Computer-based teaching module design: principles derived from learning theories

K H Vincent Lau

CONTEXT The computer-based teaching module (CBTM), which has recently gained prominence in medical education, is a teaching format in which a multimedia program serves as a single source for knowledge acquisition rather than playing an adjunctive role as it does in computer-assisted learning (CAL). Despite empirical validation in the past decade, there is limited research into the optimisation of CBTM design. This review aims to summarise research in classic and modern multimedia-specific learning theories applied to computer learning, and to collapse the findings into a set of design principles to guide the development of CBTMs.

METHODS Scopus was searched for: (i) studies of classic cognitivism, constructivism and behaviourism theories (search terms: 'cognitive theory' OR 'constructivism theory' OR 'behaviourism theory' AND 'e-learning' OR 'web-based learning') and their sub-theories applied to computer learning, and (ii) recent studies of modern learning theories applied to computer learning (search terms: 'learning theory' AND 'e-learning' OR 'web-based learning') for articles published between 1990 and 2012. The first search identified 29 studies, dominated in topic by the cognitive load, elaboration and scaffolding theories. The second search identified 139 studies, with diverse topics in connectivism, discovery and technical scaffolding. Based on their relative representation in the literature, the applications of these theories were collapsed into a list of CBTM design principles.

RESULTS Ten principles were identified and categorised into three levels of design: the global level (managing objectives, framing, minimising technical load); the rhetoric level (optimising modality, making modality explicit, scaffolding, elaboration, spaced repeating), and the detail level (managing text, managing devices).

CONCLUSIONS This review examined the literature in the application of learning theories to CAL to develop a set of principles that guide CBTM design. Further research will enable educators to take advantage of this unique teaching format as it gains increasing importance in medical education.

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INTRODUCTION

The computer-based teaching module (CBTM) is a teaching format that has gained prominence in the last decades, in which a self-contained lesson is delivered in a computer multimedia package, without the complementary classroom component that is traditional in computer-assisted learning (CAL).

The efficacy of the CBTM in medical education has been validated by several randomised controlled trials in the past decade. Compared with the faculty-led lecture, small-group format or self-study, the CBTM has been found to have improved[1–4] or at least comparable[5–7] teaching efficacy. The CBTM has been validated in the fields of psychiatry,[1,6] dermatology,[2] genetics[7] and the teaching of procedures.[5] Although individually robust, these studies involved heterogeneous topics, design methodologies and outcome measures. It remains unclear under which circumstances the CBTM is best implemented in undergraduate and graduate medical education.

In theory, the CBTM offers significant advantages over traditional teaching modalities, which include increased learner convenience, a learner-set pace, individualised interactability, a one-time resource cost and potential dissemination across institutions. However, the CBTM also poses unique challenges. It has been demonstrated to be considered less engaging by learners as a result of its lack of human interaction.[6] Learners have also reported lower levels of confidence with new knowledge, possibly attributed to uncertainty if learning is misdirected in the absence of human validation.[1] Perhaps the greatest challenge to CBTM design lies in harnessing the unique opportunities afforded by this new teaching format.

Despite its immense potential, to the author's knowledge there has been no significant effort to assess and ensure the quality of the CBTM format in medical education. The use of design principles to guide educational material has been validated in other teaching formats within medical education,[8] such as in CAL design,[9] webpage design[10] and multimedia material design.[11,12]

The purpose of this review was to examine the literature in CAL and learning theories to develop a set of design principles that guide CBTM development in medical teaching. Given the immense potential of the teaching format, a close examination of CBTM design optimisation is warranted.

Learning theories

The three leading classes of traditional learning theories are cognitivism, constructivism and behaviourism.[13] Cognitivism emphasises: (i) the existence of a memory system which assesses and organises new information, and (ii) the importance of prior knowledge in the role of learning. Cognitivism is often applied to modern education in the form of cognitive load theory (CLT).

Constructivism emphasises active learning and learner-specific knowledge construction.[14] It describes the important role of the teacher in understanding the learner's rhetoric and intentions, and in presenting information in such a way to fit into the learner's pre-set schema. Constructivism serves as a basis for the discovery, elaboration and scaffolding theories.

Briefly, behaviourism describes learning via conditioning which ultimately changes behaviour such as by maintaining learners' attention,[15] but the theory has few applications in adult knowledge-based education.

Classic learning theories

Cognitive load theory

Cognitive load theory describes learning efficacy as a function of working memory, which is divided into intrinsic, germane and extraneous loads[16,17] and has a sum total that cannot be exceeded.

Intrinsic load refers to the inherent difficulty of the material and typically cannot be modified. Germane load refers to the understanding of information and contextualisation through which to integrate the new knowledge into one's permanent memory. Extraneous load refers to the attention paid towards the presentation of the material as opposed to the material itself. In CLT, the goal is to minimise extraneous load in order to increase reserve for germane load.

A simple example in education concerns the guidelines for the delivery of PowerPoint presentations, which suggest, for instance, that the number of lines of text per slide or the number of unique font colours should be limited to prevent distraction from the presentation contents.[18]

Elaboration theory

Elaboration theory emphasises a meaningful sequence of instruction.[19] Over the years, the theory

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has moved from a simple-to-complex model to a familiar-to-unfamiliar model. The simple-to-complex model assumes that all learners perceive information in the same way. The familiar-to-unfamiliar model accounts for learner differences. There is emphasis on learner motivation, which affects the learner's progression from the topics that are most relevant and translatable to the learner, to topics perceived as less important. The revised elaboration theory also argues that new information be grounded in authentic performance setting, illustrated, for example, by the presentation of a concrete problem and the subsequent backwards working to attain the information necessary to solve it.[20] Two related theories are discovery theory,[21] which emphasises learning based on the learner's inquiry, and connectivism theory,[22] which emphasises learner interaction.

A basic example in medical education is in one-to-one teaching, in which the teacher assesses a learner's prior understanding of material and elicits questions in order to establish the context on which further knowledge can be built.

Cognitive and learning styles theory

Recently investigated for its application to web-based learning,[23] the most direct application of cognitive and learning styles (CLS) theory is in the adaptation of instruction to learner style. The concept of an aptitude–treatment interaction is applicable when one group of learners learns better with one method and another group learns better with another method.[23] Although Cook *et al.*[24] championed the idea, more recently Cook[25] has argued that strong instructional methods take precedence over possibly negligible differential learning styles, and that tools for characterising heterogeneous groups of learners remain inadequate. Currently, the validity of CLS theory as applied to multimedia in medical education is unclear.

Multimedia-specific learning theories

Cognitive theory of multimedia learning

In 1999, Moreno and Mayer[11] investigated learning via computer animation. These authors demonstrated improved learning through concurrent auditory narration with animation over concurrent text with animation, supporting the principles that learning efficacy is improved with the presentation of multiple modalities of instruction simultaneously in time, and that the working memory is split into visual and auditory channels. For example, a skill-based video that teaches the placement of a central line may be accompanied by audio narration rather than subtitles or block texts.

Technical scaffolding theory

First described in the 1950s, scaffolding refers to planned or unplanned expert assistance targeted towards learners as they learn a concept or task. The assistance may refer to spontaneous assistance, such as that delivered by answering a student's question, or planned assistance, such as that delivered by providing a new tool with which to solve a problem students are not expected to solve on their own. Recently, Yelland and Masters introduced the term 'technical scaffolding', which refers to a situation in which students are posed a question and then provided with a finite number of computer-based resources (e.g. websites or online tutorials) through which they are encouraged to seek the assistance they need to solve the problem.[26]

An example of scaffolding is the concept of problem-based learning in medical school, which has gained widespread adoption. A problem is introduced and resources are provided for learners to find their own solutions, guided by teachers on an as-needed basis only.

METHODS

Searches were carried out in Scopus for studies of classic learning theories under the three major classes of cognitivism, constructivism and behaviourism and their application to computer-based learning. In addition, to capture more recent studies based on learning theories that may not stem from these classic theories, a second search for studies into any learning theories applied to computer-based learning, published since 1990, was performed. Search parameters and results are summarised in Fig. 1.

The literature search provided an impression of the learning theories that garnered the most interest within computer learning, notably CLT, elaboration theory and scaffolding theory. Also relevant were the connectivism and discovery theories. Based on their relative importance, these learning theories were collapsed to develop a set of 10 succinct principles to guide CBTM design, and divided into three design levels to facilitate application.

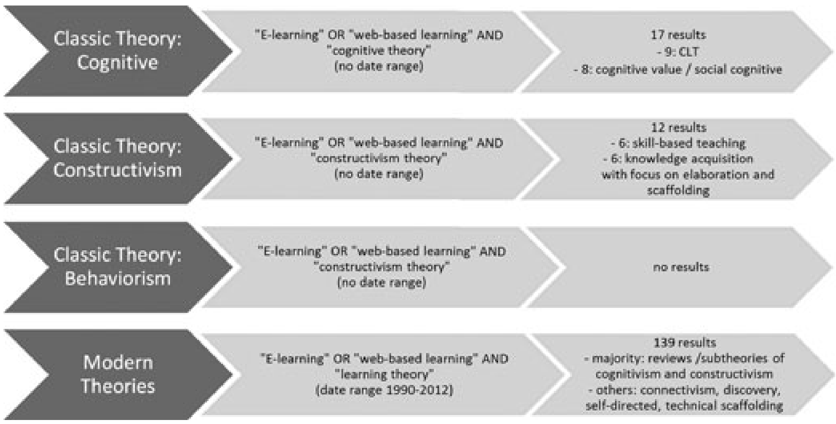

Figure 1 Literature search methodology. CLT = cognitive load theory

RESULTS

The principles derived were divided into three categories of application: global principles to be applied at initial conceptualisation stages; rhetoric principles to be applied during the development of individual segments and revisited during initial revision stages; and detail principles to be applied to text and multimedia decisions throughout development, and revisited in final revision stages.

Global principles

Managing objectives

Central to adult learning theory[27] is learner participation in educational goal setting. In the CBTM, the entire lesson is taught through the computer program with no complementary instructional format. As such, the objectives must be communicated within the CBTM itself. It has been demonstrated that both intellectual and social curiosity (towards applicability to the clinical disease process) improve learning and retention.[28,29]

Students should be encouraged to set goals in both pre-clinical and clinical lessons. Students may be prompted to enter their own learning objectives in the form of questions. For example, a pre-clinical lesson on lung cancer may invite questions such as 'What predisposes a person to lung cancer?' 'How does smoking cause lung cancer?' and 'What is the natural progression of lung cancer?' The purpose is not that learners should identify all the objectives of the module, but to encourage them to begin to develop a conceptual framework on which further knowledge may be built. After the learners have entered their questions, the instructor's objectives may be displayed simultaneously to reconcile learner and instructor goals.

Framing

Supported by the CLT principle of maximising germane load, framing is the establishment of context, which is more important in CBTM than in other teaching formats because it is not supplemented by verbal instruction from a human instructor. Given heterogeneous knowledge bases and learning styles, context is learner-specific (e.g. the sequential–global learner theory distinguishes between those who learn through a linear analytic process and those who learn in seemingly random segments until they make sense of the whole[30]), as supported by the CLS. Therefore, framing becomes an important device for the reconciliation of the learner's needs with the teacher's objectives.

A simple example is the display of a concept map at the margin of the screen, in which the segment with which the learner is currently engaged is highlighted in order to establish how the present segment fits into a part of the whole. For example, a module that teaches about cirrhosis may feature a concept map in which, on a segment describing liver function tests (LFTs), the path to the topic is highlighted (e.g. 'Overview→Diagnosis→Non-clinical→Lab→LFTs'). The purpose is to help learners understand the context of each segment.

Minimising technical load

On the basis of the CLT principle of minimising extraneous load, the technical aspects of the CBTM should remain in the background and unnoticeable to the learner.

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Ideally, the goal of minimising extraneous load is not to develop a long tutorial explaining the technical aspects of the module, but, rather, to develop a module that uses navigation and signalling devices common to typical computer applications, such that no technical tutorial would be required at all. For example, a neuroanatomy module may allow the use of a computer mouse drag to rotate a 3-dimensional representation of the brain, much as other web-based applications allow for mouse dragging to move an object along a web page.

Rhetoric principles

Optimising modality

In line with the CLT principle of maximising germane load, developers would benefit from familiarity with the principles proposed and validated by Mayer in his cognitive theory of multimedia learning.[12] Every decision in choosing a modality (any combination of text, diagram, audio, video, with or without interactivity) should be supported by evidence whenever possible.

Important guidelines include using word and picture format simultaneously, displaying related text in close proximity to the figure, and avoiding redundant modality.[31] An example of the lattermost is to use voice narration to accompany an endoscopy video rather than using subtitles and to allow for the simultaneous use of visual and auditory modalities rather than saturating the visual modality.

Making the modality explicit

On the basis of the CLT principle of minimising extraneous load, the selected teaching modality should be made explicit. Learners should not exert effort on understanding the method of content delivery. They should also not exert effort in questioning the validity of the modality. In medical school, learners often seek out 'high-yield' resources and are more receptive to learning when they feel their time is well spent. The predetermined selection of the modality assumes that the effect of CLS is dominated by the efficacy of the teaching modality.[25] In other words, the modality is justifiably content-centred, not learner-centred.

Learners may benefit from the provision of an explicit statement of the teaching modality, as well as a brief justifying explanation. For example, an electrocardiogram (ECG) reading module may be prefaced with the statement: 'Education research shows that ECG reading is best learned via repeated self-testing with incremental variations, which is the modality used for this teaching module.'

Technical scaffolding

Technical scaffolding introduces aid to learners at predefined junctions, as advocated by Yelland and Masters.[26] The most efficacious use of this principle is in the context of 'just-in-time' learning,[32] in which users are asked a question which requires additional information to answer. Learners are then provided with a finite list of resources with which to solve the problem.

The CBTM offers the unique advantage of applying technical scaffolding by providing learners with hyperlinks to faculty-approved Internet resources. They may be offered in the context of a posed question to ensure users have a specific intent when accessing these resources. For example, a module may present a patient with new-onset atrial fibrillation and ask whether the patient should receive anticoagulation. Web links (e.g. Uptodate.com) that lead to information about the CHADS2 (*c*ongestive heart failure, *h*igh blood pressure, *a*ge ≥ 75 years, *d*iabetes, previous *s*troke [2 points]) score may be provided. After understanding the concept, the learner must apply the new tool to the patient in the case. Note that the purpose was not to find the information, but to apply it.

Elaboration

Elaboration theory emphasises learner decisions in scope and sequence. The CBTM is uniquely advantageous for the application of elaboration theory as it can allow the learner to make decisions on the sequence of viewing content and on skipping segments altogether if he or she is confident in the subject area. Although users may control the scope and sequence of their learning, they should not be permitted to skip entire segments without validation of their knowledge. Passive validation may take the form of a summary of skipped content. Active validation may take the form of a mandatory quiz calibrated to demonstrate competence prior to skipping a segment.

For example, a module segment on electroencephalography (EEG) reading may offer the learner the opportunity to attempt a quiz involving the identifying of common EEG patterns; if the learner scores above a threshold, he or she may skip the module.

Spaced repeating

Well established in classic education theories,[33] spaced repeating is the concept of improving learner understanding and retention via non-sequential repetition. Built-in repetition may take the form of a summary, as often employed in a traditional lecture. In the CBTM, developers may use a quiz to revisit previous content while assessing retention. To encourage active learning, developers may choose to use the teach-back method, in which the module prompts free-text answers to quiz questions, and subsequently displays the correct answer for comparison and reconciliation.

Detail principles

Managing text

There is robust literature on text-based instruction in medical education. Instructors would benefit from familiarity with the basic principles.

Table 1 Principles of computer-based teaching module design and examples of applications

Principle	Example of application	Learning theory basis	Reference(s)
Global level			
Managing objectives	Prompt learner to enter self-set objectives in the form of questions, then display instructor objectives for reconciliation	Adult learning Connectivism Discovery Scaffolding	Sun & Li (2010)[21] Xu & Zhang (2011)[22] Roman & Kay (2007)[28] Roman (2011)[29]
Framing	Display a concept map of contents that is accessible throughout the module	CLT – extraneous	Felder & Silverman (1988)[30]
Minimising technical load	Use intuitive and user-friendly technical devices employed by common computer applications	CLT – extraneous	Moreno & Mayer (1999)[11] Cooper (1990)[16]
Rhetoric level			
Optimising modality	Use both audio and visual modalities simultaneously when appropriate	CLT – germane Mayer's cognitive theory of multimedia learning	Moreno & Mayer (1999)[11] Cooper (1990)[16]
Making modality explicit	Explain modality and briefly justify its validity	CLT – extraneous	Moreno & Mayer (1999)[11] Cooper (1990)[16]
Technical scaffolding	Prompt learner with questions; provide outside resources to fill in gaps in knowledge	Scaffolding Technical scaffolding Discovery	Sun & Li (2010)[21] Yelland & Masters (2007)[26] Cheuh & Barnett (1997)[32]
Elaboration	Enable learner to control the sequence and offer an alternative to completing basic segments (e.g. by using a calibrated quiz)	Elaboration Discovery CLT – germane	Moreno & Mayer (1999)[11] Cooper (1990)[16] Sun & Li (2010)[21]
Spaced repeating	Provide quiz at end of segments, use teach-back	Spaced learning effect	Dempster (1989)[33]
Detail level			
Managing text	Use audience-appropriate language	CLT – intrinsic germane	Gunderman & McCammack (2010)[34] James & Linte (2010)[35] Lim (2012)[36]
Managing devices	Use signalling and visual grouping	CLT – extraneous	Moreno & Mayer (1999)[11] Mayer (2010)[12] Khalil *et al.* (2005)[31]

CLT = cognitive load theory.

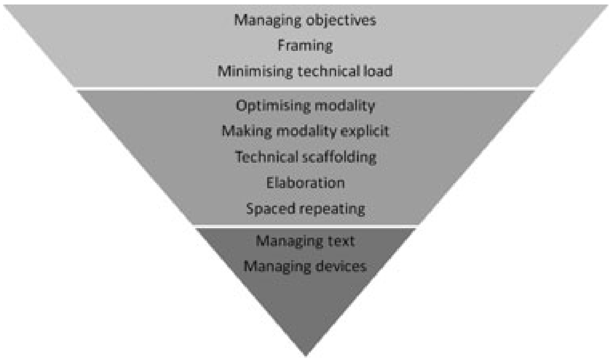

Figure 2 Learning theory-based principles guiding computer-based teaching module design

Examples include using audience-appropriate language and managing curiosity with questions.[34–36]

Managing devices

Similarly to the managing of text, there is strong literature on the use of technical devices in computer-based learning.

Examples include the use of signalling and cuing to highlight important material[12] and making use of visual grouping.[31]

Examples of the application and learning bases of each principle are detailed in Table 1. A visual representation of the principles divided by categories is shown in Fig. 2.

DISCUSSION

The present review has examined classic and modern multimedia learning theories to identify a set of principles to guide CBTM design. This study complements recent empirical works which demonstrate validity and efficacy. Future work would include prospective studies comparing the efficacy of principle-guided versus non-principle-guided CBTM design to validate and refine the principles. In addition to providing a framework with which to develop and validate CBTMs, design principles are important in optimising the CBTM format to enable a fair comparison with other teaching formats in education research.

There remain many questions regarding the validity and translatability of the CBTM modality as a nascent teaching modality. One potential barrier is development cost. The quality and complexity of CBTMs are heterogeneous, and there is great variability in time and monetary costs. Potential solutions involve the standardisation and optimisation of development as the CBTM becomes more prominent, and the inter-institution sharing of web-based resources.

Another barrier is faculty staff resistance. A study of faculty members in a nursing school identified faculty staff discomfort with web-based learning on the basis of increased workload and role reconceptualisation.[37] Faculty staff may anticipate increased work in course development and commitment to online communication with learners. They may also anticipate a challenging transition from the role of an authority figure in the classroom to that of a facilitator of knowledge acquisition in computer-based learning. Potential solutions include employing software programmers with expertise in CAL to collaborate closely with medical teachers in developing the CBTM. This may require support from institutional administration, which must be educated on the importance and long-term cost-effectiveness of CBTM design.

A final barrier to implementing the CBTM is that research remains in its infancy. Empirical research comparing the CBTM with more traditional modalities often assesses only learning outcomes and makes no mention of development costs. It also fails to assess time-related costs to students, making the conclusion that a CBTM is more effective than a traditional lecture without measuring the time students spend on a module. Despite several robust studies validating the use of the CBTM, many remain wary of this nascent teaching format.

For these reasons, it is important to standardise and optimise CBTM design, with the goal of better informing research and driving widespread acceptance in the medical education community. The versatility of the CBTM is virtually limitless as its functions expand concurrently with advances in computer technology. To give the CBTM a fair evaluation for its potential applications in the future of medical education, the design of computer-based resources must be made more robust and evidence-based.

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