layer. It is very easy for hypermedia learning resources to use this type of multilayer structure.

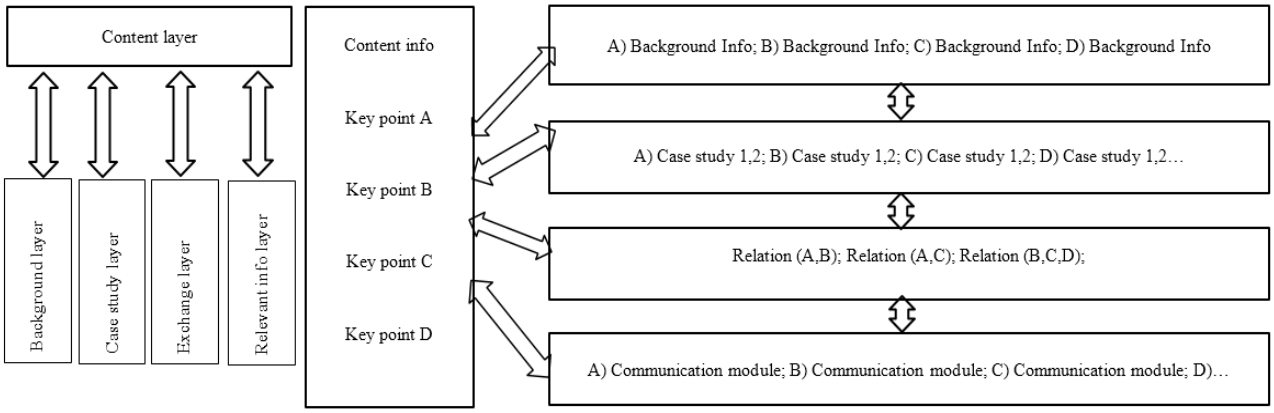

Figure 1: Multi-layer model framework and application for on-line learning resources, a) multi-layer model framework; and b) multi-layer model application diagram.

Human-machine Interface Design for the Multilayer Model

The design of the human machine interface for on-line resources must follow the multimedia learning and human machine interactivity principles. Here is offered one interface design proposal based on the multilayer model. Others are possible, but space does not allow more than one, which nonetheless serves as an example.

When the learner needs to access the key information layer, it is not necessary to present all the layers for the user to selectively choose which layer is required. The easiest way to switch between pages is through Web links. For example, the learner can click the key point A link and, then, switch to the background information for this point. However, it will increase the cognitive load of the learner, who has to use his working memory to navigate the pages [14].

Meanwhile, after the switch, the learner may lose the context of the key points and have to use working memory for the links. Besides, from the cognitive psychology point of view, human beings tend to keep the entire information visible during the partial exploration and analysis [15]. As a result, when the user accesses information from other layers, it is better to avoid the page flipping and maintain the context of the key points.

The multilayer on-line information model discussed here would use focus and context technology. Focus and context technology is an important visualisation technology. It can show the focus of a user and the relevant context in the same display area, and can automatically zoom in and out based on the focus intensity of the user [16].

Many experiments show that focus and context technology can reduce user cognitive load and improve the efficiency of a visual information search. Specifically, to define the key words in the learning content, when the learner clicks the focus links, layer information of this point is zoomed in and the learner can switch quickly among multiple layers and view its content in the tag menu format, without flipping the pages. Figures 2 and 3 show the diagram developed by jQuery. When the user clicks the key word *telephone*, as in Figure 2, a new sub-window is popped up, with a tab menu on the current page and shows the multi-layer information for the user to switch as in Figure 3.

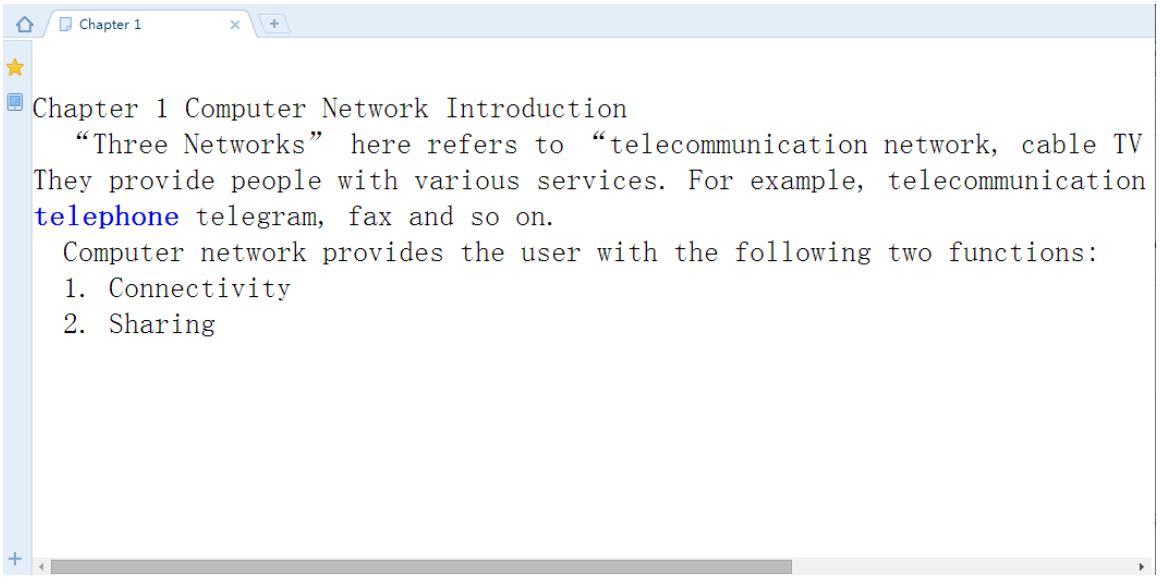

Figure 2: Interface of on-line resources; focus (key points) highlighted.

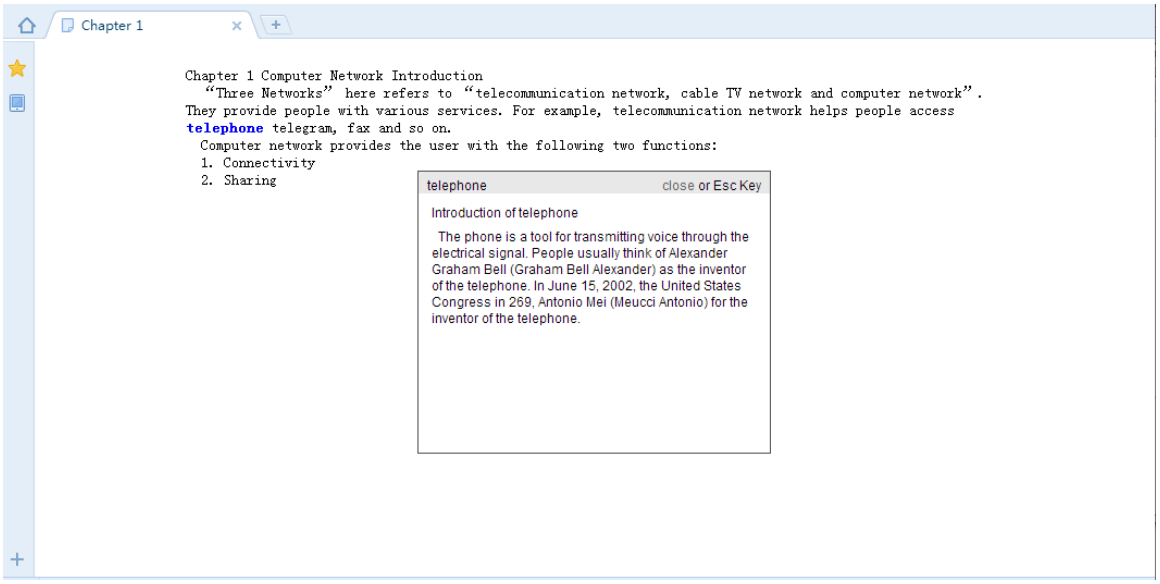

Figure 3: Multi-layer information after the user clicks the focus (*telephone*).

CONCLUSIONS

Learning is a two-way exchange of communication by which learners obtain, interpret and challenge some of the points covered. It is the key component of the teaching process and an important method of knowledge transfer. During Web-based learning, interactivity between learners and learning resources is the most common interaction mode. However, the existing on-line materials lack interactivity and learners have a high cognitive load and low performance.

It is believed that using the open and interactive multi-layer model to construct on-line materials will meet the potential interactivity needs of learners, enrich the content, reduce the cognitive load and improve efficiency. The use of mature information visualisation technology for the human machine interface will provide a highly efficient and intelligent presentation.

The recommendation from this work is the use of focus and context technology to present multilayer materials, reduce unnecessary page switches and decrease working memory load. This is also applicable to the spatial proximity principle of multimedia learning theory.

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